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SINTEF Building and Infrastructure Klaartje De Weerdt (editor)

Nordic Concrete rheology workshop

– Trondheim, Norway 3–4 October 2011

COIN Project report 35 – 2011

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FA 2 Competitive constructions

SP 2.1 Robust highly flowable concrete and SP 2.3 High quality manufactured sand for concrete

COIN Project report 35 – 2011

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Key words:
Concrete aggregate, rheology, SCC - self consolidating concrete, manufactured sand

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Preface

This study has been carried out within COIN - Concrete Innovation Centre - one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, work on presently 5 projects:

- Advanced cementing materials and admixtures
- Improved construction techniques
- Innovative construction concepts
- Operational service life design
- Energy efficiency and comfort of concrete structures

COIN has presently a budget of NOK 200 mill over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %).

For more information, see www.coinweb.no

Tor Arne Hammer
Centre Manager

Introduction

SINTEF and NTNU organize a **NORDIC CONCRETE RHEOLOGY WORKSHOP**, **3-4 October 2011** in Trondheim. This workshop is held over two days and will be combined with a **Nordic SCC Net meeting**.

Researchers from different Nordic research institutes working on these topics e.g. CBI (Sweden), DTI (Denmark), ICI (Iceland), NTNU and SINTEF (Norway) are participating.

Some major industrial users will participate, sharing their experiences in the field related to concrete rheology and the use of manufactured sand.

Both researchers and industrial users were encouraged to sign up for workshop and share their experiences.

Workshop

The idea is to give an insight on today's ongoing research and experiences in the field of concrete rheology in the Nordic countries.

The participants were asked to prepare a presentation and a short abstract. In order to create an informal and including workshop, the contributions have been accepted as received. The participants are therefore solely responsible for the quality of each contribution.

Nordic SCC Network meeting

The Nordic SCC Network has the objective to exchange results and knowledge in order to establish an improved basis for the use of Self Compacting Concrete. Annual meetings are hosted by members of the network. In this occasion, it was opted to combine the Nordic SCC Network meeting with a concrete rheology workshop.

Organizers

The Concrete Innovation Centre (COIN) is a centre for research based innovation supported by the Norwegian Research council and industrial partners. In order to achieve the goal of innovation for concrete industry, communication and cooperation between different research centers and with the industry are crucial. For more information on COIN please visit our website (www.coinweb.no).

Participants

name	company	Country
Sven-Henrik Norman	Velde AS	Norway
Reidar Velde	Velde AS	Norway
Tero Onnela	Metso	Finland
Øystein Mortensvik	Rescon Mapei	Norway
Espen Rudberg	Rescon Mapei	Norway
Bård Pedersen	SVV	Norway
Lars Busterud	BASF	Norway
Sverre Smeplass	Skanska	Norway
Knut Kjellsen	Norcem	Norway
Ernst Mørtsell	Norbetong	Norway
Nikola Mikanovic	HTC	Germany
Øyvind Sæter	Unicon	Norway
Eivind Heimdal	Unicon	Norway
Poul Licht	Omya	Danmark
Christine Hauck	Veidekke	Norway
Bernt Kristiansen	AF	Norway
Stefan Jacobsen	NTNU	Norway
Mette Geiker	NTNU/ DTU	Norway/ Denmark
Børge Wigum	NTNU/Norstone	Norway
Ya Peng	NTNU	Norway
Rolands Cepuritis	NTNU	Norway
Tor Arne Martius Hammer	SINTEF	Norway
Klaartje De Weerdt	SINTEF	Norway
Svein Willy Danielsen	SINTEF	Norway
Mari Bøhnsdalen Eide	SINTEF	Norway
Peter Billberg	CBI	Sweden
Björn Lagerblad	CBI	Sweden
Peter Simonsson	LTU	Sweden
Jon Elvar Wallevik	NMI	Iceland
Olafur Wallevik	NMI	Iceland
Jon Spangenberg	DTU	Denmark
Jan Skocek	DTU	Denmark
Claus Pade	DTI	Denmark
Lars Nyholm Thrane	DTI	Denmark

Program

Monday 3. October

10:30	11:00	Registration		
11:00	11:30	Welcome speech - COIN	Bård Pedersen Tor Arne M. Hammer Klaartje De Weerdt	SVV SINTEF SINTEF
11:30	12:15	LUNCH		
MANUFACTURED SAND				
12:15	12:30	Manufactured aggregates for concrete – why, where and how?	Svein Willy Danielsen	SINTEF
12:30	12:45	Manufactured sand in concrete. Practical experiences from aggregate and sand production and concrete mix design.	Sven-Henrik Norman	Velde AS
12:45	13:00	Filler and filler quality of crushed rocks in concrete production	Björn Lagerblad	CBI
13:00	13:45	DISCUSSION MANUFACTURED SAND + COFFEE	Børge Wigum	NTNU/ NorStone
13:45	14:00	Creating a manufactured sand - Factors to consider and methods of processing	Tero Onnela	Metso
14:00	14:15	Effect of aggregate crushing on fresh concrete	Rolands Cepuritis	NTNU
14:15	14:45	DISCUSSION MANUFACTURED SAND + COFFEE	Bård Pedersen	SVV
SCC STABILITY				
14:45	15:00	Measurements of rheological properties of mortar using the V-funnel test	Lars Nyholm Thrane Claus Pade	DTI
15:00	15:15	Rheological Properties of SCC Stabilized With additional filler or chemical stabilizer	Klaartje De Weerdt	SINTEF
15:15	15:30	Some Fresh Properties of Powder-, VMA- and Combination-Type SCC	Peter Billberg	CBI
15:30	15:45	SCC Stability: STAR review and plans for PhD research	Ya Peng	NTNU
15:45	16:30	DISCUSSION SCC STABILITY + COFFEE	Peter Billberg	CBI
RHEOLOGY				
16:30	16:45	On the influence of entrained air on rheology of paste and mortar	Tor Arne Martius-Hammer	SINTEF
16:45	17:00	"Rheology according to Olafur"	Olafur Wallevik	NMI
17:00	17:30	DISCUSSION (Train to city centre leaves at 17:56)	Claus Pade	SINTEF
19:00		DINNER at Rica Nidelven		

Tuesday 4. October

SCC FIELD EXPERIENCES

09:00	09:15	How polycarboxylate superplasticisers affect the rheology of self-compacting concrete	Øystein Mortensvik	RESCON MAPEI
09:15	09:30	Sensitivity of SCC proportioning to variations in raw materials	Sverre Smeplass	SKANSKA
09:30	09:45	Experiences with SCC - challenges met in the field today	Bernt Kristiansen	AFgruppen
09:45	10:30	DISCUSSION FIELD EXPERIENCES + COFFEE	Tor Arne Martius Hammer	SINTEF
10:30	10:45	Concrete with high flyash content - Ready mix production	Øyvind Sæter	UNICON
10:45	11:00	Smart Dynamic Concrete, a new generation of highly fluid concretes	Lars Busterud	BASF
11:00	11:30	DISCUSSION FIELD EXPERIENCES	Knut Kjellsen	Norcem
11:30	12:30	LUNCH		

MODELLING

12:30	12:45	Explicit and implicit cfd-calculations of SCC: A numerical study	Jon Spangenberg	DTU
12:45	13:00	Modeling of flow induced inhomogeneities in self-compacting concrete	Jan Skocek	DTU
13:00	13:15	Rheometer-4SCC used as a stability meter for SCC	Jon Elvar Wallevik	NMI
13:15	13:30	Steel fibres in fresh concrete; packing-, lubrication phase-, fibre jamming- and proportioning parameters	Stefan Jacobsen	NTNU
13:30	14:30	DISCUSSION MODELLING	Stefan Jacobsen	NTNU

NORDIC SCC NET MEETING

14:30	15:30		Klaartje De Weerdt	SINTEF

Session 0

WELCOME

COIN - Concrete Innovation Centre

Centres for Research-based Innovation (CRI)

- In 2005 the Research Council of Norway announced a call for CRI "as a tool to stimulate the industry to further innovation"
- **The purpose** of the CRI is to build up and strengthen Norwegian research groups that work in close collaboration with partners from innovative industry and innovative public enterprises

Annual funding (NOK), 2007-2014

Research Council of Norway	9.5 mill
Industry	12.0 mill
SINTEF	1.0 mill
NTNU	4.5 mill
SUM	**27.0 mill**

Focus Areas

1) Environmental friendly concrete structures

2) Competitive construction

3) Technical performance

1) Environmental friendly concrete structures

- Binders with low emission and reduced resource consumption
  - All round environmentally friendly binder systems (PhD finished)
  - Admixtures to control hydration development (PhD)
  - Alternative pozzolans ((PhD))
- Utilisation of concrete in low energy building concepts

2) Competitive construction

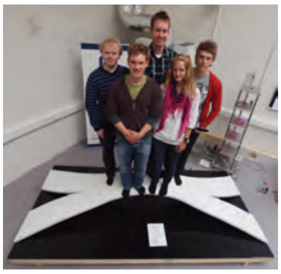
2.1 Stable and robust highly flowable concrete with controlled surfaces ("1/2" PhD)

- Test methods for evaluation of stability
- Materials development
- Production systems
- Classification system and methods for aesthetic quality of concrete surfaces

2) Competitive construction

2.2 High tensile ductile strength concrete (2 PhDs)

- Test methods for FRC
- Materials development
- Production methods
- Guidelines for design and execution



2) Competitive construction

2.3 High quality manufactured sand for concrete ("1/2" PhD)

- Production techniques related to geological origin
- Concrete mix design
- Fresh concrete properties
- Volume stability

3) Technical performance

3.1 Crackfree concrete (PhD)
- Binder systems
- Calculation tools

3.2 Service life
- Chloride threshold value (PhD - finished)
- AAR-test methods (PhD)
- Electrical resistivity in concrete (PhD)
- Chloride ingress mechanisms (PhD)

3) Technical performance

3.3 Structural performance
- Development of Super LWA(C) (PhD)
- Performance of advanced concrete materials and combinations (2 PhD)
- Concrete in arctic marine environment (PhD)

COIN 2.3

High quality manufactured sand for concrete

Bård Pedersen

vegvesen.no

Background

- The project group was established in 2008 based on an initiative from NorStone (HC group)
- The motivation for this activity was the resource situation in Norway which will be reaching a critical level within a decade or so.

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Project members

- NorStone: Børge Johannes Wigum, Gaute Veland
- Veidekke Industri: Lillian Uthus Mathisen
- Norsk Stein: Odd Hotvedt
- Nord-Fosen Pukkverk
- NorBetong: Ernst Mørtsell
- Rescon Mapei: Espen Rudberg
- Metso Minerals: Tero Onnela
- SINTEF: Svein Willy Danielsen
- NTNU: Prof. Stefan Jacobsen, PhD students Ya Peng and Rolands Cepuritis
- Skanska: Sverre Smeplass
- NPRA: Bård Pedersen (previously NorStone)
- Velde pukk – not yet formalized

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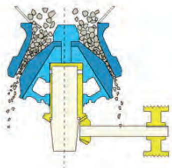
Focus areas

Crushing technology

- Cone crushing vs. VSI
- Crushing parameters (feed, speed etc.)
- Effects on particle shape, fines content etc.
- Relation to geological parameters



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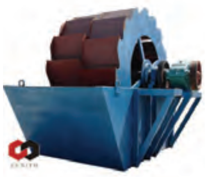
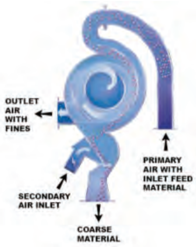
Classification systems to optimize the fines characteristics



Sand washing



Centrifugal air classification. Can be adjusted for "cut-points" between 20 and 100 microns

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Mix design and rheology

- Development of concrete mix design for competitive properties and reverse/iterative effect on aggregate product development
- Aggregate vs. cement and admixtures interaction/ synergies
- Link to COIN 2.1 (stability of SCC)

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Characterization and verification methods

- Characterization of fillers (PSD, surface area, shape etc.)
- Particle packing studies
- Screening tests such as NZ Flow cone

Some activities in 2011

Case study Nord-Fosen Pukkverk:

- Fresh concrete properties
- Possibilities for improved processing of aggregates

Master thesis of Rolands Cepuritis:

- "Effects of Concrete Aggregate Crushing on Rheological Properties of Concrete and Matrix"
- \- to be presented during this workshop»

Changes in project organization

- Børge Johannes Wigum replaces Bård Pedersen as Project Manager
- Velde Pukk is invited to join COIN 2.3

COIN FA 2.1

Robust highly flowable concrete

Klaartje De Weerdt,
Nordic Concrete Rheology Workshop, Trondheim, 3-4 October 2011

Active Project members

1. NTNU - Prof. Stefan Jacobsen, PhD student Ya Peng
2. SINTEF - Klaartje De Weerdt, Mari Bøhnsdale Eide
3. Skanska - Sverre Smeplass
4. Rescon Mapei - Espen Rudberg
5. Norbetong – Ernst Mørstell
6. Norcem – Knut O. Kjellsen
7. International advisor – Olafur Wallevik

Focus of the project

1. SCC – stability issues
2. Concrete surface classification tools and system

SCC - STABILITY

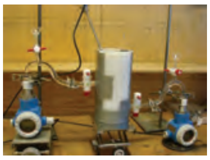
SCC - stability

- NTNU - Master thesis of Britt B. Marstrander (2010-2011)
  Bleeding and stability



SCC - stability

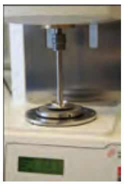
- NTNU - PhD project of Ya Peng
  on the development of novel techniques to assess stability of SCC (concrete and matrix)



SCC - stability

- SINTEF – Laboratory testing
  different methods of stabilizing SCC





SCC - stability

- SINTEF – Full scale testing
  correlate rheological properties of concrete and surface finishing


CONCRETE
SURFACE CLASSIFICATION

Surface classification

- No Norwegian surface classification system
- Several other countries DO have classification specifications, for example:
  - Sweden
  - Denmark
  - Germany
  - Austria

- The Norwegian building industry want to develop a new specification tool

Surface classification

- Surface classification tool

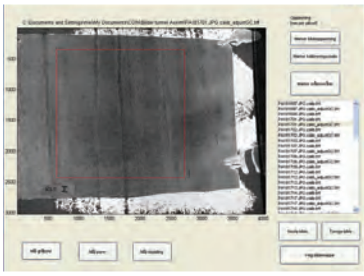
Surface classification

- SINTEF – Concrete Surface Classification tool

Surface classification

- SINTEF – Concrete Surface Classification tool

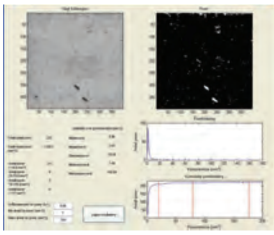
BetongGUI



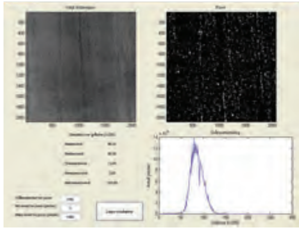
Surface classification

- SINTEF – Concrete Surface Classification tool

Pore distributions



Greyscale variations



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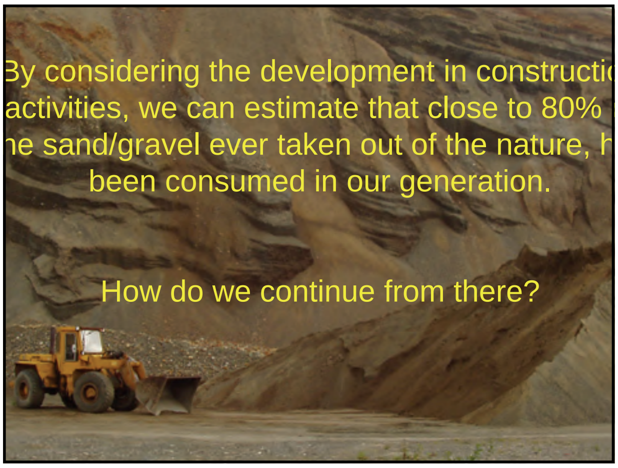
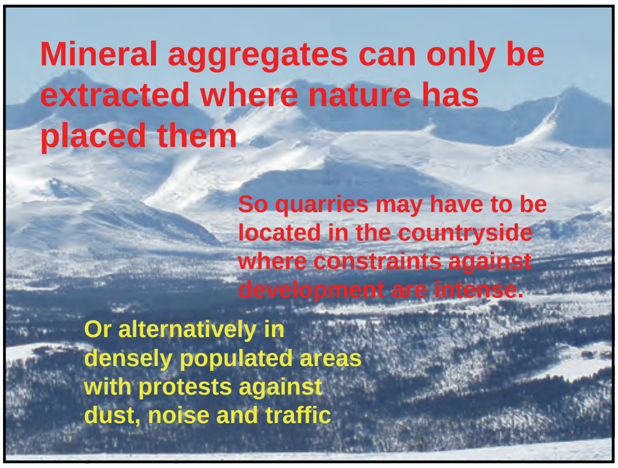
Session 1

MANUFACTURED SAND



The availability of materials will be one of the important global market drivers in the years to come

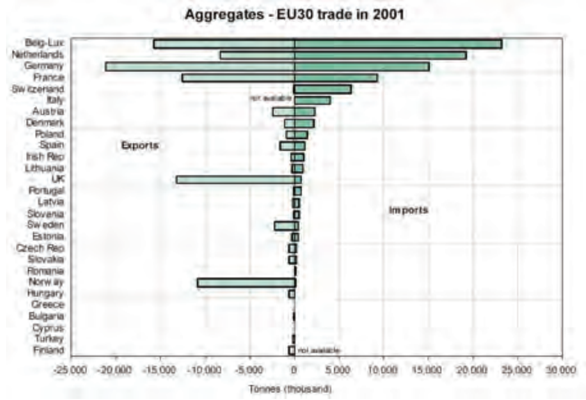
(Prof. Roger Flanagan UK)



Some international key figures

- Global demand for aggregates is some 15 billion tons/year
- Expected to increase to 22 billion, where China alone will account for some 6 billion
- European aggregate industry produced >3 billion tons in 2005, at a value of >40 billion €
  - 47 % sand/gravel, 45 % crushed hard rock
  - The remaining part was recycled and artificial materials
  - Production took place in 28.000 quarries
- European concrete production is almost 600 mill m3, and uses approx 1,2 billion tons of aggregates per year

- Europe has approx 500 mill people
  - Expected average consumption of mineral aggregates 10 tons per capita
    - ⇨ Total of 5 bill tons per year Europe wide
  - Assuming an average equivalent road transport distance of 40 km
    - ⇨ 200 billion ton-km per year for aggregate transport, which means approx 20 billion tons of CO_2 emission annually
- Two key questions:
  - Where do we find these resources on a long range?
  - How long will society accept this CO_2 emission?



Norwegian relevance

- Large total resources (sand/gravel)
  - Theoretically 12'''m3 → 450 years
- Much less available resources (50 → 15%)
  - Land use conflicts
  - Geological issues / technical quality
  - Location, practical availability
  - Size, production economy
- About 50% of total resources too far from realistic markets
  - Shortage near most populated areas within 10 – 30 years

% distribution for some countries

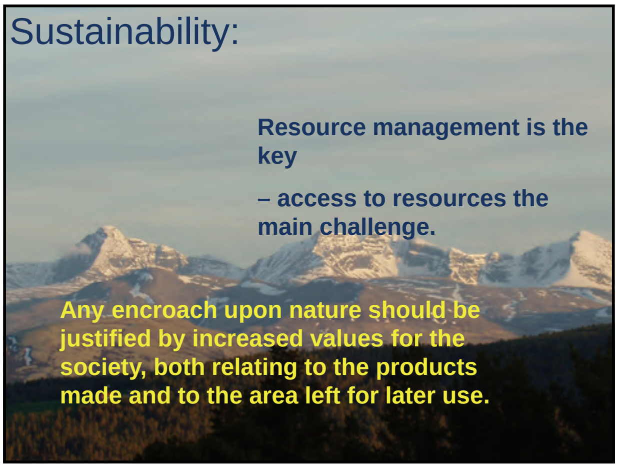
%	Crushed	Recycled	Of European total prod.	Of Eur. no. of quarries
Norway	72	<<1	1,8	16
Sweden	61	10	2,6	6,5
Netherlands	8	42	1,6	0,7
Germany	34	9	17	11
UK	31	20	9	4,6
France	54	2,5	13,5	9,5
Spain	65	<<1	15	6,8

Development in sand/gravel versus crushed rock (Norway)

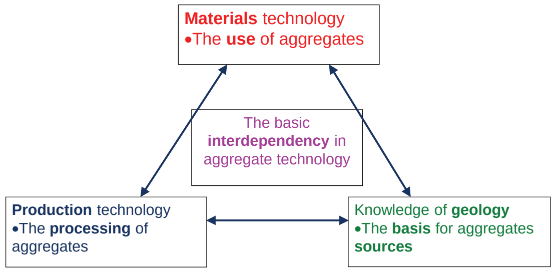
	Production value mill. NOK					Mill. t 2002
Year	1982	1991	1997	2000	2002	
Sand/ gravel	1000	900	900	760	590	15
Crushed hard rock	**800**	1350	1859	1825	**1950**	35
Total	1800	1920	2759	2585	2540	50
% sand/ gravel	56	47	33	29	23	

Four essential phases
in aggregate business

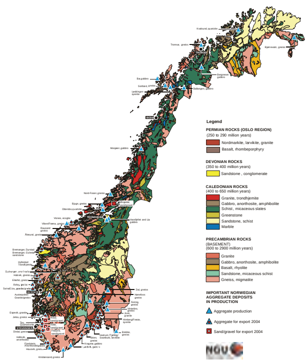
1. Inventory and planning
2. Quarrying and production
3. Use of aggregates in construction
4. Reclamation of mined-out area



Aggregate technology



BEDROCK MAP OF NORWAY WITH IMPORTANT AGGREGATE DEPOSITS



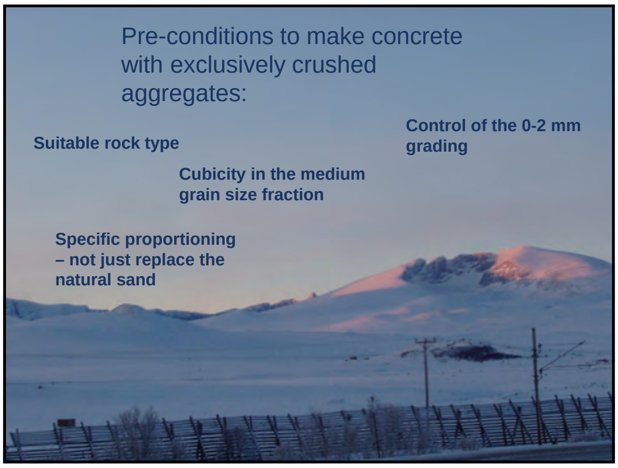
Materials technology has to a large degree been developed in dependence of the aggregate resources available, and thus of the local/regional geological conditions

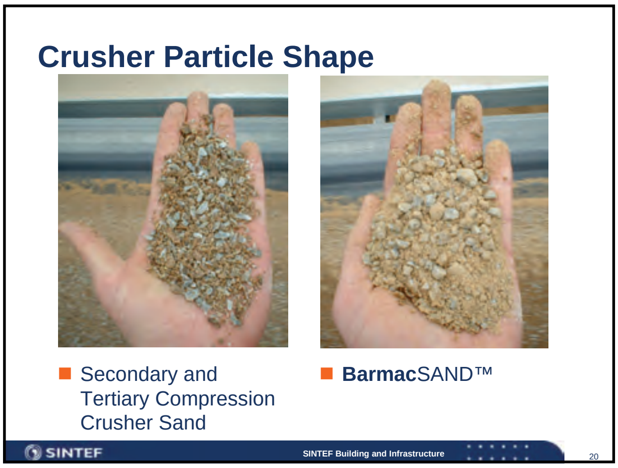
Developments in production and use of manufactured aggregates in Norway

- A holistic approach to enable local supply and production
  - Utilize local resources of sand and hard rock
  - Minimize long transport of remote materials
- Obtain a no-waste production
  - Plan for an optimum mass balance in production and market
  - Minimize the need for depositing surplus products
- Two directions for technology development
  - Improved aggregate production from hard rock
  - A tolerant concrete mix design that plays with the aggregates
- Development of integrated, industrial plants
  - Aggregate quarry
  - Materials production (asphalt, concrete)
  - Waste handling/recycling

What can we achieve by using crushed rock aggregates in concrete?

- New developed technology opens new possibilities
  - Aggregate production
  - Concrete proportioning
- Utilise the properties of different rock types
  - More design opportunities
- Have a more industrialised production
  - Less surprises
- Utilise surplus sizes
  - Mass balance
  - Less need for fines deposits – *"no-waste production"*
- Competitive – but different – materials properties


Pre-conditions to make concrete with exclusively crushed aggregates:
Suitable rock type
Control of the 0-2 mm grading
Cubicity in the medium grain size fraction
Specific proportioning – not just replace the natural sand


Crusher Particle Shape
Secondary and Tertiary Compression Crusher Sand
BarmacSAND™
SINTEF
SINTEF Building and Infrastructure
20


Buell dry classifying plant at Skien Quarry
Feed: 60 tph 0-2 mm
Moisture ca 2%
Filter
Centrifugal
Gravitational – "GI"


Future action and research
1. Tools for mineral resource management
2. Concepts and technologies for optimum production and use

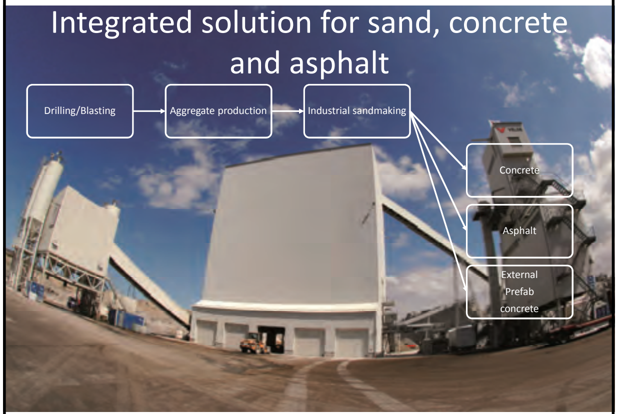

Research topics
•Concepts for competitive use of manufactured aggregates
•Technology to benefit from specific rock properties
•Utilisation of secondary aggregates /marginal resources
•Concepts to constantly obtain mass balance (100% utilisation)
•Concepts to use more kinds of local materials, all new materials technology?
•Integrated plant concepts, with cost effective production
•More economically feasible subsurface quarrying, combined with establishing underground space


Crushed hard rock aggregates for concrete
• A need
• A challenge
• And an opportunity

Manufactured sand in concrete. Practical experiences from aggregate and sand production and concrete mix design.

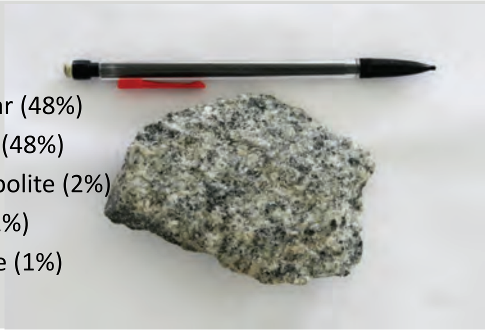
Sven-Henrik Norman
Velde AS

Integrated solution for sand, concrete and asphalt



Velde Pukk –Rock properties

Feldspar (48%)
Quartz (48%)
Amphibolite (2%)
Mica (1%)
Chlorite (1%)



End product properties

Metode	Enhet	0/0,063		0,063/0,5		0,25/2		2/5		5/8		8/11		11/16		16/22	
		Res	Kat	Res	Kat	Res	Kat	Res	Kat	Res	Kat	Res	Kat	Res	Kat	Res	Kat
Flisighetsindeks	Fl							8	Fl15	4	Fl15	2	Fl15	2	Fl15	3	Fl15
Korndensitet	M							2,6	-	2,6	-	2,63	-	2,6	-	2,6	-

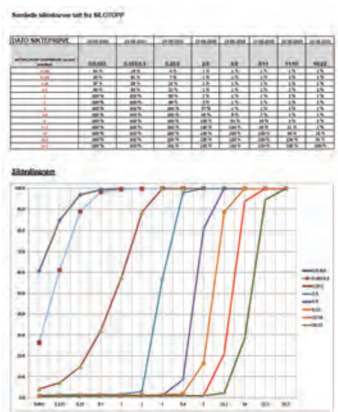
Properties of end products:
Micro Deval, test value 5, category M_{DE} 10
PSV, value 51, category PSV $_{68}$
Los Angeles, test values Coarse 12, Fine 24, category LA_{30}
Nordic abrasion value Category A_N 10
Flakiness Index of 5-22mm fractions: values 2-8, Category FI15

Typical moisture content

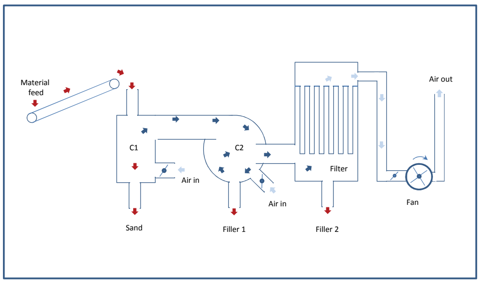
Fuktprøver på Silofraksjoner

VELDE

Dato	0-0,063	0,063-0,5	0,25-2,0	2-5	5-8	8-11	11-16	16-22
24.09.2009	1,49	1,96	0,56		0,45	0,20	0,20	
28.09.2009	2,11	1,90	0,27					
06.10.2009	1,83	1,67	0,33		0,30	0,30	0,20	
13.10.2009		1,44	0,58			0,40	0,60	
19.10.2009	1,75	1,49	0,50	0,60	0,10	0,20	0,10	0,20
21.10.2009	0,79	0,94	0,60					
23.10.2009	1,02	0,60	0,20					
26.10.2009	0,63	0,81	0,29	0,19	0,10	0,33	0,19	0,11
13/11	[illegible]	1,1	0,5	0,5	[illegible]	[illegible]	[illegible]	[illegible]



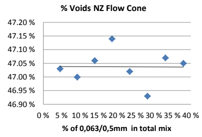
Air Classification

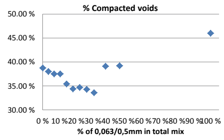


The particle matrix method used in mix design
Particle phase – Voids content

Fraction	0,25/2mm	2/5mm	5/8mm	8/11mm	11/16mm	16/22mm
Compacted voids (%)	40,5	41,8	34,25	30,63	29,7	30,5

Table 1: Compacted voids of individual fractions Average result from 6 tests of each fraction.





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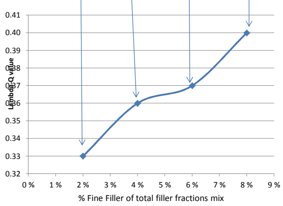
The particle matrix method used in mix design
Matrix phase – FlowCyl - Filler

	Mix no	Mix no	Mix no	Mix no
Ingredients/m3	1	2	3	4
0,25/2mm	35%	35%	35%	35%
0,063/0,5mm	8%	6%	4%	2%
0/0,063mm	2%	4%	6%	8%
Cement	300 kg	300 kg	300 kg	300 kg
Free mix Water	177 kg	177 kg	177 kg	177 kg
Dynamon SX-n	1,0%	1,0%	1,0%	1,0%



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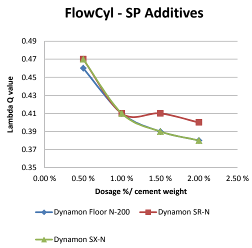
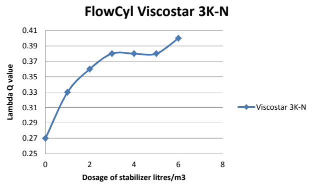
The particle matrix method used in mix design
Matrix phase – FlowCyl - Additives





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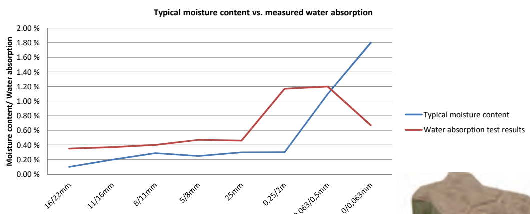
Water absorption / moisture



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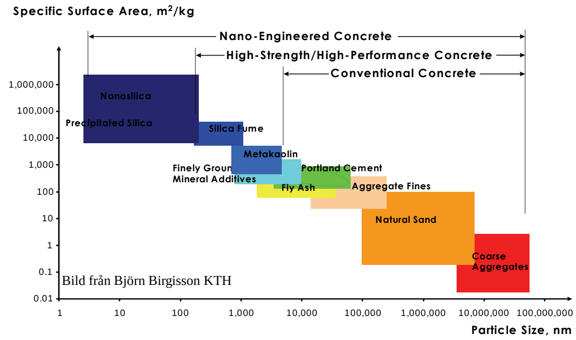
Filler and filler quaility of crushed rocks in concrete production

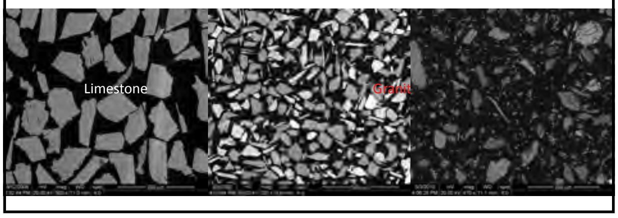
Björn Lagerblad (CBI)
Mikael Westerholm (CBI)
Hans-Erik Gram (Cementa)

Grain distribution in concrete



What is a filler

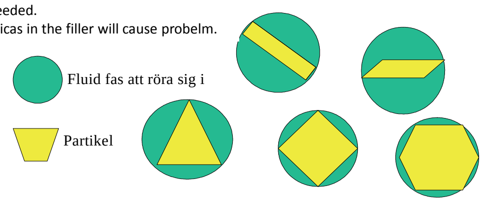
- The "fluid" phase consist of filler-cement-pozzolana-Water. The aggregate filler are defined as particles < 63 µm and mainly consist of individual mineral particles.
- In natural aggreragate it is mainly rounded quartz and feldspar and clays.
- In crushed rocks is depends on the rock type. With granitoid rocks it is crystalls of quartz, K-feldspar, biotite, muscovite and often some hornblende.



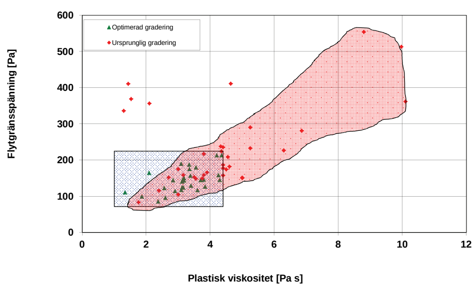
The importance of grain shape

•Particles from crushed rocks are more angular and flaky than natural aggregate
•The fine material consists of free minerals
•The shape of the particles is related the form of the individual mineral
•The mineral composition of the rocks will decide shape of the particles
•Granites contains mica that is a flaky mineral.
•The mineralogy of the rock will decide the behavior of the paste.

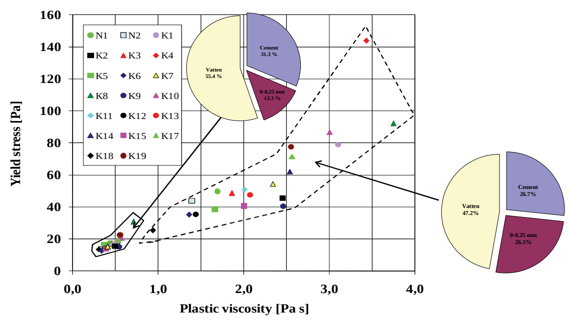
A flaky particle needs more space to move. Thus more paste/fine material is needed.
Micas in the filler will cause probelm.



Rheology of mortar (0-2 mm) with crushed rocks. As it comes and resorted to optimal grain distribution

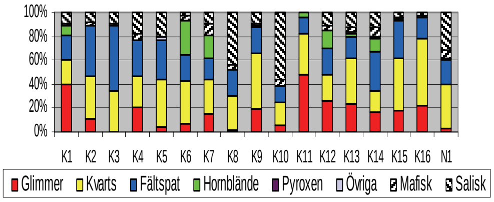


Effect of fine materials (0-0,25 mm) on rheology



The effect of 13.3 and 26.1 volume % 0-0.25 mm aggregate on the yield stress and plastic viscosity of a standard mortar. N= natural aggregate and K = crushed granites. From Lagerblad et al 2008

Mineral distribution in 0,125-0,25 mm



Comparision between filler and 0.125-0.25

Prov	Biotit Filler---Finkorn	Prov	Biotit Filler---Finkorn	Prov	Biotit Filler---Finkorn
K 57	16,5------------20	K 41	25,4----------13	K 2	15,9-------------11
K 40-1	29,5------------13	K 4	5--------------20	K 3	1,8----------------1
K 40-2	16,7------------10	K51	25 ---------- 27	K 48	5,3 ---------------4

Mineral composition of filler

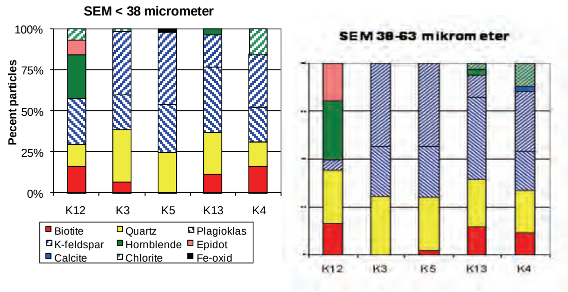
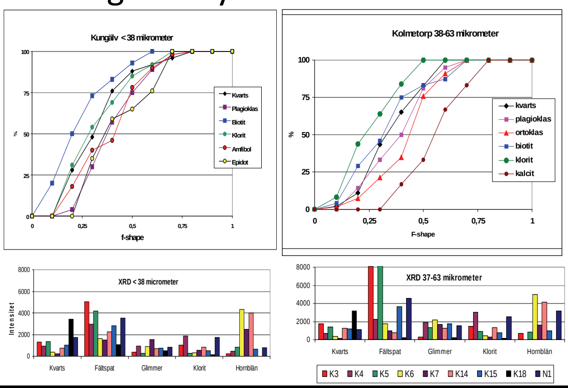


Image analysis of filler minerals



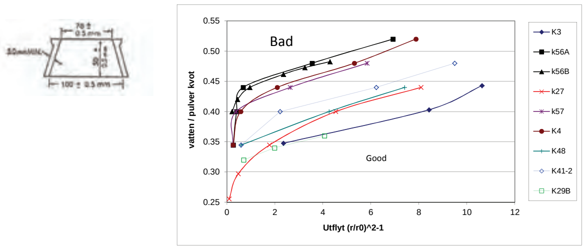
Counting of mineral grains of filler i SEM

Only larger grains are counted

Mineral	Biotit	Klorit	Hornblände	K-fsp	Plagioklas	Kvarts
K 57	16,5 (13,4)	3,8 (7,4)	13,9 (21,8)	17,7 (35,3)	29,1	19,0 (22,1)
K 40-1	29,5 (20,2)	1,6 (4,2)	19,6 (23,8)	9,8 (29,6)	23,0	16,4 (22,1)
K 40-2	16,7 (17,0)	1,5 (2,4)	34,9 (24,2)	10,6 (36,2)	27,3	9.0 (18,6)
K 41	25,4 (9,9)	0, (1,0)	16,9 (10,8)	16,9 (39,7)	21,1	19,7 (37,7)
K 4	5,9 (9,1)	12,5 (16,2)	--- (4,8)	41,9 (36,8)	19,1	20,6 (33,2)
K51	25,0 (37,3)	3,3 (3,9)	30,0 (5,1)	1,7 (30,1)	20,0	20,0 (19,8)
K 56	15,9 (23,7)	4,4 (6,6)	5,8 (3,2)	31,9 (36,0)	15,9	26,1 (30,5)
K 3	1,8 (2,6)	3,6 (3,6)	1,8 (1,9)	37,5 (47.0)	28,6	26,8 (44,3)
K 48	5,3 (2,5)	17,5 (32,3)	5,3 (1,2)	28,1 (60,7)	40,4	3,5 (2,3)
K 29	8,1 (28,7)	10,3 (4,0)	25,3 (15,4)	21,8 (40,6)	24,1	10,3 (9,9)

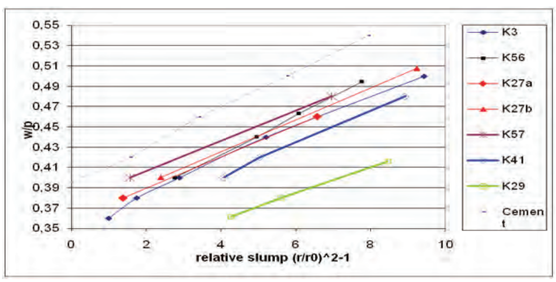
In ( ) semiquantitative analysis in X-ray diffraction

Flow valued for different fillers. K27 is limestone and the other from crushed granites and granodiorites.



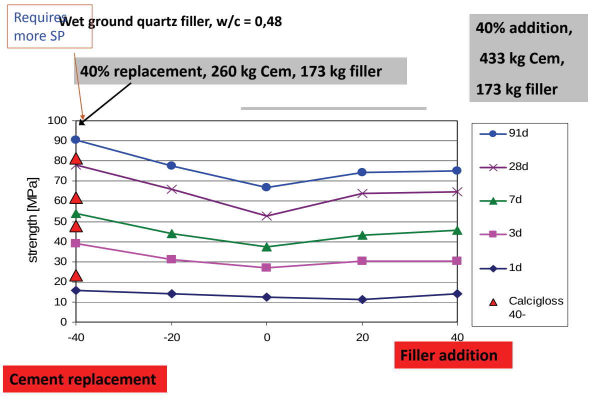
Filler is mixed with water. At a certain amount of water the mix can flow. When more water is added it will flow more.

Flow for mixes with cement

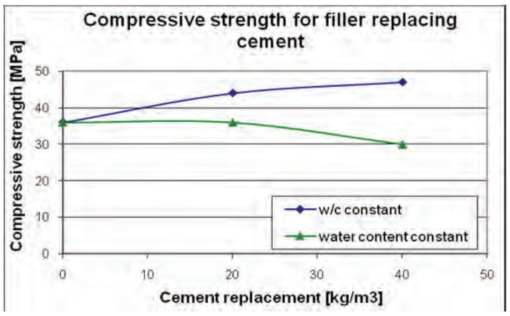


The grains of K29 is coarser than cement. K57 has a lot of mica.

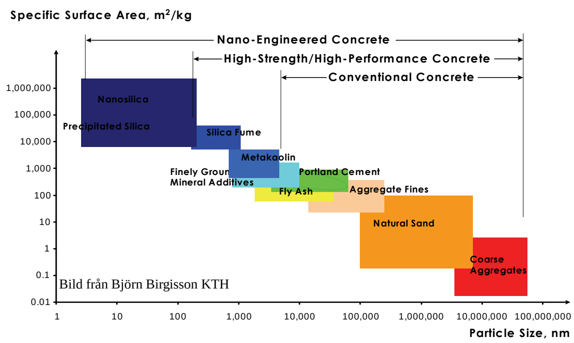
Strength of concretes with static w/c



Use of good filler



Grain distribution in concrete



What is a good filler

- Consist of round cubic grains
- A good size distibution that is includes the shape of cement and pozzolanas
- It can be analysed by
- Sand equivalent test
- Laser sieve
- Packing
- Puntke test
- Flow.

Manufacturing Sand

Factors and methods to consider

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Areas of Application - Manufactured Sand

- Manufactured sand has been used for many years in a variety of concrete applications
  - Dam projects
  - Highway and airport paving
  - Bridges
  - Power plants
  - All types of industrial and commercial construction
  - Concrete products (pipes, blocks and pre casts) of all kind
  - Plasters and mortars, where sand has a full role as aggregate
  - Asphalt, road building, earth fillings, bricks, glass etc.

Three Gorges Dam in Yangtze river

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Areas of Application for Air Classification

Manufacturing sand

To achieve a sand that meets specifications for concrete and asphalt, the sand grading is often needed to adjust

The ‘superfines/filler/dust’ (<125µm) often needs to be reduced to amounts similar to natural sands to meet specifications

Superfines are formed as a normal part of any crushing or grinding process

In natural sands the ‘rock’ superfines have normally already been removed by various natural processes and the clay superfines are washed out during sand production

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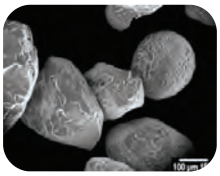
How do Natural Sand Deposits Occur?

Natural sand is formed by natural physical and chemical weathering and erosion processes

The sand is then often transported and sorted by natural means

Sand is often stratified into different particle size bands



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MANUFACTURING ASPHALT SAND

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Manufacturing Asphalt Sands

The majority of the air classification units in the USA have been installed for asphalt sand production

Typically 0/4mm sand is produced with a high speed cone crusher with 15% 75µm (200 mesh)

The 75µm normally needs to be <5% to achieve ASTM asphalt specification

This processing is normally carried out with a gravitational inertial unit

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Manufacturing Asphalt Sands

Air classification advantage

- Big savings achieved over traditional wet processing
- The dry feed requires significantly less oil to heat compared to a wet feed*
- Filler does not require further processes such as thickeners, lagoons etc.
- Asphalt sand specification are quite variable worldwide and the ASTM asphalt specifications are quite stringent

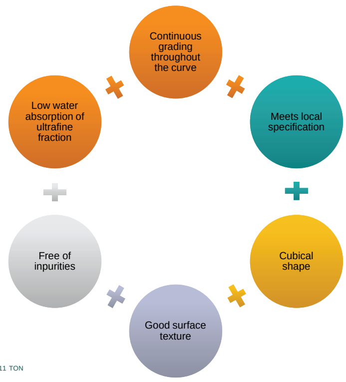
*Evaporating 2% of humidity in a sand means 8,7kWh per ton. Source : www.carbontrust.co.uk/publications
For comparison a crusher plant consumes ~ 2 kWh per ton to crush rock.

MANUFACTURING CONCRETE SAND

Concrete Sand

- Concrete sand is a high value product where natural sands are unavailable due to natural or environmental restrictions
- Traditional 'quarry dust' is a by-product that has poor shape and high ultrafines content that making it a very poor substitute for natural sand
- Natural concrete sand is well shaped (rounded), well graded (typically 40-70% passing 600µm) with all clay and ultrafines washed out
- The 0/4mm quarry dust is often produced from compressive crushing with poor shape, high ultrafines (15-25%), low 600µm (25-35%) and a high percentage of +1mm

What is aimed for in Manufactured Sand?



Manufacturing Concrete Sand

Rock Characteristics

- The production of a quality manufactured sand is not a process that can be achieved by accident
- Careful thought is required and a total approach is best to achieve quality products
- Manufacturing sand requires a greater understanding of the source rock then normal crushing and screening
- This is due to chemical and physical characteristics that exist in fine aggregates

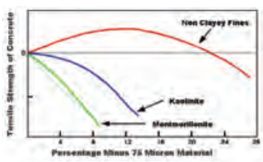
Concrete Compressive Strength Test

Slump Test

Manufacturing Concrete Sand

Clean Source Rock

- The first factor to consider is the cleanliness of the feed rock
- All feed should be scalped as required at the primary crusher to remove any potential clay
- Clay is detrimental to the strength of the concrete as it reacts adversely with the cement



Source, A. Maldonado, S. Orsetti and C. Tourenq,

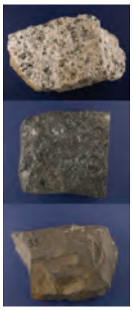
Manufacturing Concrete Sand

Rock Type

The grain size will effect the grading curve produced from the crushing process

The finer grained rock producing more ultrafines

Once the rock has been crushed to it's grain size, it requires a significant amount of energy to crush the individual grains



Granite, Gabbros and Basalt

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Particle Shape

Characteristics

Flaky Particles:
- Poor Workability
- High Water Demand
- High Cement Demand

Elongated Particles:
- Poor Workability
- High Water Demand
- High Cement Demand

Cubical Particles:
- Excellent Workability
- Excellent Finishability
- Reduced Cement Demand
- Higher Compressive and Flexural Strength

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Manufacturing Concrete Sand

Preceding Crushing and Screening Process

The processing the rock receives is one of the key factors on the quality of the end product

More crushing stages => better shape and gradation

Accurate final screening is needed to control the top size of the sand as this needs to be in spec

The crushing plant needs to be on-stream as much as is practical so as to avoid absorbing moisture

To control moisture, aim for a primary stockpile being the only exposed storage with all conveyors and screens covered

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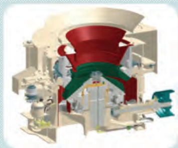
Manufacturing Concrete Sand

Preceding Crushing and Screening Process



Cone Crushing
- The correct feed must be presented and the cone operate in the correct setting
- Choke fed so as to achieve inter-particle crushing

Impact Crushing
- The rotor speeds need to be high enough to shape and grade
- Closed circuit should always be considered so that the correct gradation can be achieved

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Crusher Selection – Dependant on Sand Type

Application: Concrete / Mortar						
Sand Requirement:	Rounded Cubical Shape					
	Minus 5mm	Minus 12.5mm	Minus 25mm	Pea Gravel	12.5 -5mm	25 - 5mm
Soft Rock*	Barmac B-series					
Medium Rock**						
Hard Rock***						

Application: Concrete / Mortar						
Sand Requirement:	Angular Cubical Shape					
	Minus 5mm	Minus 12.5mm	Minus 25mm	Pea Gravel	12.5 -5mm	25 - 5mm
Soft Rock*	Barmac B-series			HP / GP / Barmac VI		
Medium Rock**				HP / GP / Barmac VI		
Hard Rock***				HP / GP		

Application: Asphalt						
Sand Requirement:	Angular Shape					
	Minus 5mm	Minus 12.5mm	Minus 25mm	Pea Gravel	12.5 -5mm	25 - 5mm
Soft Rock*	Barmac B-series	Barmac VI	Barmac VI	HP / GP / Barmac VI		
Medium Rock**		Barmac B-series		HP / GP		
Hard Rock***				HP / GP		

For inches divide by 25,4

Notes:
** Abrasiveness <500 g/t*
*** Abrasiveness 500 – 1000 g/t*
**** Abrasiveness >1000 g/t*

Barmac B-series: rock on rock configuration
Barmac VI: shoe and anvil configuration
HP / GP: Metso high performance cone crushers
Pea Gravel: consists of small, smooth, rounded stones. Typically 3-12,5 mm by size.

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Metso Minerals Handbook

Comparison

Most Suitable Sand Producers

Vertical Shaft Impactors

High Speed Cones

Ref. Toshi Ohashi

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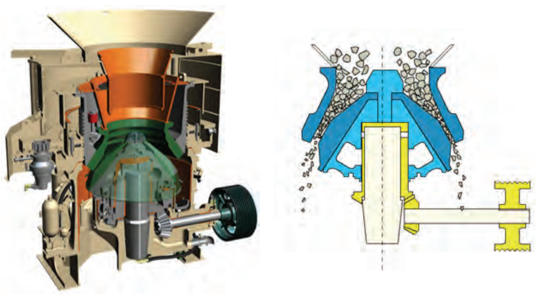
High speed cone crusher



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CONE CRUSHED MANUFACTURED SAND
Advantages

- Higher energy efficiency
- Higher capacity for same installed power
- Lower energy consumption per tonne of sand
- Generate sand with a more favorable size distribution
- Lower generation of ultrafines
- Higher utilization flexibility – Can be used in other crushing stages
- Higher reduction ratio - Lower circulating load
- cubical product
- Less sensitive to rock hardness

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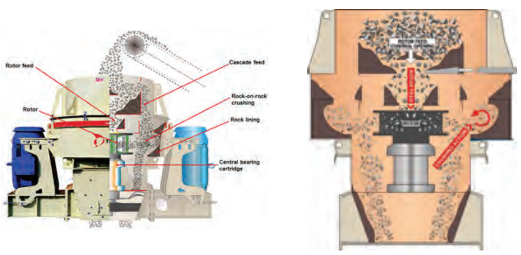
Ref. Toshi Ohashi

Vertical Shaft Impactor



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BARMAC VSI MANUFACTURED SAND
Advantages

- Capability to process fine feed and non scalped feed
- Good tolerance to moisture
- Good tolerance to heterogeneous and irregular feed
- Produces rounded cubical particles
- smooth surface
- Larger VSI allow higher performances
- Constant performance independent of wear parts life
- Shape correction in all particle size range

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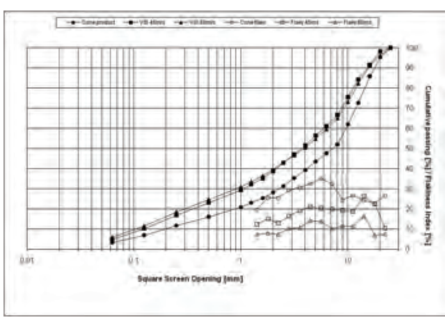
Ref. Toshi Ohashi

Low speed Cone crusher vs. VSI product



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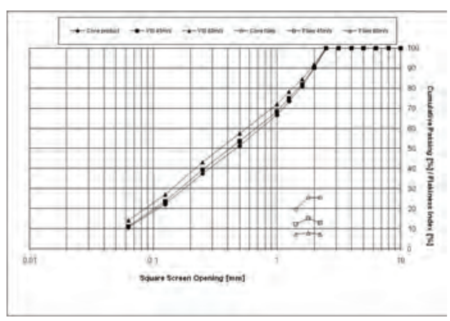
..and the sand grading more specifically



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Example: Crushing and screening process

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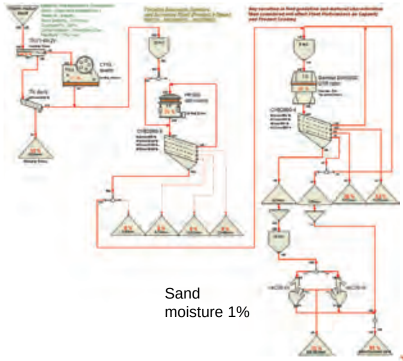
Process flowsheet



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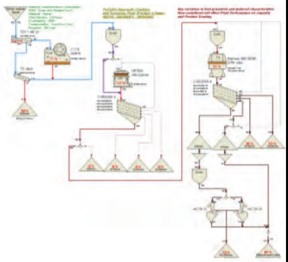
Processing manufactured sand

- Remove natural fines
  - Inpurities, moisture, process feed
- Choke fed high speed cone crusher
  - Choking chamber design
- Cone crusher in closed circuit to control VSI feed (top size & stability)
- Last crushing stage VSI in closed circuit
  - Gives flexibility and possibility to re-grind 3-5mm fraction
- Remove filler with air classifier (AC)
  - Is affected by feed
    - Moisture, tonnage, shape, grading, density
  - Luckily 0-2mm sand grading is typically stabile and rock specific
  - So; control tonnage and moisture
  - Desired amount of filler removal is found by adjusting air flows
- Finally, blend needed amount 3-5mm sand to reach in spec grading



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Sand curve control

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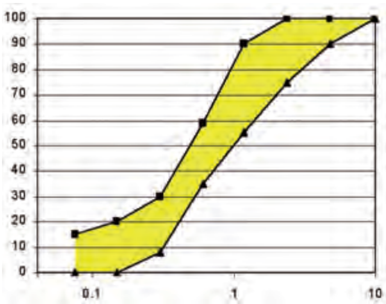
Sand curve according to IS383



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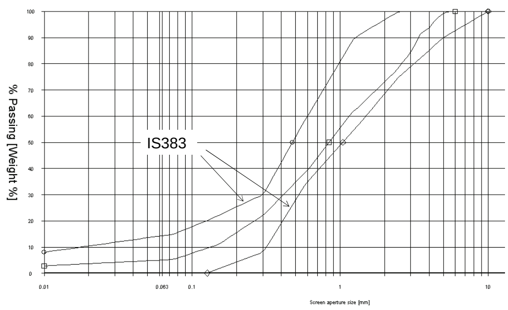
AC unit separation performance utilised 100%



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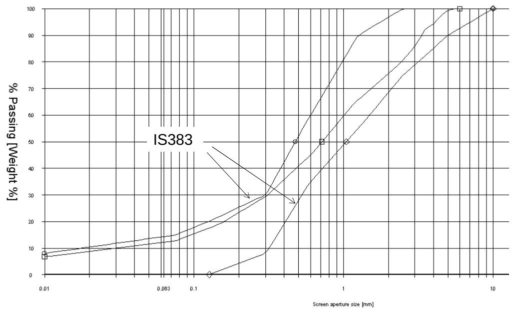
AC unit separation performance adjusted by air flow settings



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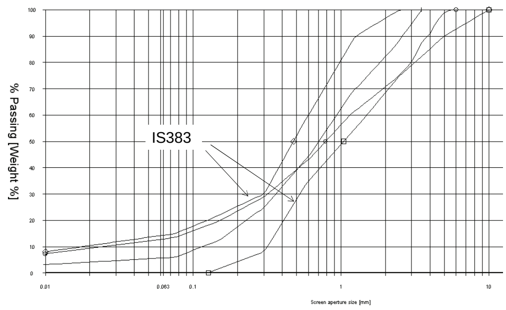
Sand adjusting range



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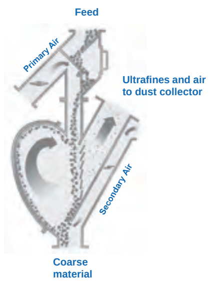
Gravitational Inertial (GI) Classifier

- For cut points from 300µm to 63µm
- GI is a perfect choice for the construction industry for filler removal
- Secondary air is drawn to induce a scrubbing effect on near size particles
- Note that this returning, scrubbing feature is what gives this classifier its unique high efficiency and control of ultrafine removal



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AC30GI Installation

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Manufactured sand for a big dam project

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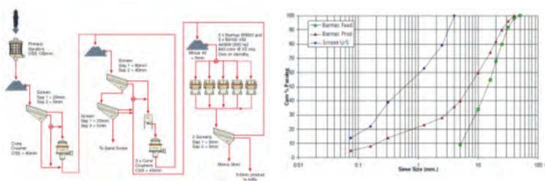
Three Gorges Dam in Yangtze river

- Material: hard and abrasive granite
- In sand production VSI replaces partly rod milling
  - Operating cost significantly lower for VSI compared to rod milling



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Any Questions?

Thank you for your time

EFFECT OF AGGREGATE CRUSHING ON FRESH CONCRETE


Rolands Cepurītis*
Stefan Jacobsen
Tero Onnela
Bård Pedersen

Nordic Concrete Rheology Workshop

3-4 October 2011
Trondheim, Norway

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NORSTONE metso minerals

NEED FOR RESEARCH:

Factors affecting on the quality of crushed fine aggregate are not so distinct the main reason being that there is hardly any research made for the very fine particles.

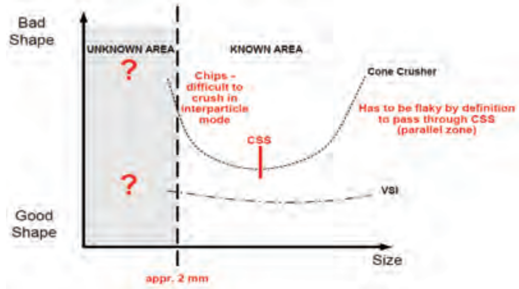


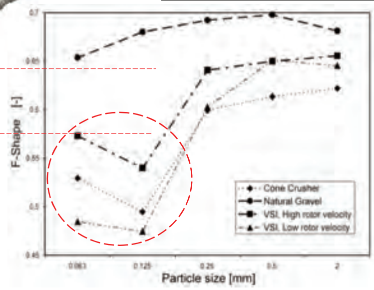
Figure from : **Schouenborg B.,** 2008. Microstructure versus mechanical properties and influence on aggregate production (a contribution to project planning and collaboration). In: Wigum, B.J. ed, 2008. *Manufactured sand – Workshop, Stavanger, Norway, October 30th and 31st 2008.* Summary of Presentations. Trondheim: SINTEF.

NEED FOR RESEARCH/ PREVIOUS RESEARCH:

Are filler particles hard to shape?

Is the mineral composition essential?

Does this affect the rheology?



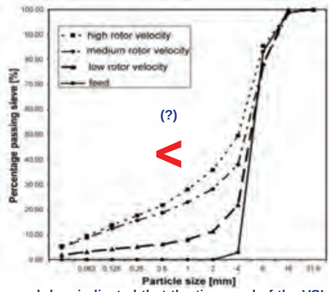
As the advantage of the cone crushers usually the ability of limiting the amount of waste material produced is given while the disadvantage is the poor shape in most fraction sizes. The performance of the VSI crushers is considerably different from the cone crushers. They are capable of producing cubical particles in all size range while the disadvantage is the large amount of fines generated. Though almost no research with fresh concrete has been done.

Figure from : **Bengtsson M., Evertsson C.**, 2006. Measuring characteristics of aggregate material from vertical shaft impact crushers. *Minerals Engineering*, 19 (15), pp. 1479-1486.

NEED FOR RESEARCH/ PREVIOUS RESEARCH:

DRAWBACKS:

- **More energy needed;**
- **Higher wear costs;**
- **More fines generated;**
- **Reduced output (t/h).**



BENEFITS:

- **Better shape – improved concrete rheology (?);**
- **Improved «mass-balance» (?);**
- **Possible cement savings – (?);**
- **Reduced CO_2 emissions (kg/m³) – (?).**

Some preliminary research has indicated that the tip speed of the VSI can reasonably affect the particle shape. Thus the aggregate production industry (and the society as whole) would need feedback if it's reasonable to choose VSI instead of cone crushers and if the energy input by increasing the tip speed would give any «real» benefits in the end product, i.e. concrete production. This has to be looked at in the light of mass balance, increased wear costs and the total CO_2 emissions of the production process.

Figure from : **Bengtsson M., Evertsson C.**, 2006. Measuring characteristics of aggregate material from vertical shaft impact crushers. *Minerals Engineering*, 19 (15), pp. 1479-1486.

OBJECTIVES:

The main objectives of the research were following:

1. **E**xamine if **tip (rotor) speed of a vertical-shaft impactor (VSI)** and **crusher type** for the last crushing stage (VSI or cone crusher) affect grading, shape, surface texture and filler properties of 0/2 mm crushed sand fraction from different bedrocks to an extent measurable in fresh **concrete** and **matrix*** rheology tests.
2. **V**erify which of the **fundamental rheological parameters** of concrete (τ_0, μ, slump and slump-flow) correlate with **crushed aggregate properties** like filler type, particle size distribution, flakiness index, specific surface, loose and compacted packing, flow time (rheology) in New Zeland's flow-cone etc.;

***matrix = filler modified cement paste.** This approach is used in **the Particle-Matrix model** for proportioning where all particles > 0.125 mm are treated as a particle phase dispersed in a lubricating matrix made up of all fluids (water, admixtures etc.) and particles (binder, filler etc.) < 0.125 mm (Mørtsell 1996, Smeplass and Mørtsell 2001).

MATERIALS AND PROCESSING TESTS:

No	Quarry	Producer	Rock type	Crushability, %	Description*	VSI type	VSI tip speed
1	Tau	NorStone AS	Mylonite	23	80% of VSI and 20% of tertiary cone crusher product	Barmac B5100SE	45
							60
2	Jelsa	Norsk Stein AS	Gneissgranite	34	4th step cone crusher GP 550 (50105) feed	Barmac B5100SE	50
							60
3	Hokksund	Hokksund Pukkverk AS	Gneiss	41	3rd step cone crusher Svedala H 36 M product	Barmac B5100SE	45
							60

Each product prepared in two 0/2 mm variations using laboratory sieve-shakers:

1. Filler content **reduced** to a given amount (**10%**) that is equal for all the manufactured sands;
2. Most of the filler **removed** (**1% left**) and replaced with additional **9%** of **limestone filler**.

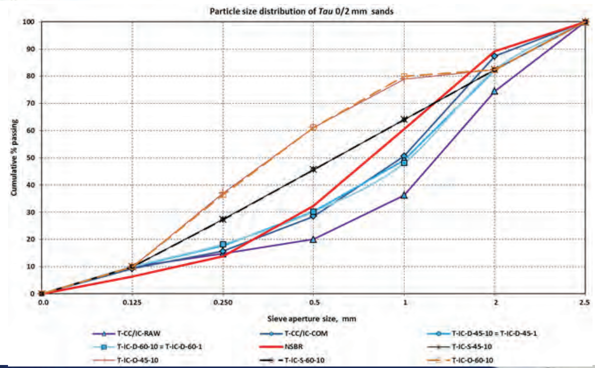
For Tau 45 m/s and 60 m/s 0/2 mm products with **10% crushed filler** three variations of grading were prepared – **«dense»**, **«straight»** and **«open»**.

Crushing tests and sand characterization was carried out at Metso Minerals Research and Test Center in Tampere (full-scale test plant and rock laboratory).

~1700 kg of crushed sand sieved through laboratory sieve shakers!

SOME RESULTS - GRADING:

Particle size distribution of Tau 0/2 mm crushed sands:



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PROCESSING TESTS:

Metso Minerals Research and Test Center in Tampere (full-scale test plant and rock laboratory):

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AGGREGATE CHARACTERIZATION RHEOLOGY TESTS:

0/2 mm sand characterization:

- Particle size distribution (PSD);
- Water absorbtion;
- Flakiness (non-standard bar-sieves for material retained on 2 mm, 1.6 mm and 1.25 mm sieves);
- Flow time in New Zealnd Flow-cone according to NZS 3111:1986 ;
- Loose and compacted packing.

Concrete proportioning using Particle-Matrix model: highly flowable concrete with a reference slump ~200 mm, D_{max} of 16 mm, matrix content 320 l/m³.

Rheological parameters determined in concrete rheology tests (BML-Viscometer 3 by ConTec):

- Fresh concrete slump and slump-flow values. Testing carried out on flow-table. Slump and slump-flow values were determined before and after 5 dumps on the flow-table;
- Flow curves: "Bingham plots" - $\tau_0 + \mu$;
- Compressive strength at age of 28 days.

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COMPACTED PACKING MEASUREMENTS:

«Aggregate producer friendly» compatcted packing measurements:

Steel cylinder with the same geometry as original flow-cone cup

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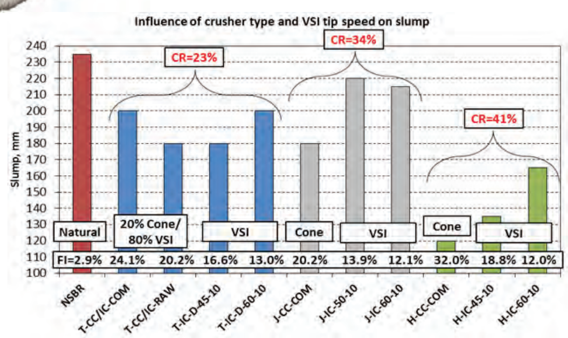
SOME RESULTS – CONCRETE RHEOLOGY:



Slump values showed very good relation to the Bingham yield stress.

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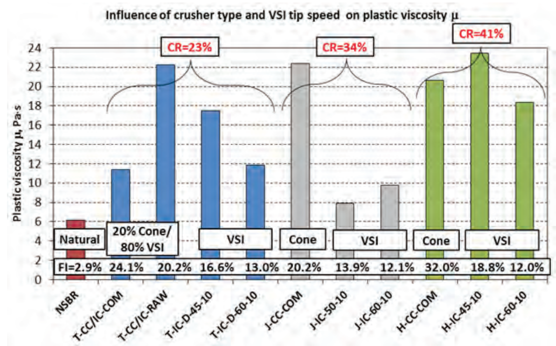
SOME RESULTS – CONCRETE RHEOLOGY:



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SOME RESULTS – VSI TIP SPEED INCREASE COST ANALYSIS:

Is it resonable to increase the VSI tip speed?

Factors considered:

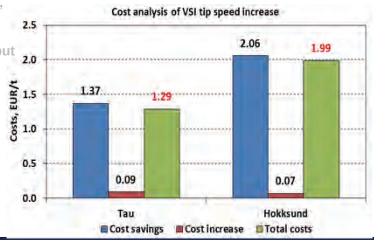
DRAWBACKS:

- More energy needed (kWh/t);
- Higher wear costs;
- Different PSD, more fines generated;
- Reduced output (t/h).

N.B.: Costs used (cement price, power (kWh) price etc.) are informative and correspond to some average prices (excluding VAT) in the Norwegian market.

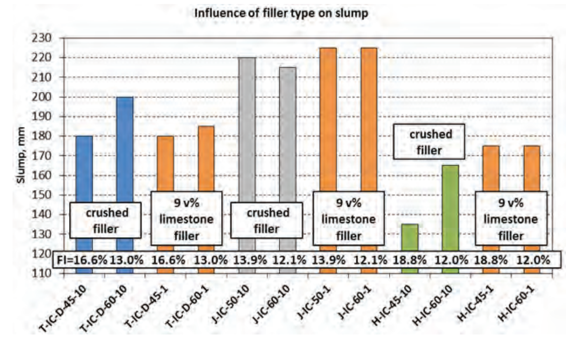
BENEFIT:

- An increase in the VSI tip speed would allow reduce the matrix amount and thus the cement content kg/m³ of concrete to maintain the same workability.



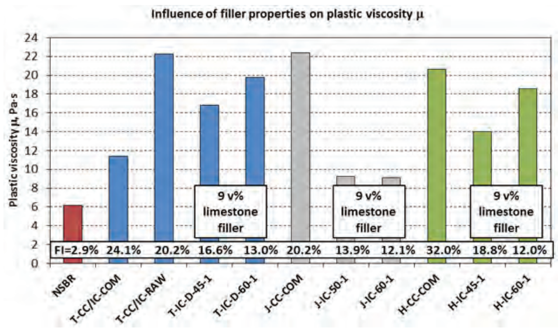
SOME RESULTS – CONCRETE RHEOLOGY:

How big is the effect from the filler part?



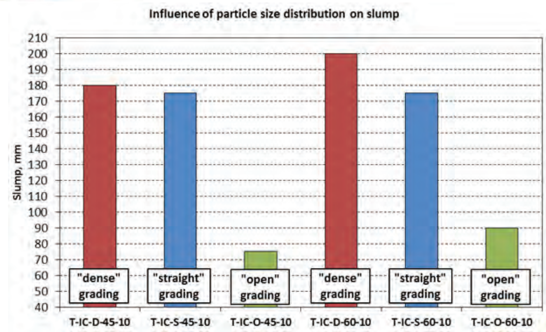
SOME RESULTS – CONCRETE RHEOLOGY:

How big is the effect from the filler part?

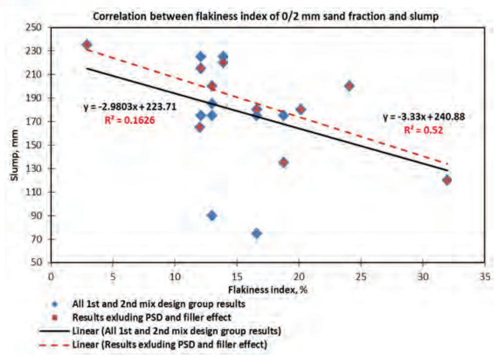


SOME RESULTS – CONCRETE RHEOLOGY:

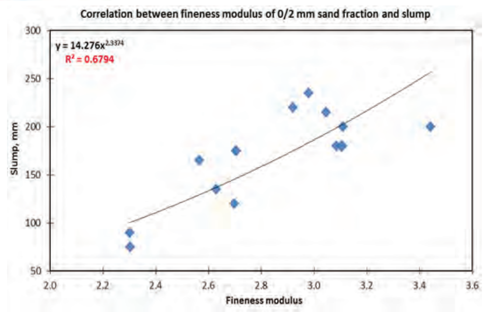
How big is the effect from the PSD?



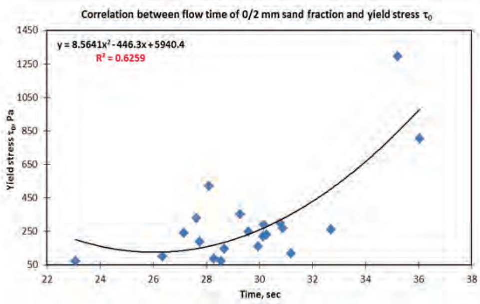
SOME RESULTS – CORRELATION ANALYSIS:



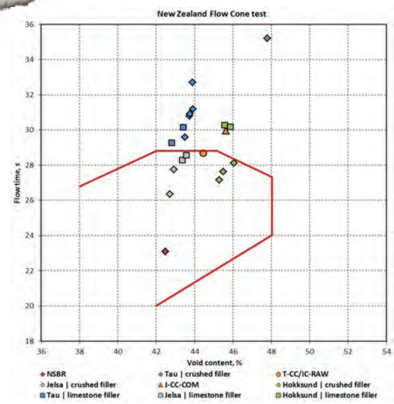
SOME RESULTS – CORRELATION ANALYSIS:



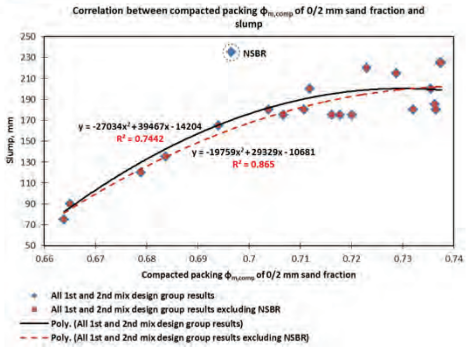
SOME RESULTS – CORRELATION ANALYSIS:



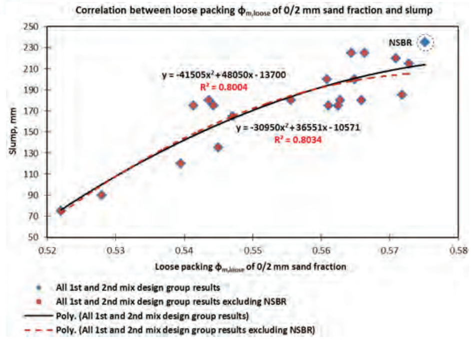
SOME RESULTS – NZ FLOW-CONE:



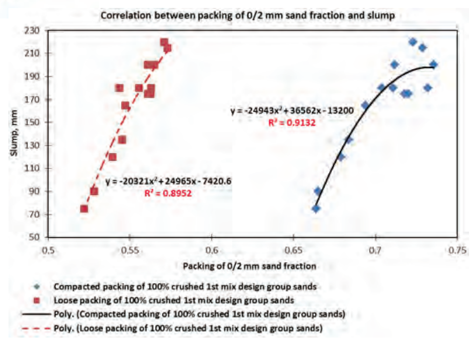
SOME RESULTS – CORRELATION ANALYSIS:



SOME RESULTS – CORRELATION ANALYSIS:



SOME RESULTS – CORRELATION ANALYSIS:

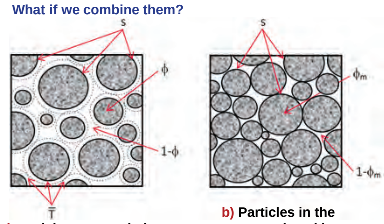


SOME RESULTS – THE SIGNIFICANCE OF PACKING:

Is packing or maximum packing fraction an unambiguous parameter?

- The relation (packing-rheology) is better when particle shape, surface roughness and filer properties (shape and PSD) of the material are more similar.
- Packing is not an unambigous paramater. The same as in case of so widely used PSD – aggregates with equal or very similar packing values can still have indefinite amount of very different specific surface value combinations. Specific surface of aggregates has been related to rheology of concrete since the time of Powers (1968).

What if we combine them?



a) particles suspended in paste/ matrix

b) Particles in the compacted packing denisty state

Approach proposed:

a) equivalent paste thickness

$$\overline{T} = \frac{1-\phi}{s}$$

b) «closeness» or «proximity»

$$"closeness" = \frac{1-\phi_m}{s}$$

COIN

ACKNOWLEDGEMENTS:

TO ALL OF THE PEOPLE WHO HELPED ME WITH SOME THINGS – THERE'S A LOT OF THEM!

TO THE CONTRIBUTING COMPANIES/ INSTITUTIONS:

SINTEF

NTNU – Trondheim
Norwegian University of Science and Technology

metso minerals

NORSTONE HEIDELBERGCEMENTGroup

norsk STEIN

VEIDEKKE

THANK YOU FOR THE ATTENTION!

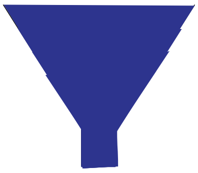
SINTEF NTNU sfi

Session 2

SCC STABILITY

V-funnel

Measurements of rheological properties of mortar using the V-funnel test



L N Thrane, C Pade, M Kaasgaard, T Madsen

Rheology workshop
NTNU Trondheim

Motivation

The V-funnel is one of many existing standard test methods.

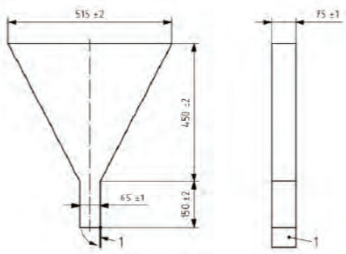
10 liters of material are filled into a funnel. The emptying time is recorded and taken as a measure of “viscosity”.

European standard EN 206-9 suggests two different viscosity classes based on V-funnel testing:

VF1: < 9 sec
VF2: 9-25 sec.

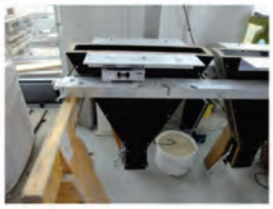
This paper presents initial work on assessment of the rheological behaviour from the V-funnel test.

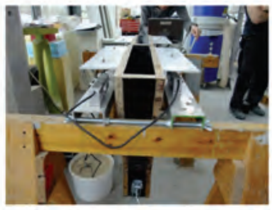
Approach



1. Prepare setup to measure weight over time.
2. Write down analytical equations for apparent viscosity in the V-funnel.
3. Prepare mortar samples with quite different rheology.
4. Compare results with values measured using the 4C-Rheometer.

Experimental setup





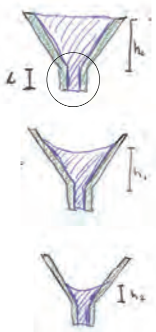
V-funnel is made of plywood. The V-funnel was hanging on three loadcells. The load cells are connected to a datalogger and the weight is logged at a frequency of 8 s^{-1}.

Video recordings were taken from the top.

Analytical equations for apparent viscosity

Shear rate [s^{-1}]:

$$\dot{\gamma} = \frac{6Q}{D^3}$$



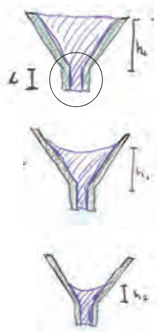
Q is the flow rate [m^3/s]

D is the diameter of an equivalent circular tube outlet [m].

Analytical equations for apparent viscosity

Shear stress [Pa]:

$$\sigma = \frac{\Delta PR}{2L}$$



ΔP is the pressure difference between the top and bottom of the orifice* [Pa].

L is the length (0.150 m).

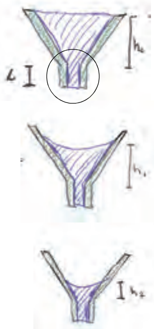
R is the radius of the outlet [m].

**Based on the weight measurement the height of suspension is estimated. The height is used to calculate the pressure difference.*

Analytical equations for apparent viscosity

Apparent viscosity [Pa·s]:

$$\eta_{app} = \frac{\sigma}{\dot{\gamma}}$$

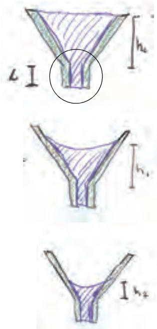


Analytical equations for apparent viscosity

Assumption for outlet diameter:

D is equal to the thickness of the orifice.

Cross sectional area of the rectangular outlet is equal to the cross sectional area of a circular outlet.



Mortar compositions

Initial tests were carried out with two different mortar compositions. The aim was to use mortars with quite different plastic viscosity.

The yield stress was kept low in order for viscosity to be the dominant flow parameter.

The first mortar was proportioned using Spanish raw materials including angular shaped aggregate and limestone filler.

Cement [kg/m³]	LS filler [kg/m³]	Water [kg/m³]	Sand [kg/m³]
439	253	226	1421

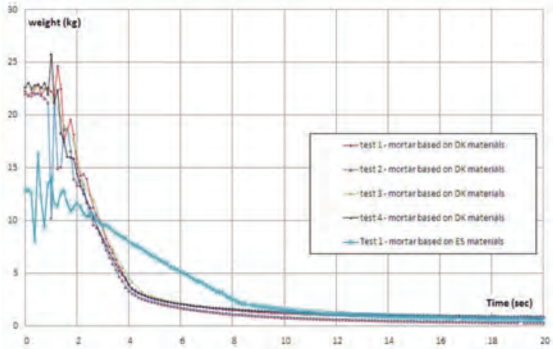
The second mortar was based on Danish raw materials including rounded aggregate and fly ash.

Cement [kg/m3]	Fly ash [kg/m3]	Water [kg/m³]	Sand [kg/m³]
441	294	250	1256

Results

Low viscosity		High viscosity	
Time	Test	Time	Test
13:07	4C-Rheometer	14:35	4C-Rheometer
13:11	V-funnel	14:47	V-funnel
13:17	V-funnel		
13:48	4C-Rheometer		
13:54	V-funnel		
14:00	V-funnel		

Results



Results

Time	Testing	4C Rheometer				V-funnel D=0,082	*V-funnel D=0,075*
		Yield stress [Pa]	Plastic viscosity [Pa s]	Slump flow [mm]	t_{500} [sec]	Viscosity [Pa s]	*Viscosity [Pa s]*
13:07	4C-Rheometer 1	16	21	709	1,8		
13:11	V-Funnel 1					24	*17*
13:17	V-Ffunnel 2					23	*17*
13:48	4C Rheometer 2	32	31	624	2,5		
13:54	V-Funnel 3					31	*22*
14:00	V-Funnel 4					28	*19*

Results

Time	Testing	4C Rheometer				V-funnel D=0,082	*V-funnel D=0,075*
		Yield stress [Pa]	Plastic viscosity [Pa s]	Slump flow [mm]	t_{500} [sec]	Viscosity [Pa s]	*Viscosity [Pa s]*
14:35	4C-Rheometer 1	13	87	738	4.4		
14:47	V-Funnel 1					82	*56*

Summary

Based on simple assumptions and flow curve analysis (weight versus time) the results of apparent viscosity have been compared to the plastic viscosity measured by the 4C-Rheometer.

Results seem to correspond well when using an equivalent outlet diameter of 0.082 m, which corresponds to the assumption that the rectangular orifice of the Vfunnel can be approximated by a circular orifice of equal cross sectional area.

Further investigations

Assessment of the boundary condition. The analytical approach assumes no-slip boundary conditions. However, it this achieved in typical V-funnels made of steel or plywood? Testing using a V-funnel with a rough surface is therefore needed to assess the effect if any of different boundary conditions.

Assessment of the effect of yield stress on the apparent viscosity determined from the V-funnel test. If the apparent viscosity is taken as a measure of plastic viscosity this is valid for zero yield stress materials (Newtonian fluids). Introducing a yield stress, the question is to what extent this will dominate the estimation of apparent viscosity. In particular, it is of interest for suspensions in the slump flow range from 500 to 600 mm, which are commonly used for simple applications.

Assessment of other assumptions. For instance, the calculations of apparent viscosity assume a levelled height over the orifice. However, to which extent a downward curved surface affect the calculations should be investigated.

Rheological properties of self-consolidating concrete stabilized with fillers or admixtures

Hedda Vikan - Norwegian Public Road Administration
Klaartje De Weerdt - SINTEF Building and Infrastructure

Self-Consolidating Concrete (SCC)?

Definition

SCC fills the formwork and surrounds the reinforcement without the need of vibration or compaction, and without considerable segregation influencing the constructions function and durability.

Self-Consolidating Concrete (SCC)?

Why use SCC?

- Better work environment
- Improved placing of concrete

→ However, stagnated at a low market share for in-situ casting in Norway

Why **don't we** use SCC?

- Can exhibit a lower robustness against fluctuations in the concrete production

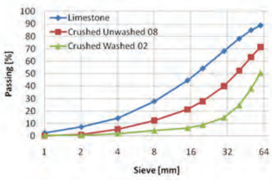
→ Higher demand of quality control

Objective of the project

- Stabilizing SCC in two ways:
  - fines and/or filler,
  - chemical stabilizer
- Investigating the influence of method of stabilization on the **rheological properties** of SCC, both on concrete and matrix
- Later on, the effect of these rheological properties on the final surface quality will be evaluated.

The materials

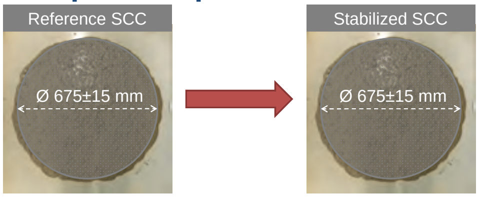
- Cement:
  - CEM II/A-V 42.5R Portland fly ash cement
- Filler:
  - sieved from crushed 0/8mm sand (C)
  - sieved from washed/sieved 0/2mm sand (W)
  - Limestone (LS)
- Aggregates:
  - Gneiss/Granite aggregates 0/8mm and 8/16mm



The materials

- Chemical stabilizer:
  - S1 – polymer with high molecular weight
  - S2 – cellulose derivate
- Super plasticizer:
  - SP1 – acrylic
  - SP2 – lower molecular weight, longer side chains and higher charge density
- Retarder
  - Gluconate based set retarder – reduce the effect of hydration on the measurements

Principle of experiments



1. Stabilize SCC by adding:
   - Filler or
   - Chemical stabilizer
2. Maintain the slump flow by:
   - adopting Super Plasticizer (SP) dosage
3. Evaluate rheology and stability

Recipes

Stabilizer	
Type	**Dosage**
Reference	-
S1	0.4 %
S1	1.2 %
S2	1.0 %
S2	2.0 %
Limestone	40 kg/m³
Limestone	80 kg/m³
Crushed 08 mm	40 kg/m³
Crushed 08 mm	80 kg/m³
Washed 02 mm	40 kg/m³
Washed 02 mm	80 kg/m³

Concrete

	Reference	Filler	
		40 kg/m³	80 kg/m³
w/c	*0.58*	0.58	0.58
w/p	*0.46*	0.44	0.40
f/c (%)	-	12	24
Matrix (l/m³)	*325*	338	352
Cement (kg/m³)	*326*	326	326
0/8 mm (kg/m³)	*1089.6*	1067.1	1043.8
8/16 mm (kg/m³)	*725.0*	711.4	695.9

Matrix

	Reference	Filler	
		40 kg/m³	80 kg/m³
w/c	*0.45*	0.45	0.45
f/c (%)	-	12	24
Total volume	200 ml		
0/8 mm (kg/m³)	Filler fraction		

Experiments

CONCRETE	MATRIX*
• T = G + H.f (4SCC rheometer) • Slump flow [mm] • T500 [s] • Visual Segregation Index (VSI)	• $\tau = \mu \cdot \dot{\gamma} + \tau_0$ (parallel plate) • Thixotropy • Gel strength • Static yield stress

* Incl. fraction < 125 µm sand


4SCC rheometer


T500 and slump flow


paste rheom

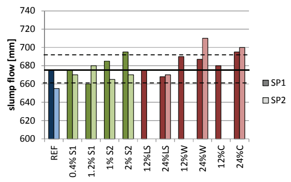
Results

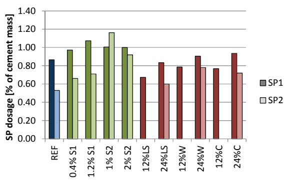
SP dosage – slump flow

Aim
- slump flow of 675±15 mm

Consequence
- varying SP dosage

→ Trend that chemical stabilizers require higher SP dosage than filler to obtain the same slump flow

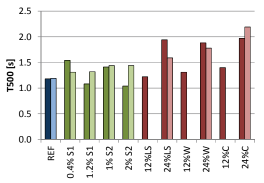


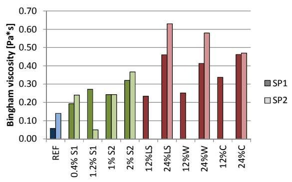


Rheology - Viscosity

Concrete - T500
- The highest filler dosage has the strongest effect. The effect of chemical stabilizer is similar to that of the lower dosage of filler added.
- The effect is similar for both super plasticizers used.

Matrix – apparent viscosity
- Inline with concrete results

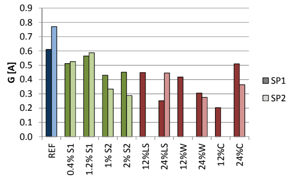


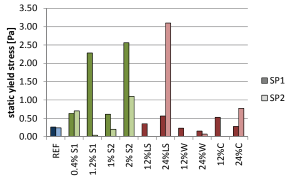


Rheology - Yield stress

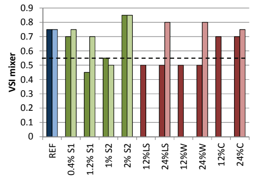
Concrete – G (4SCC rheometer)
- Decreasing trend of yield stress with stabilization

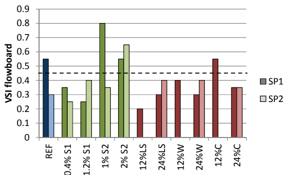
Matrix – apparent viscosity
- Depend on the SP dosage and type
  - SP1: chemical stabilizers strongest effect stress
  - SP2: additional limestone filler greatest effect





Stability – Visual Segregation Index





- Difference VSI_{mixer} and $VSI_{flowboard}$:
  The concrete is generally rated more unstable in the mixer than on the flow board
- Stabilization potential - strongly depending on super plasticizer used:
  - SP1: S1, LS and W are able to stabilize both on board and in mixer
  - SP2: generally unstable in mixer and stable on board

Conclusions

- VISCOSITY
  - Stabilization → increase in viscosity
  - High filler content (24% per cement) → most significant increase in viscosity – in line with Krieger-Dougherty
  - The effect did not depend strongly on the SP used.
- YIELD STRESS
  - Depends on the SP used (matrix results).
    - SP1: chemical stabilizer – strong increase in yield stress
    - SP2: limestone powder (24%) – strong increase in yield stress
- STABILITY
  - VSI does not give conclusive results – difference between on flow board and in mixer
  - Stabilization effect of filler or chemical stabilizer depends strongly on SP type used.

Suggestions for further work

MATERIALS:
- Combinations of chemical stabilizers and fillers

STABILITY TESTS
- Alternative stability tests e.g. sieve segregation test

FULL-SCALE EXPERIMENTS
- Select 2 stabilized concretes for full-scale experiments (wall elements) → evaluate effect of concretes with different rheological properties on the final surface quality.

Acknowledgements

COIN for facilitating this project

www.coinweb.no

Some Fresh Properties of Powder-, VMA- and Combination-Type SCC

Peter Billberg

Project Aim

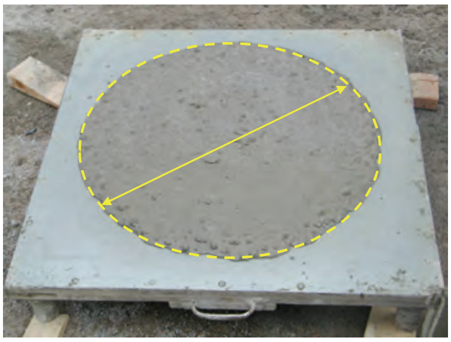
Evaluate how the different parameters:

- W/C ratio
- Powder type
- VMA type
- Type of SCC (powder-, VMA-, combination-)

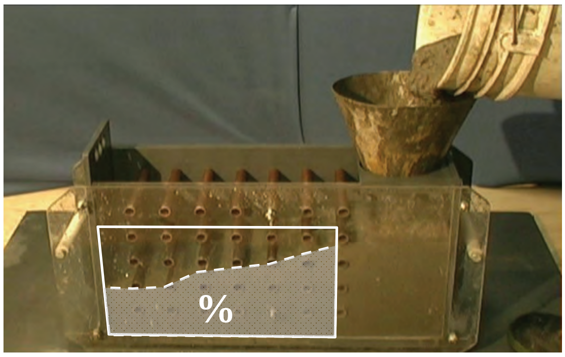
influence the sensitivity of fresh SCC to over- or underestimated aggregate (sand) moisture.

Error range: +/- 1 weight-% of sand moisture
(≈ 10 litres per m^3)

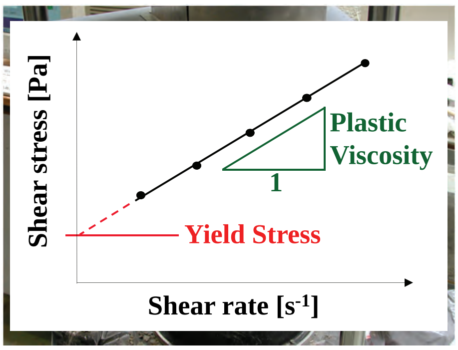
Slump Flow



Filling Capacity



Viscometer ConTec 4



Solid Materials

CEM II/A-LL 42.5 R (Byggcement)

Aggregate 0-8 mm and 8-16 mm, Natural

LP1: Crystalline limestone, $D_{0.5}$ = 40 microns

LP2: Crystalline limestone, $D_{0.5}$ = 25 microns

Chemical Admixtures

SP1: PCE, 35% solids
SP2: PCE, 30% solids
SP3: PCE, 35% solids

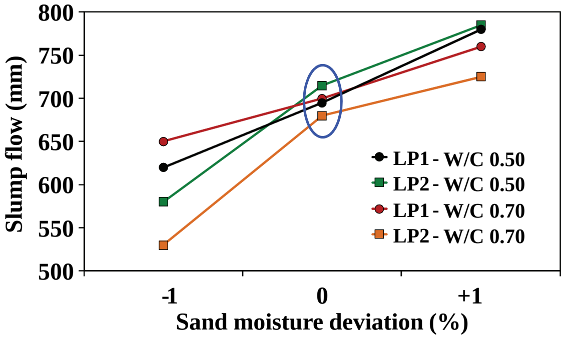
(SP2 and SP3:) Configured also for stability

VMA1: Modified starch
VMA2: Microbial anionic polysaccharide
VMA3: High molecular weight ionic polymers
VMA4: Polysaccharide

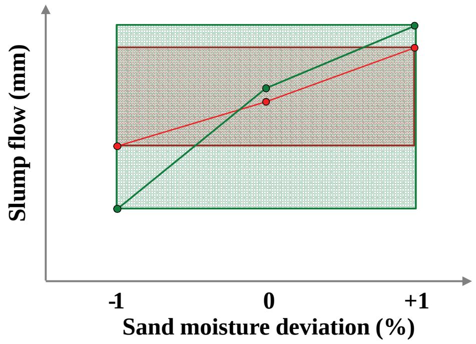
Mix Design - Reference Mixtures

Cement	300	375
Water	210	188
W/C	0.7	0.5
CA	30%	40%
SP Type	SP1	SP1
Powder Type	LP1/LP2	LP1/LP2
Powder weight	200	100

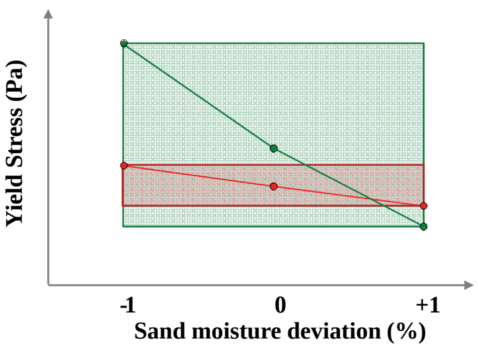
Slump Flow Responses - Refs



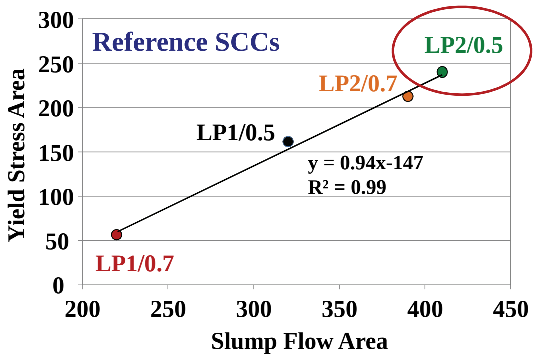
Slump Flow Area



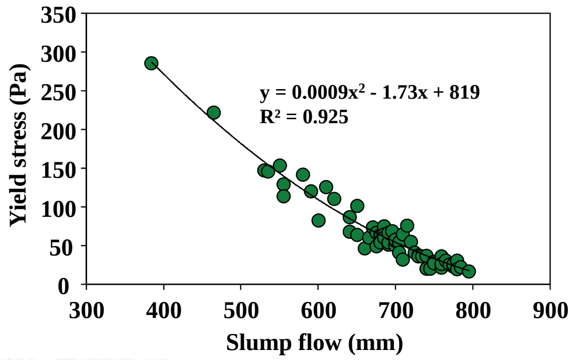
Yield Stress Area



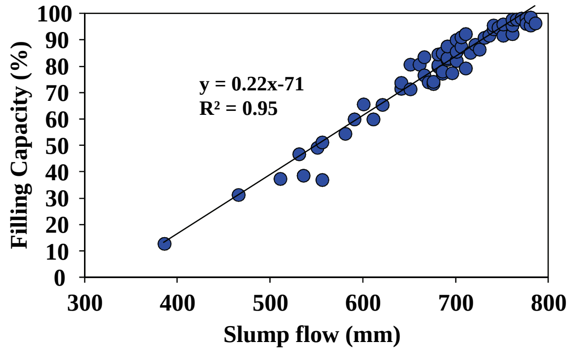
Slump Flow Area vs. Yield Stress Area



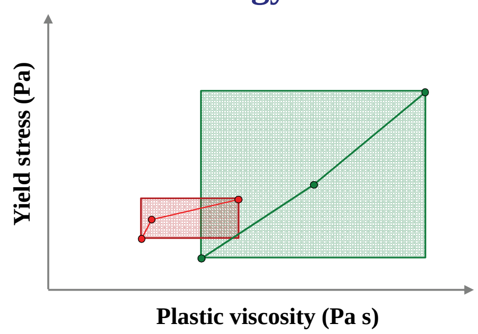
Correlation Slump Flow - Yield Stress



Correlation Slump Flow - FC



Rheology Area



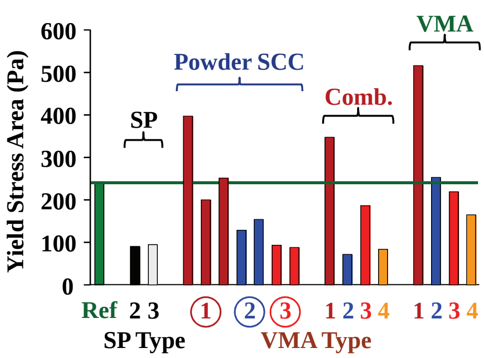
Powder/Comb./VMA Mixtures

Cement = 375, W/C = 0.5, Powder = LP2

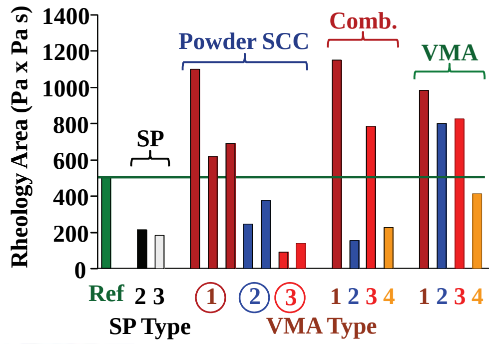
	SCC Type		
	Powder	Comb.	VMA
LP2 weight	100	50	-
CA	40%	35%	30%
SP Type	1, 2, 3	SP1	SP1
VMA Type	1, 2, 3	1, 2, 3, 4	1, 2, 3, 4

↑ low, various, dosages

Results: Yield Stress Area



Results: Rheology Area



Conclusions

The more free water (higher W/C or coarser powder), the more robust the SCC becomes.

Type of SP is important for robustness. SP2 and SP3 are better than SP1 due to enhanced stabilizing ability.

For the powder-type SCC, VMA3 performed best (slump flow, yield stress, Filling Capacity)

For the combination-type SCC, VMA2 and VMA4 performed best.

Strong correlations between slump flow and yield stress and between slump flow and Filling Capacity

Thank you!

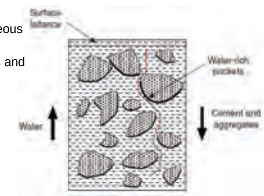
SCC Stability Review & PhD Research

Ya Peng (NTNU)
Stefan Jacobsen (NTNU)
Klaartje De Weerdt (SINTEF)
Bård Pedersen (VEGVESEN)
Oct. 03, 2011

Contents

Stability of SCC

- Stability
  - Dynamic (during the casting process)
  - Static (all placement and casting operations have been completed)
- What's the phenomena of instability
  - Particle sinking -- Segregation – unhomogeneous and inconsistant strength
  - water flowing -- bleeding – water-rich pockets and surface laitance



- What causes the static instability of SCC
  - Higher flowability with chemical admixture
  - Configuration of the form and presence of obstacles
  - Density difference

Theoretical analysis - bleeding

- Orignial Kozeny-Carman equation (KCE) based on viscous flow of a Newtonian fluid through a bed of particles:

From Darcy's law to Kozeny-Carman equation:

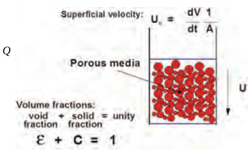
$$\frac{\Delta P}{L} = \mu\left[\frac{k_c(1-\varepsilon)^2 S_v^{\,2}}{\varepsilon^3}\right]\frac{dV}{dt}\frac{1}{A} = \mu\left[\frac{k_c(1-\varepsilon)^2 S_v^{\,2}}{\varepsilon^3}\right]\cdot Q$$

Combined with:

$$\rho_f g \,\Delta P / L = (\rho_s - \rho_f)(1-\varepsilon) g$$

Change the formula to show the bleeding rate:

$$[Q(1-\varepsilon)]^{1/3} = \left[\frac{C}{k_c S_v^{\,2}}\right]^{1/3} \varepsilon \Leftrightarrow Q = \frac{\varepsilon^3}{1-\varepsilon}\frac{C}{k_c S_v^{\,2}}$$



- The term in the square bracket is inverse permeability, σ is specific surface
- The Kozeny constant(or Carman constant) is often used as 5, but much experimental evidence including some cement paste tests by T.C.Powers (1968) suggested that kc=f(ε), i.e. the constant is a function of porosity.

Theoretical analysis - bleeding

- Based on KCE, we get the bleeding curves:

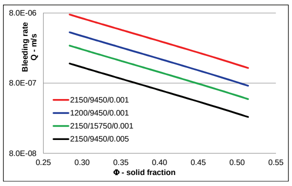


Figure 1 –Φ vs. bleeding according to KCE: effect of particle density, specific surface and fluid viscosity

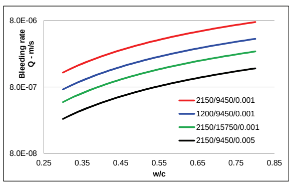
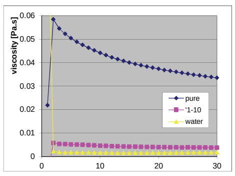


Figure 2 – w/c vs. bleeding (KCE): parameter variation as in fig.1

VMA effect – on fluid viscosity

- Example: VMA effect on viscosity of the fluid - pilot test result



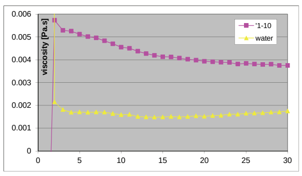


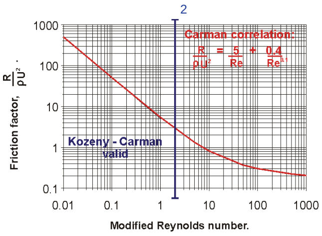
Figure 3 – viscosity of different fluid mixture

Use of KCE for matrix and concrete

- KCE valid for streamline flow
- Determine the flow regime with Modified Reynolds Number - Re_1

$$Re_1 = \frac{\rho U_0}{(1-\varepsilon) S_v \mu}$$

- Based on above calculation result, Max. Re_1=2,9E-06<<2
- Kozeny-Carman valid for cement paste and concrete bleeding
- Correspondingly, when Re_1=2,9E-06, the friction factor between fluid and solid based on Carman correlation:



$$\frac{R}{\rho U^2} = \frac{5}{Re_1} + \frac{0.4}{Re_1^{0.1}} \Leftrightarrow \frac{R}{\rho U^2} = \frac{5}{Re_1} = 1,7E06$$ *(for laminar flow)*

Theoretical conclusion for bleeding

- Fillers and VMA – effect on bleeding:
  - the effect on bleeding of reducing the powder density is smaller than the effect of increasing the specific surface
  - The effect of increasing the fineness should be quite possible to obtain in practice by increasing the cement fineness or replacing parts of the cement by other materials such as fine fillers and/or pozzolana
  - the effect of increasing the liquid viscosity is more effective than using the filler (possibly with VMA)
  - For matrix, when consider the powders or VMA effect on stability, the volume fraction must be used instead of w/c,w/b or w/p.

Measured bleeding

- Filter paper tests with master student Britt. on cement paste with SP

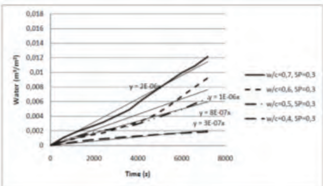


Figure 3 – bleeding rate (w/c 0.4-0.7)

w/c	Q_{calc} (m/s)	Q (m/s)
	Kozeny-Carman	Measured
0,40	1,1E-06	3E-07
0,50	1,6E-06	8E-07
0,60	2,2E-06	1E-06
0,70	2,8E-06	2E-06

Possible two factors for variation:
- *"Blaine" used for calculation, which usually gives lower surface area'*
- *Particle shape and hydration*
- *Soft interface between bleeding water layer and original concentration layer,*

Particle sedimentation

- Assuming that the particle sinks according to Stokes law as the yield stress is passed, Stokes law was combined with Bingham fluid behaviour. The force balanced as:

$$(\rho_s - \rho_f)\frac{4}{3}\pi r^3 g = \Delta\rho\pi d^3 g/6 = 3\pi d v \mu \qquad \mu = \frac{\tau_0 + f(\gamma)}{\gamma}$$

Density difference — Drag force based on Stoke's law

- Change the formular to get sinking velosity or particle diameter:

$$v = \frac{d}{\mu}\left(\frac{d(\rho_s - \rho_f)g}{18} - \tau_0\right)$$

Combined with the calculation of Roussel and He et. al., the simplified expressions are obtained to calculate the particle radius or sinking velocity as function of the other main variables

$$d_c = \frac{K\tau_0}{|\rho_s - \rho_f| g}$$

For a yield stress fluid this is then an expression for the critical diameter, d_c, which is the maximum diameter of a spherical particle not sinking in a Bingham fluid

Use of Stoke's law for concrete

Norminal particle size [mm]	Newtonian streamline fluid		Bingham fluid with τ_0=5Pa	
	Particle sinking velocity V_t [m/s]	matrix viscosity μ [Pa·s]	Particle sinking velocity V_s [m/s]	matrix plastic viscosity μ_p [Pa·s]
2	0,0150	0,160	-**	-**
3	0,0184	0,294	-	-
4	0,0212	0,452	-	-
5	0,0237	0,632	-	-
6	0,0260	0,831	-	-
7	0,0281	1,047	-	-
8	0,0300	1,280	-	-
9	0,0318	1,526	0,0086	0,414
10	0,0335	1,787	0,0137	0,728
11	0,0352	2,062	0,0173	1,015
12	0,0367	2,350	0,0203	1,297
13	0,0382	2,650	0,0229	1,587
14	0,0397	2,960	0,0252	1,883
15	0,0411	3,285	0,0273	2,190
16	0,0424	3.620	0,0293	2,505

Table 1.1 – Particle sinking velocity & relative matrix viscosity required for R_{ep}<0.3
ρ_l =1600kg/m3 for w/c=0.7, $\Delta\rho_{s-l}$=2150kg/m³(max. density difference)

Norminal particle size [mm]	Newtonian streamline fluid		Bingham fluid with τ_0=5Pa	
	Particle sinking velocity V_t [m/s]	matrix viscosity μ [Pa·s]	Particle sinking velocity V_s [m/s]	matrix plastic viscosity μ_p [Pa·s]
2	0,0097	0.135	-**	-**
3	0,0118	0.249	-	-
4	0,0137	0.383	-	-
5	0,0153	0.535	-	-
6	0,0167	0.703	-	-
7	0,0181	0.886	-	-
8	0,0193	1.082	-	-
9	0,0205	1.292	-	-
10	0,0216	1.512	-	-
11	0,0227	1.745	-	-
12	0,0237	1.988	-	-
13	0,0246	2.244	-	-
14	0,0256	2.505	-	-
15	0,0265	2.780	-	-
16	0,0274	3.060	0,0058	0.645***

Table 1.2 – Particle sinking velocity & relative matrix viscosity required for R_{ep}<0.3
ρ_l =2150kg/m3 for w/c=0.7, $\Delta\rho_{s-l}$=1600kg/m³(min. density difference)

Theoretical sinking velocity

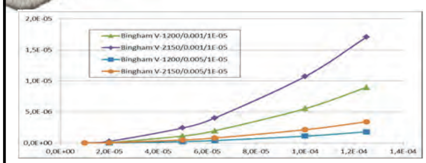


Fig. 1.1 Particle sinking velocity in Newtonian streamline fluid

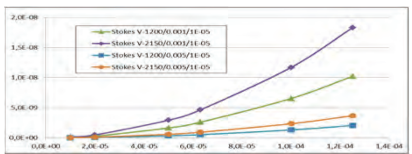


Fig. 1.2 Particle sinking velocity in Bingham fluid with τ_0=10^{-5}Pa

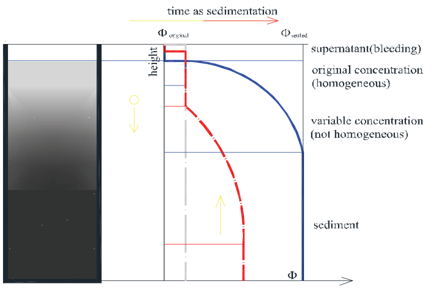
Prilimilary finding of the research

- Lower w/c-, w/b-ratio and/or superplasticizer-dosage (SP/c-ratio) increase stability and therefore robustness of cementitious materials;
- Greater fines content increases stability;
- Many researchers claimed that viscosity modifying admixture (VMA) can be used to reduce the variability of the mixtures, thus increasing the stability and robustness;
- Large aggregate size and high density decrease stability and vise-versa. However, within common ranges of SCC admixture and densities of aggregate, Bonen and Shah argued that the most important factor that governs the rate of sedimentation is the aggregate size;
- VMA improves stability significantly, the effect on rheology could be both to increase viscosity and yield stress.
- The maximum packing fraction (Φ/Φ_{max}) expresses the spacing of the particles and relates to stability.

Research project introduction

- A PhD project about rheology and stability affected by mineral additives and fillers
- The research focus on the relations between stability and both material parameters
  - Phenomena: particle sedimentation, distribution / flocculation, bleeding, yield stress build-up etc.
  - Factors: volume fraction, specific surface area of particles, density, liquid plastic viscosity, Φ/Φmax, yield stress, etc.
  - Materials: SP, VMA, fillers (limestone, fly ash (within cement), silica fume, etc.)
  - Test methods: Experimentally and practically there is a need for measurement methods for settlement, bleeding and static yield stress to evaluate the effect of different material parameters on stability.

Sedimentation model



Test methods overview

- Stability
  - Sedimentation & Segregation
    - Paste or matrix:
      - External radiation e.g. Neutrons, X-ray, γ-ray, microwaves
      - Emitted radiation e.g. Radioactive tracers, NMR, magnetic tracers
      - Electrical properties e.g. sedimentation potential, capacitance, conductance
      - Physical properties e.g. sedimentation balance, pressure measurement
      - Direct methods e.g. sampling, physical interruptions
    - concrete:
      - Visual examination method; Column segregation test (ASTM C1610); Penetration apparatus (PA) method; Segregation Probe Test; Eddy current test; Sieve stability test; Image analysis method; Multi-pair electrode conductivity approach; Air meter test; Swedish bleeding test; Falling ball test
  - Bleeding
    - Earlier settlement and bleeding tests: (ASTM C243-paste & mortar, C232-concrete)
    - Power's method (use floating panel to check surface level of fresh paste and concrete)
    - Methods by L Josserand and F.de Larrard (track for bleeding water or filter paper)
    - Bleeding test method used by Sawaide and Iketani

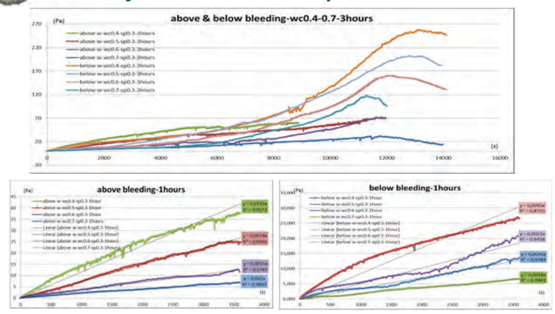
Test methods

Stability of matrix

Particle sedimentation	Density difference: vibronic test / UPV test Flux difference: hydrostatic pressure test	V_t, ρ_{matrix}, Φ change with time and height of level
Yield stress build-up	Plate test	Yield stress increasing gradiant
Rheology properties	Parallel plate rheometer	Gel strength, μ, τ_0 changing vs. time
Max. packing density	Centrifuge	Φ/Φ_{max}
Viscosity of the fluid	Centrifuge or filter test combine with parallel plate rheometer	
Particle distribution	External radiation e.g. X-ray, γ-ray, microwaves, microscopy	
Bleeding		

Test methods set-up for matrix stability

Static yield stress build-up



Thanks you for comments!

Ya.Peng@ntnu.no
Stefan.Jacobsen@ntnu.no

Session 3

RHEOLOGY

On the influence of entrained air (EA) on rheology of paste and mortar

Tor Arne Martius-Hammer
Kåre Johansen

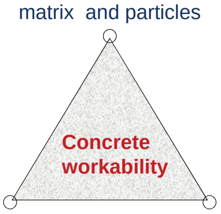
Concrete Innovation Centre
SINTEF Byggforsk

Motivation

- **Role of EA in the Particle-Matrix-Model (PMM)**
- **EA as a tool to improve workability of SCC?**

PMM (Mørtsell 1996)

The volume relation between matrix and particles



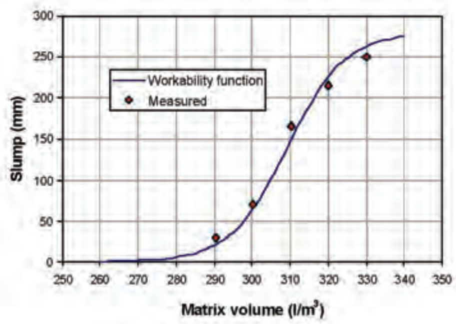
Matrix properties

(filler modified cement paste)

Particle properties

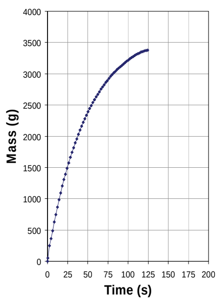
(particles >125µm)

Workability function

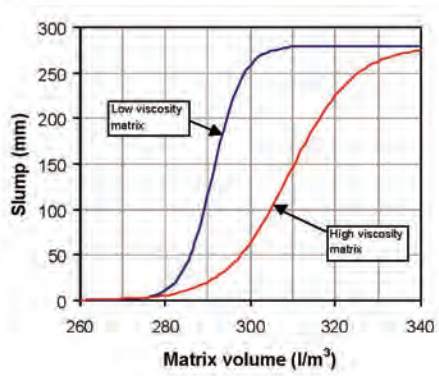


Matrix properties

FlowCyl determines the *flow resistance*, λ_Q of the matrix material which is closely related to viscosity



Flow resistance



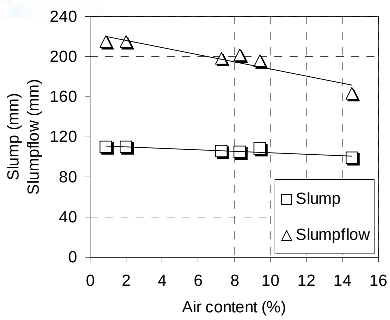
Experiments

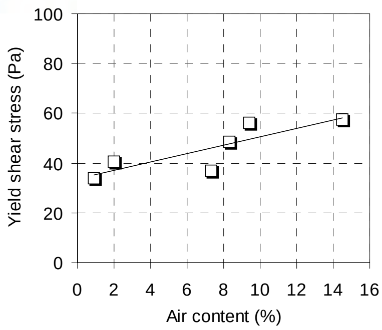
- Testing pure cement pastes with w/c = 0.35 with 0 – 15 % air content
- Testing the influence of increasing the air content from 3 – 13 % in mortars with w/c = 0.50
- Testing the influence of increasing the matrix content with 7 % in mortars with 3 % air

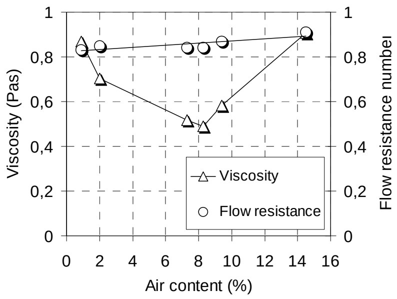
Experiments

- Slump and slumpflow (120 mm and 300 mm cone)
- Flow resistance number (FlowCyl)
- Viscosity and yield shear stress (ConTec 4 Rheometer)

Cement paste

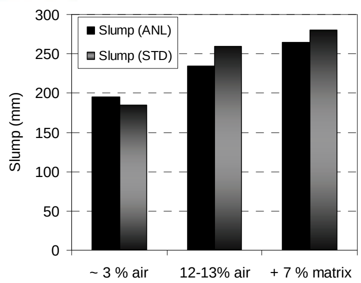




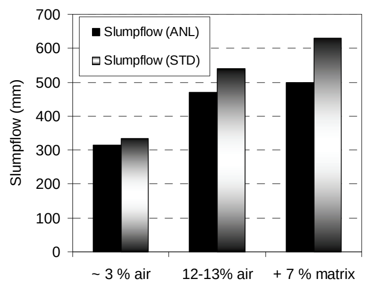


1
0,8
0,6
0,4
0,2
0
Viscosity (Pas)
Flow resistance numbe
0 2 4 6 8 10 12 14 16
Air content (%)
Viscosity
Flow resistance

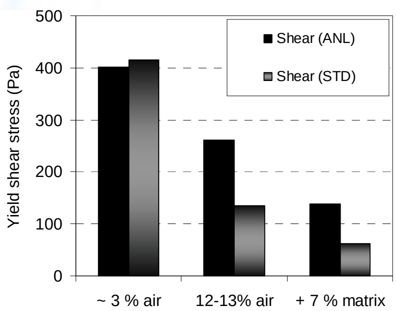
Mortar



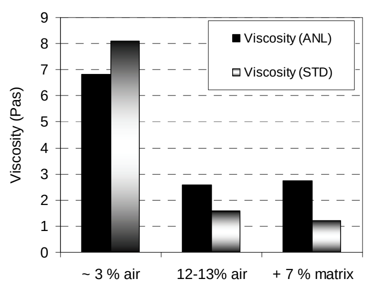
Slump (mm)
300
250
200
150
100
50
0
Slump (ANL)
Slump (STD)
~ 3 % air
12-13% air
+ 7 % matrix



Slumpflow (mm)
700
600
500
400
300
200
100
0
Slumpflow (ANL)
Slumpflow (STD)
~ 3 % air
12-13% air
+ 7 % matrix



Yield shear stress (Pa)
500
400
300
200
100
0
Shear (ANL)
Shear (STD)
~ 3 % air
12-13% air
+ 7 % matrix



Viscosity (Pas)
9
8
7
6
5
4
3
2
1
0
Viscosity (ANL)
Viscosity (STD)
~ 3 % air
12-13% air
+ 7 % matrix

COIN

Conclusion

EA reduces slightly consistency of cement paste.
Nevertheless, it contributes to increased consistency of mortars, because of increased paste(matrix)-aggregate ratio.

EA may be considered as part of ”matrix” in the PMM, but with an ”efficiency factor” less than 1

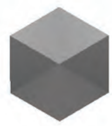
SINTEF

The importance of shear rate in concrete rheology

Olafur H. Wallevik, ICI Rheocenter,
Innovation Center Iceland,
Reykjavik Uni. & Sherbrooke University

ICI Rheocenter

The importance of shear rate in concrete rheology



Olafur H. Wallevik, ICI Rheocenter,
Innovation Center Iceland,
Reykjavik Uni. & Sherbrooke University

ICI Rheocenter

ICI rheocenter

a center of excellence in cement based materials

material science · concrete technology

research, service & education

Innovation Center Iceland · Reykjavik University

Content

Eco-SCC®
Total powder:
≥ 315 kg/m³

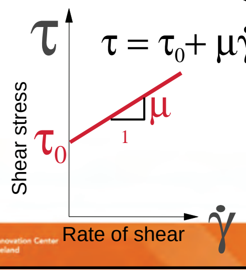
- Introduction to rheology
- Flowcurve
- Rheograph
- Importance of correct rate of shear
- Cement admixture interaction
- Importance of mixing energy
- Degree of dispersion due to agitation
- How to alter the viscosity
- Rheology; The key to Eco-SCC®

Bingham model

τ_0: yield value (Pa)

μ: plastic viscosity (Pa•s)

$$\tau = \tau_0 + \mu\dot{\gamma}$$



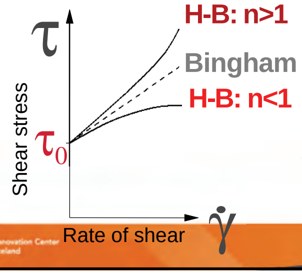
Or yield shear stress value (the shear strength)
Hardened concrete: ~3 000 000 Pa
Fresh stiff concrete: ~3 000 Pa
Fresh fluid concrete: ~300 Pa
Self-Compacting Concrete: ~30 Pa
Very viscous SCC: ~3 Pa

The plastic viscosity tells The force/stress necessary to increase the rate of flow

"Everything should be as simple as possible, but **not** simpler", Einstein

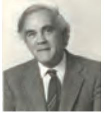
Flow curve for Herschel–Bulkley (n≠1) and Bingham (n=1) fluids.

$$\tau = \tau_0 + k\,\dot{\gamma}^n$$



Rheometers measures torque (T) and velocity (N)

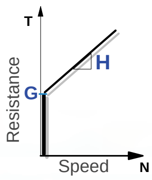
$$T = \frac{4\pi h \hat{\tau}_0}{\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right)} \ln\left(\frac{R_o}{R_i}\right) + \frac{\mu 8\pi^2 h}{\left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right)} N \equiv \hat{G} + \hat{H}N$$

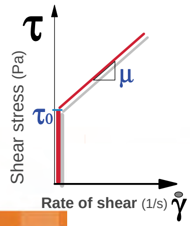


G. H. Tattersall

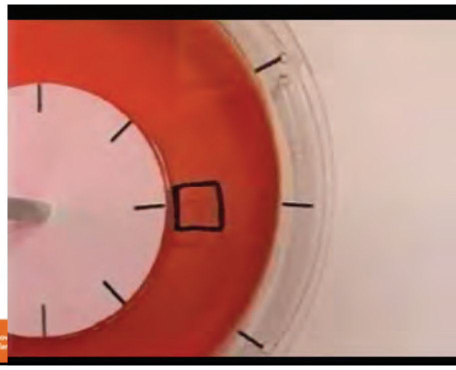
T = G + H N

$$\tau = \tau_0 + \mu \dot{\gamma}$$



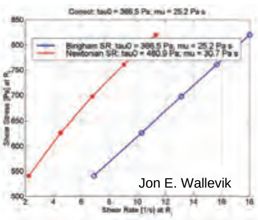


Rate of shear



Using Newtonian shear rate for non-Newtonian fluids would be wrong

- If R-R equation
  - Yield value: 367 Pa
  - Pl. viscosity: 25 Pa·s
- If Newtonian shear rate
  - Yield value: 480 Pa
  - Pl. viscosity: 30 Pa·s



$$\dot{\gamma} = 2\omega \frac{(R_o/R_i)^2}{(R_o/R_i)^2 - 1}$$

Estimation of shear rate for non-Newtonian fluid can be complex

REINER-RIWLIN equation to calculate the Bingham parameters

$$T = \frac{4\pi \mu h}{1/R_i^2 - 1/R_s^2}\omega_o + \frac{4\pi \tau_o h}{1/R_i^2 - 1/R_s^2} \ln\left(\frac{R_s}{R_i}\right)$$

Shear rate from the RR equation:

$$\dot{\gamma} = \frac{T}{2\pi\mu r^2 h} - \frac{\tau_o}{\mu} \qquad \tau = \frac{T}{2\pi r^2 h}$$

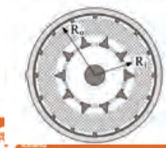
$$\rightarrow \dot{\gamma} = \frac{2}{r^2}\left(\frac{1}{R_i^2} - \frac{1}{R_s^2}\right)^{-1}\left[\omega_o + \frac{\tau_o}{\mu}\ln\left(\frac{R_s}{R_i}\right)\right] - \frac{\tau_o}{\mu}$$

REINER-RIWLIN EQUATION (see for example pp.58-59 Wallevik, J.E. (2003); Rheology of Particle Suspensions www.diva-portal.org)

An example

Input data:

- Plastic visosity: 23 Pa·s
- Yield value: 812 Pa
- Inner cylinder, Ri: 0,1 m
- Outer cylinder, Ro: 0,145m
- hight 0,199m

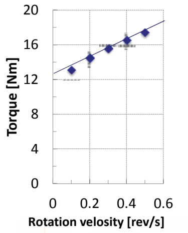


Drawing from Heirman et al.

An example

Input data: by R-R equation

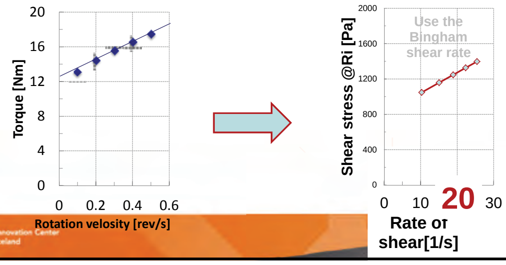
- Plastic visosity: 23 Pa·s
- Yield value: 812 Pa
- Inner cylinder, Ri: 0,1 m
- Outer cylinder, Ro: 0,145m
- hight 0,199m



Drawing from Heirman et al.

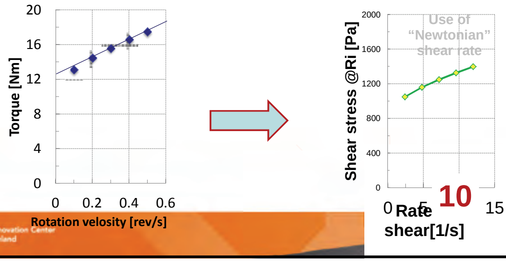
Now use R-R equation to calculate rate of shear

$$\dot{\gamma} = \frac{2}{r^2}\left(\frac{1}{R_i^2}-\frac{1}{R_s^2}\right)^{-1}\left[\omega_o+\frac{\tau_o}{\mu}\ln\left(\frac{R_s}{R_i}\right)\right]-\frac{\tau_o}{\mu}$$



Now use equation for Newtonian fluid to calculate rate of shear

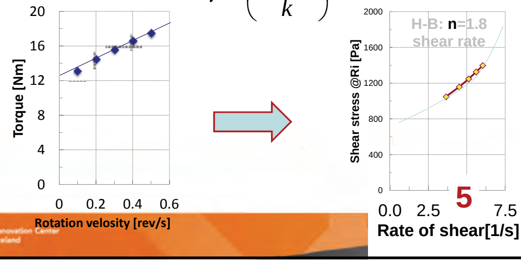
$$\dot{\gamma} = 2\omega\frac{(R_o/R_i)^2}{(R_o/R_i)^2-1}$$



Now use equation for H-B [n=1.8] to calculate rate of shear

$$\tau = k\,\dot{\gamma}^n + \tau_0$$

$$\dot{\gamma} = \left(\frac{\tau-\tau_0}{k}\right)^{\frac{1}{n}}$$

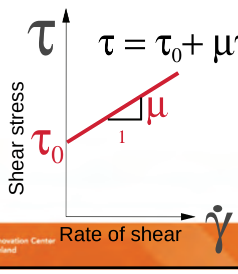


Bingham model

τ_0: yield value (Pa)

μ: plastic viscosity (Pa·s)

$$\tau = \tau_0 + \mu\dot{\gamma}$$

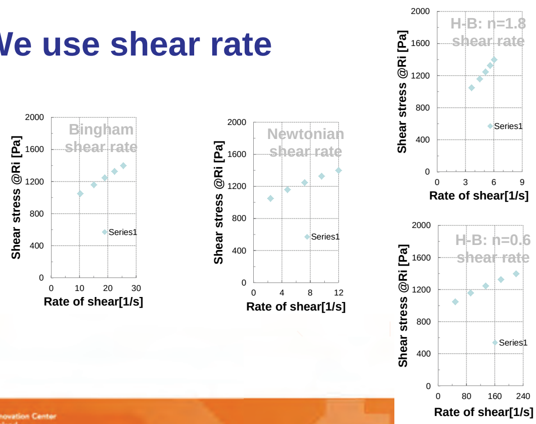


Or yield shear stress value (the shear strength)
Hardened concrete: ~3 000 000 Pa
Fresh stiff concrete: ~3 000 Pa
Fresh fluid concrete: ~300 Pa
Self-Compacting Concrete: ~30 Pa
Very viscous SCC: ~3 Pa

The plastic viscosity tells The force/stress necessary to increase the rate of flow

"Everything should be as simple as possible, but **not** simpler", Einstein

We use shear rate



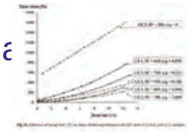
Similar to the R-R eq. the analytical solution for a H-H fluid

R-R: Reiner–Riwlin
H-B: Herschel–Bulkley

$$T = \frac{4\pi h \tau_{0,\mathrm{HB}}}{(1/R_i^2 - 1/R_o^2)} \ln\left(\frac{R_o}{R_i}\right) + \frac{2^{2n+1}\pi^{n+1} h K}{n^n (1/R_i^{2/n} - 1/R_o^{2/n})^n} N^n \equiv G_{\mathrm{HB}} + H_{\mathrm{HB}} N^J \qquad (25)$$

G. Heirman, L. Vandewalle, D. Van Gemert, O.H. Wallevik, Integration approach of the Couette inverse problem of powder type self-compacting concrete in a wide-gap concentric cylinder rheometer, J. non-Newtonian Fluid Mech. 150 (2008), 93-103.

Modified Bingha



$$\tau = \tau_0 + \mu \cdot \dot{\gamma} + c \cdot \dot{\gamma}^2$$

D. Feys, R. Verhoeven, G. De Schutter, Evaluation of time independent rheological models applicable to fresh Self-Compacting Concrete, Appl. Rheol. 17:5 (2007), 56244.

A. Yahia, K.H. Khayat, Analytical models for estimating yield stress of high-performance pseudoplastic grout, Cem. Conc. Res. 31 (2001), 731-738.

Modify the R-R equation for retrieving M-B

- D. Feys .e al.

R-R: Reiner–Riwlin”
M-B: Modified Bingham

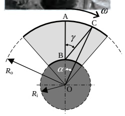
Rheology
Don’t have be expensive

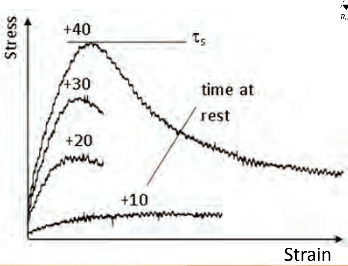
$$\tau_0 = \frac{225 \rho g \Omega^2}{128 \pi^2 R^5}$$

ρ: the density of the material (kg/m^3)
g: the gravitational acceleration (m/s^2)
Ω: the total volume of the sample (m^3)
R: the radius of the spread (m)

N. Roussel, P. Coussot, “Fifty-cent rheometer” for yield stress measurements: From slump to spreading flow, J. Rheol. 49 (2005), 705-718.

Stress strain curve & static yield stress

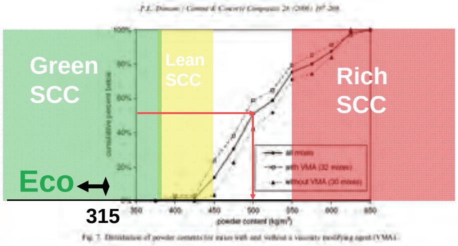




Mixer (efficient) is very important

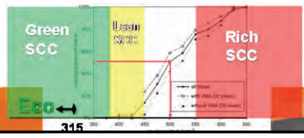
ICI rheocenter

The average cement content in "normal" SCC is about 500 kg/m³



Proposed classification
in respect of powder content
(Not including the fines in the aggregates)

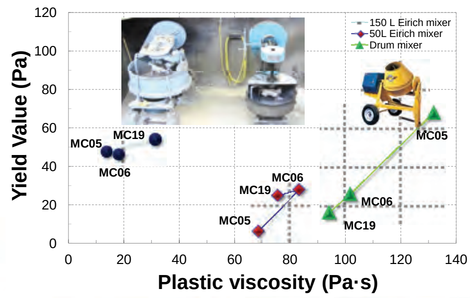
- Rich SCC ≥ 550 + kg/m³
- Normal powder content SCC: 500 ±50 kg/m³
- Lean SCC 415 ±35 kg/m³
- Green SCC 350 ±35 kg/m³
- Eco-SCC® ≤ 315 kg/m³



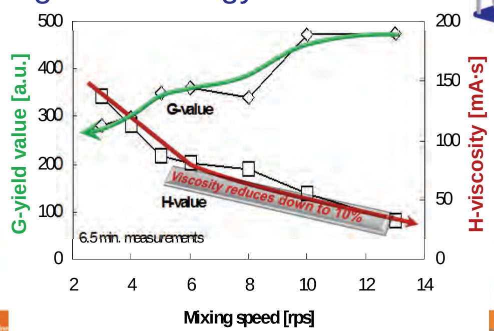
Eco-SCC® Definition

- is environmental and economical alternative,
- where the total binder/powder content
  - Cement, FA, silica fume, BFS, limestone filler
- is **315** kg/m³ or below
  - Not including filler from aggregates

Mixing: Degree of agitation affects very the plastic viscosity



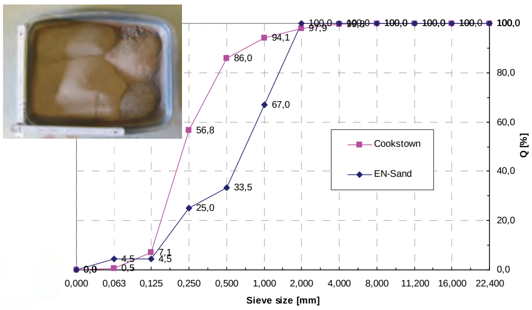
Evaluating effect of (mixing) agitation energy: Rheomixer



Final remarks

- The classic equation for calulating rate of shear is only valid for Newtonian liquid
- Bingham approch should be used for cemetitious materials due to it simplisity
  - Reiner-Riwlin equation in excelent tool
- In particular sheat thickening can be problem
  - Modified Binghan can be a solution

Sand: EN versus Cookstown

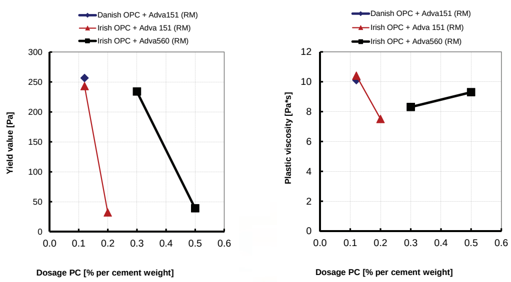


Sand: EN versus Cookstown

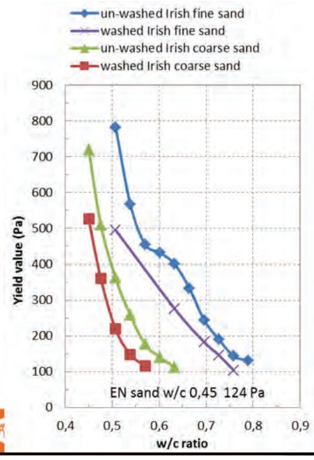
- Same mix design:
  - EN-sand: very fluid mortar
  - Cookstown: very stiff mortar

And 2 types of PC (SP)

Adva 151 & Adva 560



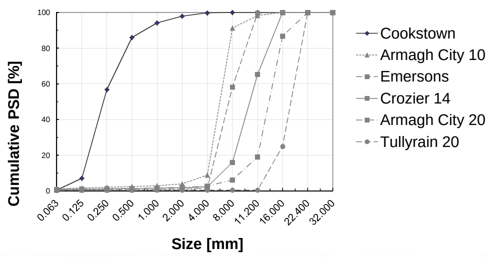
Cookstown



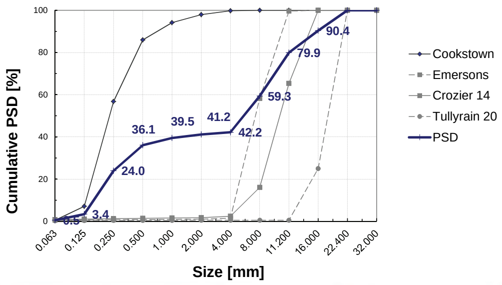
Aggregates

- Tullyrain 20 mm
- Armagh City 10 and 20 mm (not use
- Crozier 14 mm
- Emersons 10 mm
- Cookstown 2mm

Grading



Grading

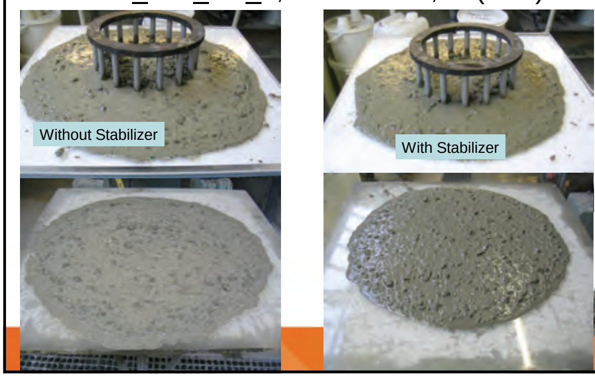


name code: Cement type_Cement content_PC content_ST content (% per cement weight)

OPC_525_0.66_0.87 – w/c = 0,38

name code: Cement type_Cement content_PC content_ST content (% per cement weight)

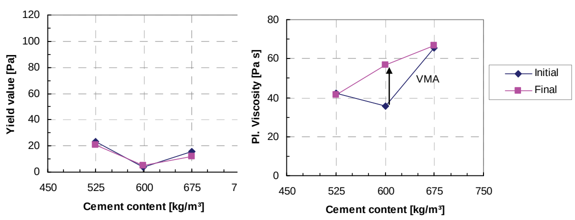
OPC_600_0.0_0,87 – w/c = 0,34 (no ST)
OPC_600_0.6_0,87 – w/c = 0,34 (+ST)



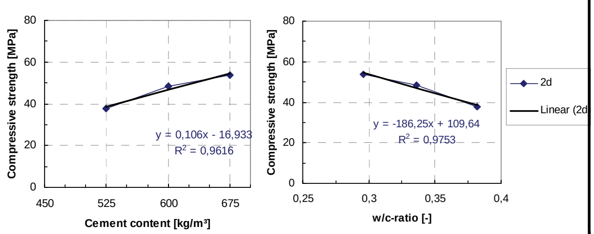
name code: Cement type_Cement content_PC content_ST content (% per cement weight)

OPC_675_0.54_0,87 – w/c = 0,30

SCC-series with OPC (IR)



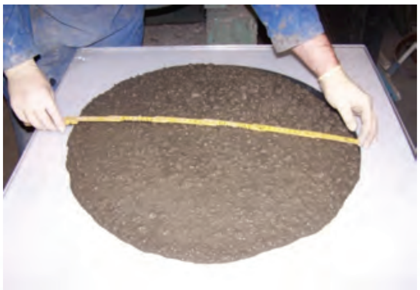
SCC-series with OPC (IR)



525 kg/m3 SR-Cement

No stabilizer (VMA)

M5 with 300 kg/m^3 DKOPC cement and 33 kg/m^3 silica fume



First lab test:
Cement 670 kg/m3

Field test feb 2011:
Cement 400 kg/m3

Session 4

SCC FIELD EXPERIENCES

technology you can build on

How polycarboxylate superplasticisers affect the rheology of self-compactiong concrete

Espen Rudberg (M.Sc)
Øystein Mortensvik (M.Sc)
Dag Vollset (MIA)

Superplasticizers

- BASF Glenium
- Chryso Chrysofluid
- Grace Adva
- Mapei Dynamon
- Remei Carboxyl
- Sika Viscocrete/Sikament

1 technology you can build on

Well, what is a superplasticizer then?

- Polycarboxylates
- Defoamer
- Water

- (Stabilizer)
- (Accelerator)
- (Retarder)
- (Air entrainer)

2 technology you can build on

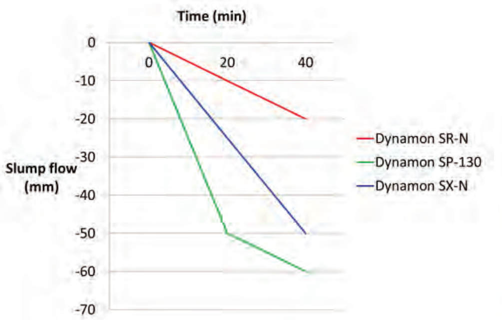
But what does it do?

Reduses the yield stress!

...but does it anything more?

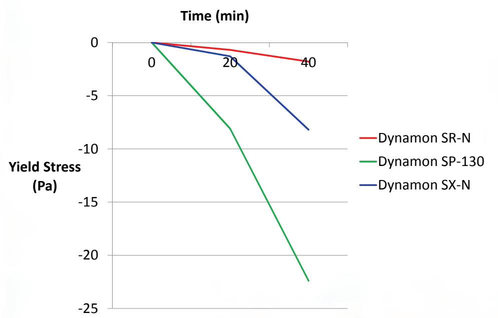
3 technology you can build on

Different polymers, different result?



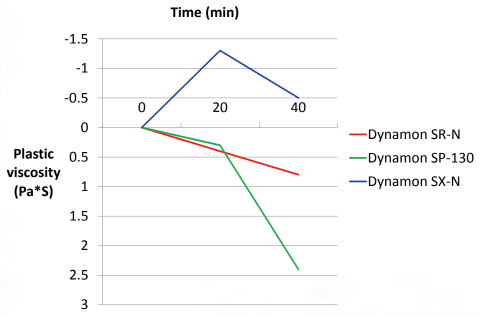
4 technology you can build on

Different polymers, different result?

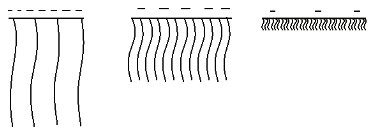


5 technology you can build on

Different polymers, different result?



Let's get technical!



- Raw material
- Polymerization process
- Different molecular weight and charge
- Different lengths and densities of side chains

Different polymers, but same result?

	SR-N 5 min	SR-N 30 min	RMC-630 5 min	RMC-630 30 min
Slump (mm)	190	190	190	190
Slump flow (mm)	350	350	360	350
Tom's method (mm)	420	410	420	400
Yield Stress (Pa)	320	328	326	340
Plastic Viscosity (Pa*s)	62	65	75	76

Crushed and natural

«Normal» measurements

	Slump flow	T500	T end
Bl. 9	620	2,1	16
Bl. 13	615	1,5	12

Rheological measurements

Yield Stress	Plastic Viscosity
43,86	35,02
44,78	25,12

Murphy's Law Applies to SCC!

Preliminary results from fullscale test

Sverre Smeplass, Skanska
Klaartje De Weerdt, SINTEF
Mari Bøhnsdalen Eide, SINTEF

Background

Low grade (C30/37) SCC's in Norway are normally based on:

- Natural sand 0/8 mm, moderate to high fines content (5-8% < 125µm)
- CEM II A/V
- No added fillers
- No chemical stabilization
- Moderate to high dosages of co-polymers

"Marginal" concrete

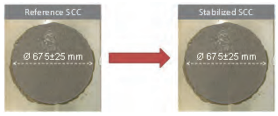
- SF = 650 mm for walls, T_{500} ~ 1 sec
- SF = 550 mm for slabs

Low total matrix volume - low viscosity matrix

SCC vulnerable to:
- Dosage deviation, cement, water, additives
- Normal variation in aggregate moisture
- Normal variation in aggregate fines content

Full scale test supplied with laboratory investigation

Objective I
What's the effect on
- rheology
- stability
- pumpability
- pore building in wall surfaces



of stabilizing a "marginal" SCC, SF= 675 mm by adding:
- filler
- chemical stabilizer

(SF maintained by adding plasticizer)

Full scale test supplied with laboratory investigation

Objective II
What's the effect on
- rheology
- stability

of "normal" variations in
- filler content and grading of 0/8 mm sand
- moisture content

Concrete

- Reference "marginal" concrete based on a well proven low grade SCC (NorBetong)
  - w/c increased to 0,65
  - sand/aggregate ratio was reduced to 0.55 to reduce filler content
  - matrix volume reduced to 310 l/m^3
  - SF adjusted to 675 mm by adding plasticizer
- Trial batches were performed at the ready-mix plant
- Somewhat unstable, but "acceptable" SCC

SINTEF SKANSKA

Concrete

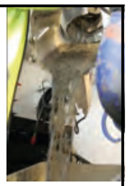


Table 1: Parameters of the three different SCCs used

Initial parameters	Unstable	Filler	Chemical
w/c	0.65	0.678(*)	0.65
w/p	0.49	0.42	0.49
f/c (limestone filler) [%]	0.0	22.5	0.0
Admixtures	**% of C**	**% of C**	**% of C**
air entrainer	0.65	0.65	0.65
SP	0.75	0.71	0.84
retarder	0.10	0.10	0.10
stabilizer	0.0	0.0	0.75
Matrix	**l/m^3**	**l/m^3**	**l/m^3**
Matrix volume	310	332	310

(*) due to an error in the moisture content of the sand the w/c ratio of the filler stabilized SCC is 0.678 instead of 0.65

SINTEF SKANSKA

Concrete

Table 2: Weighed inn quantities for the production of the different SCCs

Materials [kg/m^3]	Unstable	Filler	Chemical
CEM II/A-V 42.5 R	278.3	278.2	278.3
Limestone powder	0.0	62.5	0.0
Free water	178.2	177.8	178.2
Sand søberg 0/8 mm	1035.7	1001.2	1035.7
Aggregates Ramlo 8/16 mm	847.4	819.2	847.4
Air entrainer	1.81	1.81	1.81
SP	2.09	1.98	2.34
Retarder	0.28	0.28	0.28
Stabilizer	0.0	0.0	2.09
Density (theoretical)	2343	2342	2343

SINTEF SKANSKA

Concrete

Table 3: Dosage of SP added at ready mix plant and upon arrival with corresponding slump flow (SF) spread

	Unstable	Filler	Chemical
At ready mix plant			
SP [% of cement]	0.59	0.55	0.76
SF [mm]	630	690	700
At laboratory			
SF upon arrival [mm]	545	500	625
SP [% of cement]	+0.16	+0.16	+0.08
SF [mm]	670	665	680
Time between mixing and testing			
Time [min]	70-90	70-90	60-70

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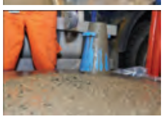
Concrete - pictures

Unstable



Chemically

Filler stabilized

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Rheology

Table 4: Properties of the different SCCs

	Unstable	Filler	Chemical
Density [kg/m^3]	2427	2368	2408
Air [%]	0.3	1.4	0.7
SU [mm]	685	660	670
T500 [s]	0.66	0.58	1.44
VSI_{board}	0.4-0.5	0.3-0.4	0.2-0.3
Segregated fraction [%]	16.5	18.2	38.4

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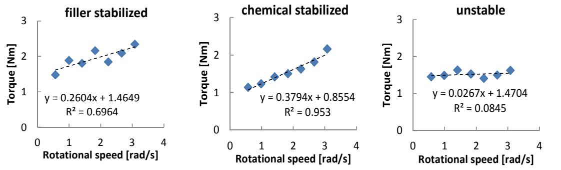
Rheology

Flow curves from BML



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Rheology

Table 5: Rheological properties of the different SCCs

	Unstable	Filler	Chemical
4SCC			
G	0.88	-	0.43
H	3.96	-	3.91
R^2	0.93	-	0.98
BML			
Yield stress [Pa]	91.7	94	55
Plastic viscosity [Pa/s]	0.6	6.2	9.0
R^2	0.09	0.70	0.95

Table 6: Rheological properties of the sieved matrix of the different SCCs

	Unstable	Filler	Chemical
Contec			
Yield stress [Pa]	109.7	63.4	95.9
Plastic viscosity [Pa/s]	24.6	9.8	63.8
R^2	1.00	1.00	1.00

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Preliminary conclusions - rheology

- All three concretes were considered to be unstable, even the stabilized ones. Hence rheological measurements should be interpreted with care.
- The unstable concrete was the most difficult to pump. Hence pumping indicated that the unstable concrete was most unstable.
- Chemical stabilization seems to work well according to the rheological measurements with BML and Contec (increase in viscosity).
- Sieve segregation test indicated increased segretation adding chemical stabilizer!

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Examples of use of SCC in AF

«Kepplar-star», automn 1999

Test with SCC and tradisjonal concrete

SCC Normal

Normal

SCC

Casting with SCC

Betongresepter

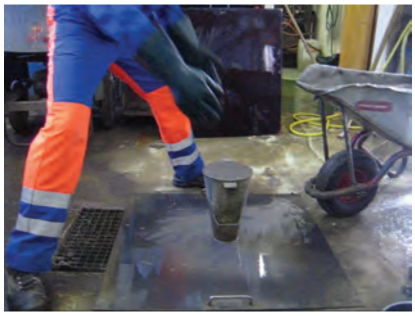
	SCC	FB
Sand, 0 - 8 mm	1083	1074
Stein, 8 – 16 mm	760	755
Sement, anlegg	405	378
silica	20	20
Vann	110	108
Sikament 130	4,5	
Sikament 92		5,5
AER	0,6	0,3
Tot. vann	168	163
v/(c+s)	0,40	0,41

Rolvsrud, 2001
Concrete C25

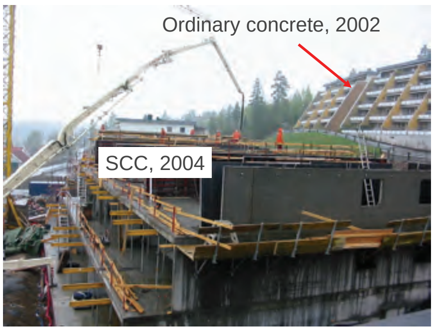
Rolvsrud, 2001

- Every batch controlled, SF and segregation
- Controll pressure and climbing speed (stigehastighet)
- Submerged pipe

SCC is not the only answer on perfect concrete surface



Inside walls, B30M60



Critera for use og SCC, B30M60 in inside walls

- SCC is a casting method:
  - Choise of formwork
    - Surface
    - Dens formwork
    - Climbing speed (stigehastighet)
  - Casting volume
    - Area of formwork
    - The concrete must be pumped
      - Normally concrete scip (tobb) is used
  - Concrete
    - «Uniform» delivery
    - No separation

Experience, B30M60

Sørenga, 2006-2010

Concrete	ca.	110.000 m3
SCC	ca.	30.000 m3

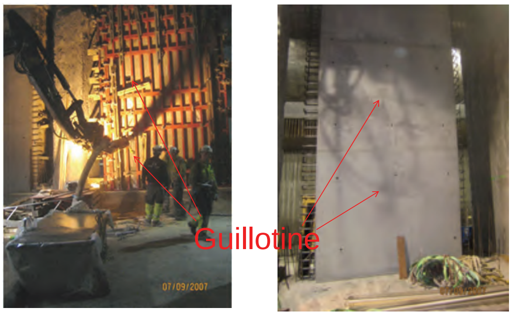
Wall

Casting walls

- SCC, SF 62cm, -3 + 5 cm
- Every batch controlled
  - SynkFlow
  - Segregation
- Casting method
  - Pipeline through the roof
    - Submerged pipe in the concrete, 1 m
  - Trapdoor (Støpeluker)
    - "guillotine"

Casting walls

Casting with pressure and guillotine



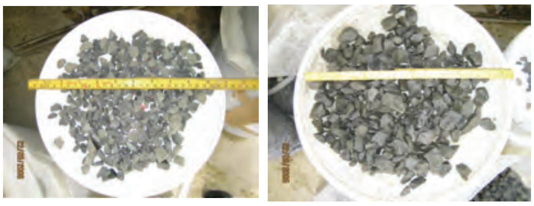
Concrete composition

Materialsammensetning (ved 5 % luftinnhold)

Resept		C40 65 % FA
Tørre materialer i kg per m³ betong	Sement	201
	Flygeaske	131
	Silikastøv	16
	Sand 0-8 mm	960
	Pukk 8-18 mm	188
	Pukk 18-32 mm	744
Glenium 151, kg/m³		5,45
Micro Air, kg/m³		0,08
Vann (totalt), kg/m³		150
effektiv v/(c+2s+0,7fa)		0,44

Aggregate

- Density concrete: 2,42 kg/dm3
- Density:3,05 kg/m3
- Fraction: 8-18 mm og 18-32 mm



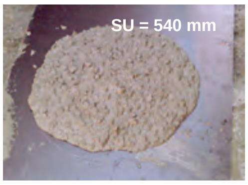
SCC walls, Sørenga

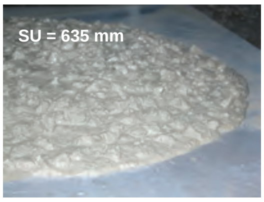
Very good surfaces

Floor, Bubbledeck 2006, 7000 m3

Sogn Arena

On site Plywood is normally underlay for concrete- testing. On fabrikk steel is often used.





Results from testing

- Factory:
  - Steel: SU = 580,
  - T50: SU = 600 → T50 = 1,9 sek.
- Construction site:
  - Steel: SU = 610 mm
  - Plywood: SU = 630 mm
  - Veneer (Finèr): SU = 560 mm
  - T50
    - SU = 600 → T50 = 1,9 sek
    - SU = 650 → T50 = 1,5 sek
- Experience:
  - Calibrate underlayer
  - Calibrate change of SF depending on
    - Time from produsing
    - Casting, pumping e.g

Walls under ground, from 2006

> 60 % of walls underground is SCC, B35M40

Gladenveien 2011

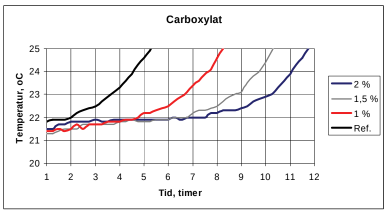
Walls 5,5-6,6 m

Challenges met in the field today

Wishes for the future:

- Control on admixtures
  - Open time, SF
  - Retarding effects, setting time

Carboxylat



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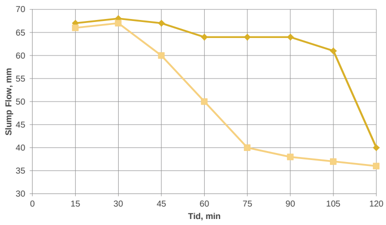
Carboxylat

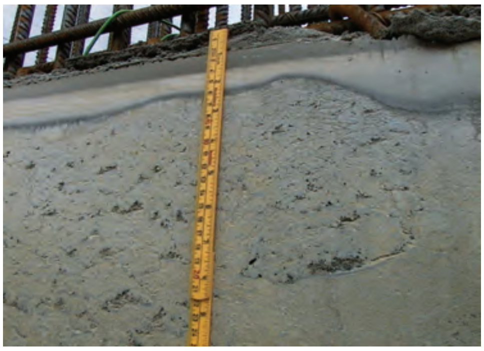


Challenges met in the field today

Wishes for the future:

- Control on admixtures
  - Open time, SF
  - Retarding effects, setting time
- Pasta
  - No risk for segregation with different W/C-levels
  - Setting time under control
    - with different temperatures

Segregation



Segregation

Challenges met in the field today

Wishes for the future:

- Control on admixtures
  - Open time, SF
  - Retarding effects, setting time
- Cementing material (pasta)
  - Stabil with different W/C-levels
  - Setting time
    - with different temperatures
- Concrete
  - «Uniform» concrete in all classes
    - «Robust» SCC


TAKK FOR OPPMERKSOMHETEN
30/08/2011

unicon
CEMENTIR HOLDING

Concrete with high flyash content
Experiences from readymix production

M.Sci. Øyvind Sæter

4.oct 2011

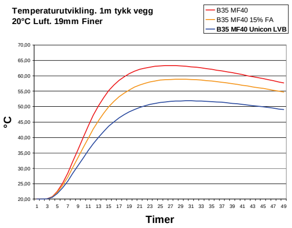
Concrete with high fly ash content

Low heat concrete with high fly ash content

- As little hydration heat as possible
  - close to critical water demand
  - fly ash used to reduce cement
  - cement reduction 32-40%

Challenges

- Workability
  - Production process
  - Experienced workability
- Air content



	Sement	Varme
LHC with FA	-32 %	-9° C

Experiences

Bjørvika infrastructure **2005-2012**
- 120.000 m^3 of low heat concrete
- Fly ash: 40% of powder (65% of OPC)

Hardanger bridge **2010-2012**
- Fly ash: 33% of powder (50% of OPC)

Økern road junction **2010-2013**
- with 2 kg/m^3 6mm micro pp-fiber for fire protection
- Fly ash: 33% of powder (50% of OPC)

Unicon LHC for "housing" **2008->**
- Fly ash: 33% of powder (50% of OPC)
- last 12 months 15% of ready-mix volume in OSLO
  - **SKB: 5%**
  - **Slump S4: 10%**

Low Heat Concrete

The low heat concrete do not follow the prequalification's of NS-EN 206-1
- Activity factor for flyash k= 0,7
- all flyash is calculatet into v/(c + k*p)

•Concrete designed close to critical water demand

40% FA LHC C35/45			32% FA LHC C35/45		
Material			**Material**		
CEM I 52,5 N	kg/m^3	201	CEM I 52,5 5	kg/m^3	250
Water	kg/m^3	140	Water	kg/m^3	140
Silika k=2	kg/m^3	16	Silika k=2	kg/m^3	0
Flyash k=0,7	kg/m^3	130 (65%)	Flyash k=0,7	kg/m^3	125 (50%)

Production

- **Production**
  - RMC produced in plants with high volume of normal concrete
  - Most of HFC produced at a plant with ~1000 m3 RMC/day
  - High flow rate of raw materials
    - **Raw material and RMC quality control is essential for stable production.**
    - **Raw material test to slow? – material already used when test is finished**
    - **Moisture control is important**
  - "Not so good" materials – what then
    - **Do not use?**
    - **Material already in production line/pipe?**
    - **Enough materials avalible?**
  - RMC quality check
    - **Workability**
    - **Stability**
    - **Air content**

Workability – RMC site

- **Mixing**
  - Mixing cycle and mixing time is important
    - **Generally need more time before stable workability reading (wattmeter)**
    - **Minor change in mixing cycle -> major impact on workability**
  - Moisture control of aggregates
  - Superplastiziser
- **Quality control**
  - **Raw material (aggregates)**
  - **Concrete Fresh properties.... "continuously"**

- **When it fail.....**
  - **Remix with additives – careful with superplastiziser**
  - **Temporary plant "shutdown" as the concrete jams between mixer and truck**
  - **Waste concrete**

Workability – Construction site

- **Customers demand**
  - S4, typical 200-220 mm slump
  - Visually looks like slump 160-200, measures 200-220
  - Superplastiziser have great impact on experienced workability

Additive	Slump	Flow diameter t=5	Flow diameter t=60
TSS 1	200	390	250
TSS 2	200	450	370

- **SCC**
  - 2-5 sec to reach T500
  - Up to 650mm without (or little) chemical/filler stabilization
  - High density aggregates, significant stabilization needed above 650mm
- **"Rubber" concrete problem**
  - High slump loss after pumping (or before)
  - caused by to little water available

Air content

- **Air content is variable…**
  - Variations in fly ash have significant impact on air content
  - Experienced 100% change in air dosage from one FA delivery to another
  - Keep an eye on loss of ignition
- **Raw material control**
  - not so easy
  - high volume, 50-150 tons FA pr day.
- **Quality control during start-up is a critical success factor**
- **Continuously control during production**
  - every 50m3

Summary

Low heat concrete with high fly ash content
- Concrete designed close to critical water demand
- Small amount of water to cower all particles
- Change in water demand or moisture of aggregates have great impact on workability if not discovered before production
- Changes in fly ash components (loss of ignition) have impact on air content. The higher fly ash content the greater the impact.

Good workability – but it behaves "different"
- Visually estimated to slump 160-180 mm. Measured +200 mm
- SCC uses "long time" (2-5sec) to T_{500}
- The effect increases with fly ash content
- Walls: Cast as normal
- Flooring etc: "No problem…."… but not simply either.
  …. "you got to learn casting again".

Thank you

SCC LHC 32% FA of powder/binder

RheoMATRIX

Smart Dynamic Construction(SDC)

BASF
The Chemical Company

Nordic Concrete Rheology Workshop
Trondheim 3-4/10 2011

Lars Busterud BASF AS

Adding Value to Concrete

List of Content

- •Market needs
- •Smart Dynamic Construction: the system
- •Features & costs
- •Benefits
- •RheoMATRIX: Centerpiece of innovation
- •Summary

Smart Dynamic Concrete

For day-to-day use

Smart Dynamic Concrete
Properties & general advantages

SDC for C25 – 35 MPa(or more, if required)
Slump flow 500 – 720mm
T50 > 2 sec
Sement content 300 – 380kg/m3
No filler addition
Simplified mix design procedure
Logistic simplification
More robust because of RheoMATRIX
Rheological properties controlled by Glenium(Yield value) and RheoMATRIX(plastic viscosity)
Cost effective

Market Needs

Challenges

Triggered by industry

•Energy efficiency to reduce CO2 emissions
•Higher durability specs require perfect covering of reinforcement
•Process economy to save time + money with an increasing deamandfor higher fluid

Market Needs

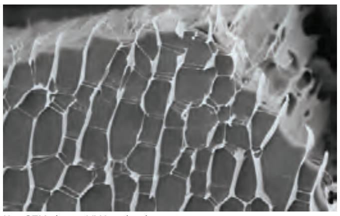
Customer

Customer needs

- Highly fluid + robust
- Cost effective
- Reducing placing time
- Boosting productivity
- Shortening construction time
- Outstanding quality

Smart Dynamic Construction (SDC)
For a new generation of highly fluid concretes

Innovative system solution
- Robust mix design with <380kg fines
- Tailor-made GLENIUM superplasticizer
- Exclusive, latest technology VMA with self-organizing molecules which enables unmatched concrete robustness



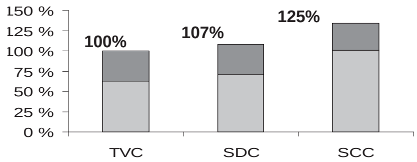
KryoSEM picture: VMA molecule structure

Solving the dilemma
Cost effectiveness | Self-compaction | Robustness

Traditionally Vibrated Concrete (TVC)		Self-Compacting Concrete (SCC)
Robust mix		No vibration
Low stickiness	SDC	High speed
Good price		Great surface

Features & Costs
Material cost per m3 concrete

Features
- Fines: < 380 kg
- Slump flow: 55-72 cm
- Strength: C25 - 35
- Robust mix-design with day-to-day raw material



Smart Dynamic Concrete
Norwegian example

C37/B30 Flooring	S4/S5(220mm)	SCC	SDC
Material	In kg Pro m3	In kg Pro m3	In kg Pro m3
Water	178	195	178
Cement	302	330	302
V/C ratio	0,59	0,59	0,59
Filler(SF)		13	
Superplasticizer	2,4	5,0	3,9
VMA		1,5(old)	1,0(new)
Sand	1118	1156	1115
Aggr.	750	650	750

Smart Dynamic Concrete
100% crushed sand+aggregate

C37/B30 Flooring	S4/S5(200mm)	SCC	SDC
Material	In kg Pro m3	In kg Pro m3	In kg Pro m3
Water	186	206	186
Cement	326	400	326
V/C ratio	0,57	0,52	0,57
Superplasticizer	2,91	5,0	3,9(new)
VMA			1,8(new)
Sand	1110	1150	1220
Aggr.	718	584	625

Construction benefits
Adding value to concrete

Benefits
Economical
- Savings on fines
- Up to 40% faster placing
- Up to 5x higher labor productivity
- Easy to produce

Ecological
- Less fines, less CO2
- Higher durability

Ergonomic
- No vibration
- No noise
- Low stickiness

Multi-win situation
- Specifier+ general contractor
  Contractor
  Ready-mix producer
- Specifier+ general contractor
- Contractor

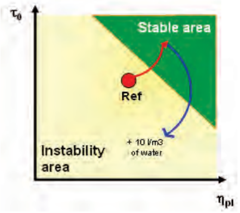
The Innovation
Centerpiece of this unique concept

Technology	Features	Benefits in the field of
•Robust mix design	•Fines < 380 kg	•Economics
•Tailor-made superplast.	•60-70cm slump flow	•Ecology
•Exclusive VMA	•Self-compacting	•Ergonomics

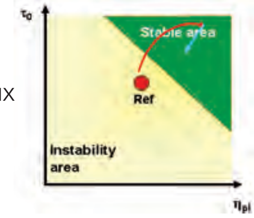
Smart **D**ynamic **C**onstruction

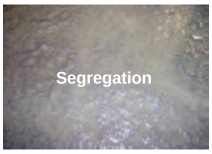
RheoMATRIX supported Concrete Stability

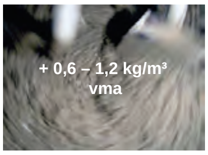
Adding 10 l/m3water



Old VMA vs RheoMATRIX







Summary

Technology	Features	Benefits in the field of
•Robust mix design	•Fines < 380 kg	•Economics
•Tailor-made superplast.	•60-70cm slump flow	•Ecology
•Exclusive VMA	•Self-compacting	•Ergonomics
Smart	**D**ynamic	**C**onstruction

New:

•SDC makes unique mix-design optimization possible

•SDC combines the advantages of both, TVC and SCC

•RheoMATRIX is the key to solve paradox requirements: robustness (stability) + fluidity + low stickiness

•SDC is cost effective: it saves labor and material costs

Building the Best Team in Industry

Thank you for your attention!

BASF The Chemical Company

Structural Engineering
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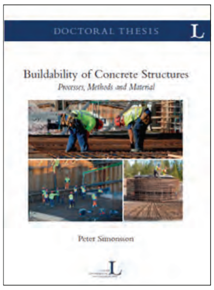
Buildability of concrete structures

Processes, Methods and Material

Peter.Simonsson@LTU.se



SVEVIA Betongindustri CEMENTA

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Buildability of concrete structures

- Components in thesis:

- Buildability and Lean Construction
- Standardization
- IT
- Innovations
- Working environment
- Introducing innovations in production
  - E.g. SCC

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Introduction

"If you refuse to look back
and do not dare to look ahead
you need to look out"

Tage Danielsson

A late Swedish: Poet, Actor, Writer, Comedian, Director

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Buildability

What does buildability comprise?

Definition:

"the extent to which the design of a project facilitates ease of construction"

Source: CIRIA -96

Through buildability:

- **Create conditions for optimal construction**
- **Use resources in the best manner**
- **Create durable construction**

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Buildability for a bridge is influenced by:

- Early involvement of contractor
- Workplace structuring
- Available space on-site
- Production planning
- Prefabrication

According to a questionnaire survey performed by the researcher

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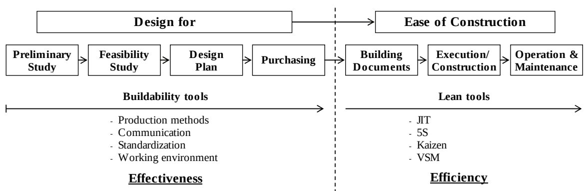
Combining Lean and Buildability

- **Lean Construction**
  - **Eliminate waste, Minimizing lead times and inventory**
- **Buildability definition:**
  - **"the extent to which the design of a project facilitates ease of construction"**
  - **"Design for – ease of construction"**



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Combining Buildability and Lean

- **Expected effects on construction process:**
  - Repetitive work
  - Enhanced working environment
  - Understandable work instructions

  - **Improved productivity**

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Potential SCC

- Shorten construction time
- ”Releasing” resources
- Improved quality
- **Improved working environment**

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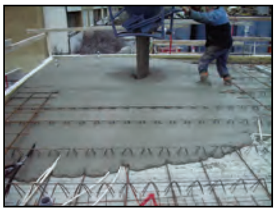
Market share SCC in-situ cast

- **Denmark ~ 30 %**
- **Norway ~ 5 % (large projects)**
- **Finland ~ 1 - 2 %**
- **Iceland ~ 1 %**

- **France ~ 2 %**
- **GB ~ 1 %**
- **Netherlands ~ 1 %**
- **USA ~ 2,5 - 3,5 %**
- **Japan - ?**

- **Sweden ~ 8 % (locally 30 %)**



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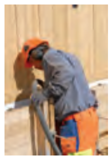
Working environment

- 69% of all reported workrelated injuries within construction industry SWE 2005 was WMSDs
- WMSDs caused by ergonomic risk factors:
  - Heavy lifting
  - Work in awkward positions
  - Repetitive work (not productive repetitive work)
  - Stress and mental factors



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Working environment

- Costs for society and the construction industry considering deaths, WMSDs and invalidity within EU:
  ~75 billion Euro annually or ~8.5% of construction costs
- In SWE a bit lower

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Working environment

- 26% of a concreters average day consist of casting (10%) and reinforcing (16%) (Nielsen, DTU, 2006)
  - Awkward positions
  - Heavy material and equipment
  - Repetitive work (still not productive repetitive work…)

Example

• 279 cases of WMSDs (muscles, skeleton etc) reported for concreters 2004 (in Sweden)
• Cost for sick leave 14 M kr/year – for society
- No costs for companies is counted here

Can be extrapolated to EU -> approx 214 M €/år

Working environment measurement

Encompassing

- Ergonomic studies
- Vibrations i hands and arms
- Sound measurement

Ergonomic measuring methods

- **ErgoSAM analyses**
  – A computer based working environment program used within the car manufacturing industry
  – Detailed
- **QEC analysis (Quick Exposure Check)**
  – Focus on physical site factors
  – Performed by workers and management together
- **PLIBEL analysis**
  – Checklist, factors affecting the ergonomics

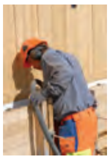
Observations of workers in action
– Affecting Back, Shoulders/arms, Wrist and Neck
– Video filming of work cycles, casting

Working environment

Typical work postures when compacting traditional concrete

Will be performed over 200 times when casting this wall



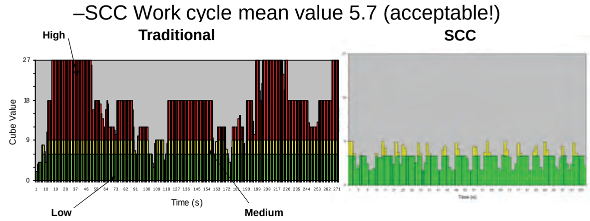



Working environment

Concrete casting

–Traditional cycle mean value 18.2 (needs immediate attention!)

–SCC Work cycle mean value 5.7 (acceptable!)

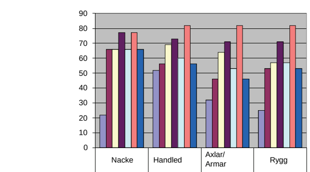


Making sure skilled workers are healthy and able to stay in construction

QEC

- QEC% value = (E/Emax) * 100
- E - Exposure value for body area
- Emax – Exposure value for maximal potential body area

Risknivå	Föreslagen åtgärd	QEC% värde
1: Acceptable risk	Acceptabel arbetsställning	< 40%
2: Moderate risk	Ytterliggare undersökningar behövs; Förändringar kan krävas	40-49%
3: High risk	Utredning och förändringar behövs snart	50-69%
4: Very high risk	Utredning och förändringar krävs omgående	≥ 70%



	Nacke	Handled	Axlar/ Armar	Rygg
SKB gjutning (golv)	22	52	32	25
Ytavjämning golv	66	56	46	53
Trad gjutning (golv)	66	69	64	57
Vibrering Trad btg (golv)	77	73	71	71
Trad gjutning (vägg)	66	60	53	57
Vibrering Trad btg (vägg)	77	82	82	82
SKB gjutning (vägg)	66	56	46	53

High risk already over 50%!

Vibrations Hand-Arm

EU Directive 2002/44/EC:

- Average value per day 2,5 m/s2
- Max value 5 m/s2

- Vibration injuries might appear with lower exposure than 2,5 m/s2

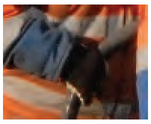
Vibrationer resultat

Average day value

	Pneumatic vibrator	Electric vibrator
Left hand	1.93 m/s²	1.57 m/s²
Right hand	1.67 m/s²	4.12 m/s²

Allowed working time

	Pneumatic vibrator	Electric vibrator
Left hand	>8 hrs	>8 hrs
Right hand	>8 hrs	5.9 hrs



Results not final

Only one project studied

Needs verification

Sound measurement

According to Arbetsmiljöverkets (2005) recommendations:

- Values below < 80 dBA ok
- 80-85 dBA hearing aid
- > 85 dBA Necessary to change the working situation!

	No of vibrators	Other equipm	Distance (m)	Leq	Lmax	Part vibrated	Comment
1	1	Pump hose	1	83,6	98,1	Edge beam	
2	1		1	93,3	112,5	Edge beam	OVER 112,5!
3	1	Pump hose	4	80,1	89,7	Edge beam	
4	1	Pump hose	1	86,5	101,3	Superstructure	
5	1		3	83,2	97	Superstructure	
6	3		1	85,1	97,2	Superstructure	
7	3		1	83,5	97,7	Superstructure	
8	3		1	82,6	99,8	Superstructure	
9	3		5	78,4	94,5	Superstructure	
10	4		1	88,1	104,9	Superstructure	
11	4		1	83,4	95,5	Superstructure	

If the vibration sound is eliminated, sound level decreases with at least 10 dB(A)!

SCC - economy

Total economy for a project:

+ Higher productivity when casting
+ Reduced cost for sick leave enhanced working environment
+ Lower site costs (establishment mm)

Important to consider the comprehensive picture to be able to introduce SCC since its more expensive to manufacture

Plan SCC castings, example RV73

- Planed casting, TVC
  - Need for many workers
  - Expensive casting
  - "Low" productivity

Traditional casting (planned work)

m3	No of workers	proj time	Over time	work time	OT Cost	cost €
206,8	9	15	7	135	1 179	6 579
206,8	9	15	7	135	1 179	6 579
413,6				270	2 358	13 158

- Outcome SCC
  - Faster casting
  - Same No of workers
  - Cheaper casting despite "to many workers"

Outcome

m3	No of workers	proj time		work time	OT Cost	cost €
206,8	9	10,5	2,5	94,5	293	4 073
206,8	9	9,5	1,5	85,5	176	3 596
413,6				180	468	7 668

- Optimized casting SCC
  - Divide workers in two teams
  - Less hrs needed
  - Cheaper casting
  - Higher productivity

SCC Optimum

Two teams	No of workers	proj time		work time	OT Cost	cost €
7-14,30	3	7,5		22,5	0	900
10-16,30	4	6,5		26,0	0	1 040
7-14,30	3	7,5		22,5	0	900
10-16,30	4	6,5		26,0	0	1 040
				97,0	0,0	3 880

Example traffic junction Stockholm

Supporting walls:
20 sections

Traditionell btg		Kostn	Summa kostn
Mängd m3	943		
Ant lev	198		
Gjuttid/lev Min	17		
Gjuttid tim	49		
Projekttid tim	37		
Arbetad tid tim	346	370	127 891
		Summa	127 891

Plan castings!
Make sure workers have other work assignments!

SKB		Kostn	Summa kostn
Mängd m3	943		
Ant lev	198		
Gjuttid/lev Min	12		
Gjuttid tim	34		
Projekttid tim	34		
Arbetad tid tim	59	370	21 658
			21 658

SCC - casting needs 287 less man-hours (7 weeks) 106 233 kr

Example traffic junction Stockholm

Concrete trough:
20 sections

SKB

	Betongmängd	Kostnminskn	Tidminskning
Etapp 11-13	321	20 557	47
Etapp 21-23	475	35 505	84
Etapp 31-32	346	34 094	80
Etapp 41-44	1 345	117 268	260
Etapp 51-54	670	65 605	153
Etapp 61-63b	597	55 621	123
Totalt	3 754	328 649	747

Saved working time 19 weeks

Plan so that the workers have other work tasks at hand!

Example traffic junction Stockholm

Assume 3 weeks shorter construction time through better planning

Möjlig kostnadsbesparing genom SKB

Kostn Hv/dag	Ant hv i proj	Ant dagar	Tot lönekostn
2960	15	15	666 000
Bodhyra/mån	**Ant veckor**	**Ant bodar**	**Tot kostnad**
3 000	3	20	45 000
Maskinhyror	**Ant veckor**	**Ant maskiner**	**Tot kostnad**
1 000	3	15	45 000

∑ Kostnad
756 000

Total profit: 0,1 + 0,3 + 0,7 = 1 Mkr

Example bridges Uppsala - Mehedeby

Concrete amounts 32 bridges

Betong mängder i de olika delarna

	BP	ÖB + ramben	BP Länkplatta	Slitl. UE	Summa
C716/2	101,2	393,8	84	284	**863**
C719/2	266,2	331	80,2	284	**961**
C720/1	142	1239	84	715	**2180**
C828/2	294,9	254,9	109,5	321	**980**
C723/2	267,1	319,1	89,7	263	**939**
C777/1	126,4	336,2	84,3	223	**770**
C731/2	129,9	348,4	84,2	180	**743**
C732/2	162,8	1587,7	79,8	644	**2474**
C734/2	77,8	160,1	107,1	104	**449**
C736/2	100,7	297,4	92	168	**658**
C739/2	61,9	151,7	81,9		**296**
C740/2	88	264	84		**436**
C741/2	96	299,2	84		**479**
C743/2	91,4	143,4	81,9		**317**
C744/2	194,3	861,5	75,6		**1131**
C745/2	88	295,91	84		**468**
C746/2	62,4	145,3	84		**292**
Summa	**2 351**	**7 429**	**1 470**	**3 186**	**14 436**

Example bridges Uppsala - Mehedeby

11 250 m3 can be casted with SCC

Traditionellt	Volym m3	Gjuttid tim	**Ant Hv trad**	Arb tid	Kostnad
Fundament	2 351	118	4	470	164 570
Överb + Ramben	7 429	371	8	2971	1 040 005
Länkplatta	1 470	74	4	294	102 914
Summa		562		3 736	**1 307 489**

SKB	Volym m3	Gjuttid tim	**Ant Hv SKB**	Arb tid	Kostnad
Fundament	2 351	78	1	78	27 428
Överb + Ramben	7 429	248	5	1238	433 336
Länkplatta	1 470	49	1	49	17 152
Summa	11 250	375		1365	**477 916**

Decreased casting costs – 829 573 kr

”Saved” working time – 2370 tim (59 v)

Plan workers time so they have alternative tasks at hand during castings!

Conclusions

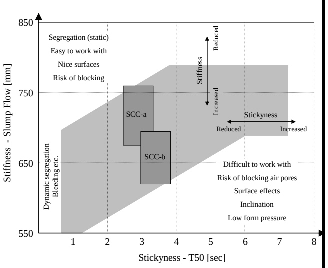
Advantages with SCC, working environment:
- 3 times reduction of physical strain
- No mechanical vibration results in less sound pollution at site
- Eliminating of potential vibration damage
- Skilled workers stay in the construction industry

Economic advantages SCC:
- Reduction of site costs considering casting
- Minimized waste of workers time
- Helps keeping timeframe

Other benefits with SCC:
- Improved quality, e.g. tunnel linings
- Increases the image of concrete

SCC studies

Performance of adapted SCC
- Two sets of slump flow and T50
- SCC-a vertical parts of a bridge e.g. front wall and column
- SCC-b horizontal elements e.g. bridge deck and large foundations



Robustness in relation to steady production

Research

- properties of the fresh concrete were documented by means of visual inspection, workability and rheology tests.

SCC in my research

Robustness in relation to steady production

VMA,

Trying to sum up

"If you refuse to look back
and do not dare to look ahead
you need to look out"

Combining Lean and Buildability

Introduktion

- 69% av alla inrapporterade arbetsrelaterade skador i Sverige 2005 var WMSDs
  (WMSD = Work related MusculoSkeletal Disorder)
- WMSDs orsakade av ergonomiska risk faktorer:
  - Tunga lyft
  - Arbete i påfrestande ställningar
  - Momentana ensidiga arbeten
  - Stress och mentala påfrestningar
- Kostnader för samhället och byggindustrin map dödsfall, skador och invaliditet inom byggindustrin i EU är ~75 miljarder Euro årligen eller ~8.5% byggkostnaderna

Conclusions

Difference between the two risk assessment methods

QEC:

- Both worker and researcher work together in the study

PLIBEL:

- Asks the worker how he or she experience the work task
- The researcher does not consider own experience

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Introduce changes:

- Prefabricated reinforcement solutions
- Left concrete form systems
- SCC

as a mean to increase productivity at site, a need to create projects that are buildable and able to be constructed,

i.e. constructions that we know in advance are practically feasible and productive.

Buildability and Lean

- Buildability i.e. “the extent to which the design of a building facilitates ease of construction”
- Buildability - design for “ease of construction”
- Lean construction - planning of a productive flow of work tasks and resources

Självkompakterande betong –
ett självklart val för bättre *ekonomi* och *arbetsmiljö*

Arbetsmiljö och ekonomi, SKB

Innehåll

- Introduktion
- Mätning av arbetsmiljö
- Resultat arbetsmiljö
- Ekonomi
- Diskussion

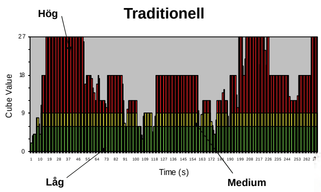
Cube-model

Resultat från ErgoSAM;
tre belastningstyper:

- Arbetsställning (1-3)
- Kraft (1-3)
- Frekvens (repetition) (1-3)

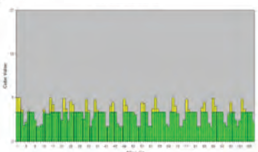
Ansträngningsnivå = Kraft x Arb.ställning x Frekvens
Värsta fallet 3 x 3 x 3 = 27

Resultat



Traditionellt vibrerad betong; 18,2

SKB



SKB; 5,7

0 < X < 6	Acceptabel Grön
6 ≤ X < 9	Acceptabelt korta stunder Gul
9 ≤ X ≤ 27	Oacceptabelt Röd

SKB är 3 ggr bättre!

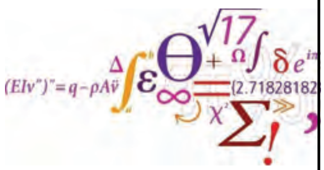
Session 5

MODELLING

Numerical simulations of SCC flow, e.g. to predict development of inhomogeneities during casting of SCC

Jon Spangenberg, Phd-student
Supervisor: Jesper H. Hattel
Co-Supervisor: Mette R. Geiker and Henrik Stang

FTP project Partners:
DTU Mechanical Engineering
Department of Mechanical Engineering
DTU Civil Engineering
Department of Civil Engineering
DTU Chemistry
Department of Chemistry
LCPC Laboratoire Central des Ponts et Chaussées



Outline

- Programming flow of SCC
  - Channel flow test
- SCC segregation experiment
  - Setup
  - Results
- Simulating segregation experiment with Flow3D
  - Continuous phase
  - Particles
  - Results

Programming flow of SCC

Governing equations:

- Mass conservation equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_j)=0 \;\Rightarrow\; \frac{\partial u_j}{\partial x_j}=0$$

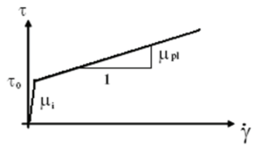
- Momentum conservation equation

$$\frac{\partial u_i}{\partial t}=-\frac{\partial u_i u_j}{\partial x_j}+\frac{1}{\rho}\frac{\partial \tau_{ij}}{\partial x_j}-\frac{1}{\rho}\frac{\partial p}{\partial x_i}+\frac{1}{\rho}S_i$$

Solving the equations in order to obtain:
Pressure and velocities

Propagation of SCC carried out with the Volume Of Fluid (VOF) method

Material model:
Bi-viscosity model

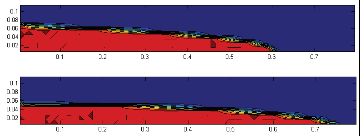


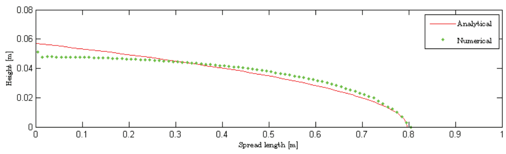
Programming flow of SCC

Channel Flow Test:
Test to analyze the final shape

Investigate:

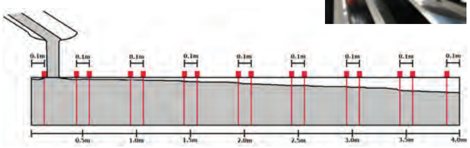
- Calculation time
- Stop criterion
- Parallelization possibilities





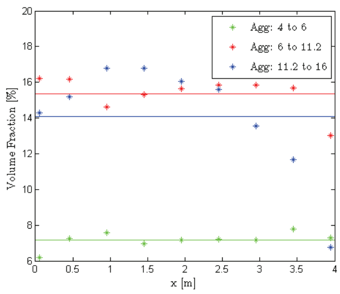
SCC segregation experiment

- Form filling of beam
- Dimensions: 4.0x0.3x0.2 m
- Casted from one end
- Casting duration 160 seconds
- Volume fraction measured in 9 sub-regions
- Three aggregate fractions measured



SCC segregation experiment

Results:



Simulating experiment with Flow3d

SCC calculated with an one way momentum coupling between continuous phase and aggregates

Continuous phase
- Calculated as a single phase
- Considered as paste and a percentage of the finest aggregates
- Modeled with bi-viscosity material model
- Modeled with density and rheological parameters of the SCC

Simulating flow of SCC with Flow3d

Aggregates
- Represented as a volume fraction scalar
- Considered as spheres

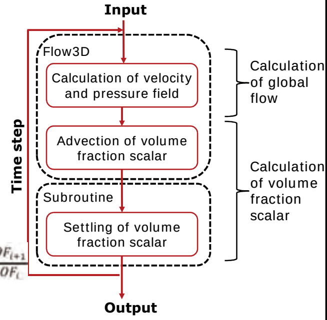
Settling velocity equation

$$u^s = \frac{d^2 g(\rho - \rho_f)}{18\mu_{tan}},$$

Volume fraction equation

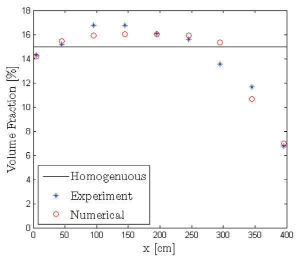
$$\varphi_i^{\Delta t+t} = \varphi_i^t\left(1 - u_i^s\frac{\Delta t}{\Delta y}\right) + \varphi_{i+1}^t u_{i+1}^s \frac{\Delta t}{\Delta y}\frac{VOF_{i+1}}{VOF_i}$$

Flowchart



SCC segregation experiment

Experimental and numerical results:



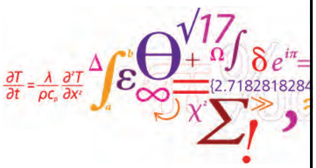
Thank you

Modelling of flow induced inhomogeneities in self compacting concrete

Jan Skoček

Co-authors:
- Oldřich Švec
- Mette R. Geiker

Cooperation:
- N. Roussel
- J. Spangenberg
- J. Hattel
- H. Stang
- P. Szabo



DTU Civil Engineering
Department of Civil Engineering

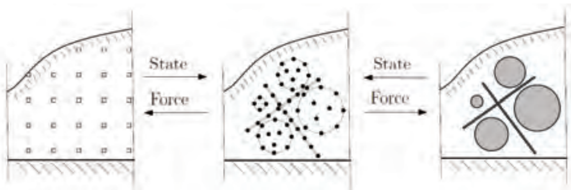
Outline

- **Model**
  - Motivation & requested features
  - Methods & implementation
- **Applications**
  - Analysis of phenomena, processes and mechanisms observed during casting of SCC
  - Full-scale simulations of casting process
- **Conclusions and perspectives**

Model

- Motivation
  - Simulate flow of SCC as a flow of suspension of rigid particles in non-Newtonian fluid
- Requested features of the model
  - Fluid Dynamics Solver
    - Non-Newtonian fluid rheology
    - Free surface flow
  - Particle Suspension
    - Fluid – Particles interaction – two-way coupled
    - Accurate dynamics of particles
    - Particle – Particle interactions (collisions, forces...)
  - Efficiency (real-size laboratory experiments, details of structures...)
  - Accuracy

Model



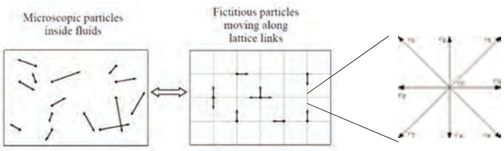
- fluid dynamics
- free surface
- non-Newtonian rheology
- boundary conditions

- two-way coupled interaction
- forces on fluid and particles

- dynamics of particles
- interaction of particles
- interaction with B.C.

Fluid Dynamics Solver

- Lattice Boltzmann Method
  - Comes from the Kinetic theory and cellular automata

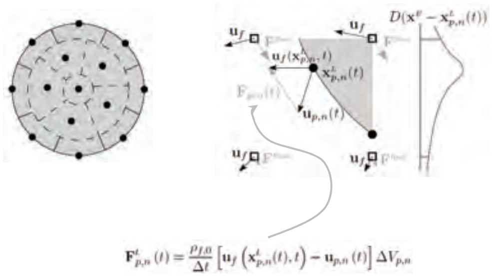


- System evolves due to propagation of fictitious particles and their collisions (dissipation)
  - Simple implementation and reasoning
  - Most of the code is local (shear stress tensor ...)
  - Simple parallelization
  - Simple implementation of free surface

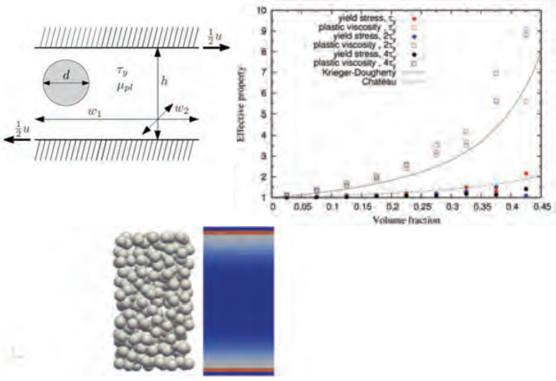
Particles

- Rigid solid bodies – spheres, cylinders, ellipsoids
- Runge-Kutta Fehlberg integration of equations of motion with adaptive time sub-stepping
- Continuous forcing (e.g. repulsion, lubrication)
- Instantaneous collisions – friction, coefficient of restitution

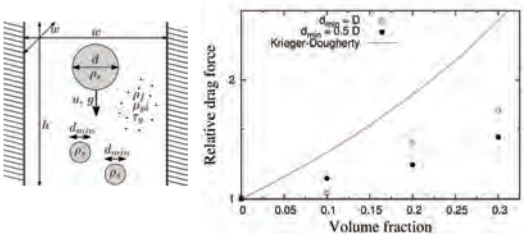
Immersed boundary method



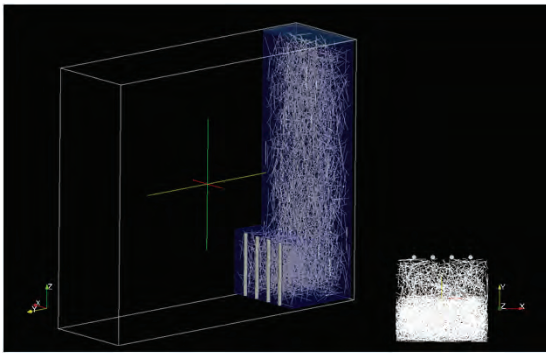
Applications – Effect of spheres on viscosity



Applications – segregation in suspension



Applications - LBox

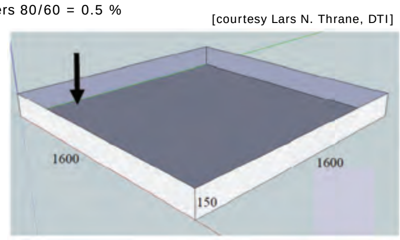


Applications - LBox

Plate casting

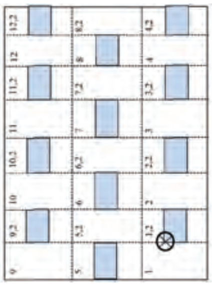
- Plate 1.6 x 1.6 x 0.15 m was casted
- Rheology:
  - Plastic viscosity = 75 Pa s
  - Yield stress = 45 Pa
- Steel fibers 80/60 = 0.5 %

[courtesy Lars N. Thrane, DTI]



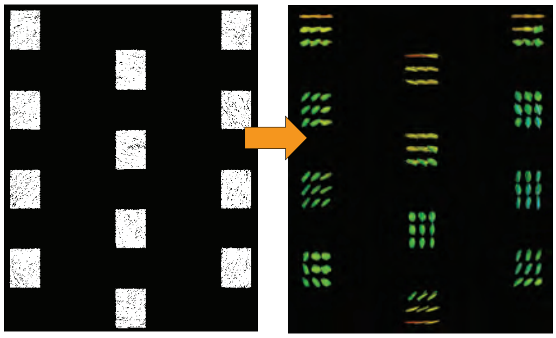
CT Scans

- The plate was cut into 3 x 8 beams
- 12 middle sections of size 200x150x150 (blue) were CT scanned

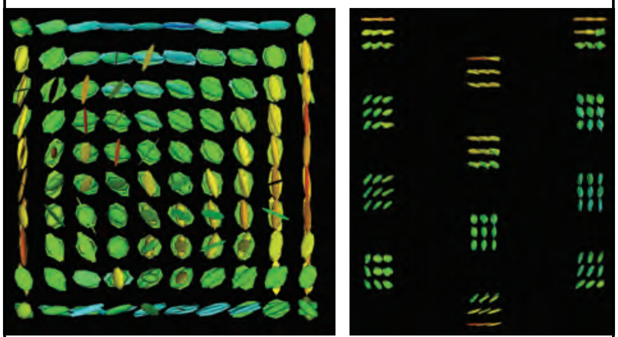


[courtesy Lars N. Thrane, DTI]

Skeletonized CT scans into Orientation tensors (3D ellipsoids)



Comparison



Conclusions and perspectives

- Model is accurate and efficient
  - Robust, stable, without any fitting parameters
  - Parallel implementation in progress
- Further studies on effective rheological properties and segregation
  - Poly-dispersity
  - Aspect ratio of ellipsoids and cylinders
  - Fibers – orientation, interaction
  - Surface properties of aggregates
  - Yield stress values
- Collaborations are welcome

Rheometer-4SCC used as a stability meter for SCC

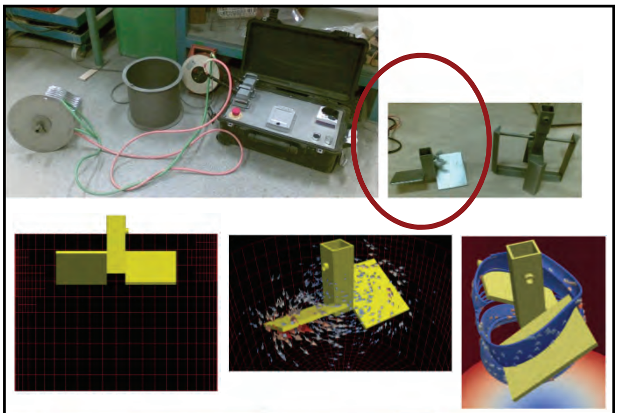
Nýsköpunarmiðstöð Íslands

Jon E. Wallevik: ICI Rheocenter, Innovation Center Iceland, jon.w@innovation.is

Source literature:

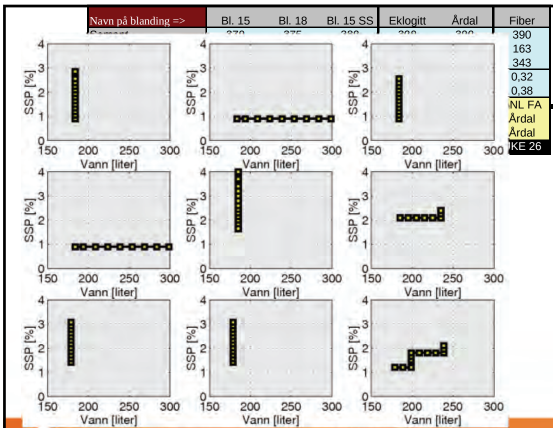
- Utvikling av stabilitetsmåler for SKB, Rapport - P653 SKBB - 9D4/09017, NORCEM, 2009.
  - Sponsors of the project were: NFR, Norcem, Elkem, Skanska, Unicon, Norbetong, BASF, Rescon Mapei, Betong Øst og Veidekke.

Rheometer-4SCC



Dynamic vs. static stability tester

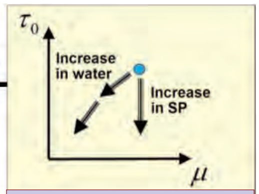
- As the rheometer is segregating the SCC by mechanical means (by rotating impeller), it could be considered as a “dynamic” stability tester
- “Static” stability testers (by gravity) would then be for example the
  - *Surface settlement test* [2]
  - ***Sieve segregation resistance test*** [5].
    - [2] P.J.M. Bartos, M. Sonebi, and A.K. Tamimi (editors). Workability and Rheology of Fresh Concrete: Compendium of Tests; Report of RILEM Technical Committee TC 145-WSM, Workability of Special Concrete Mixes. RILEM Publications S.A.R.L., Cachan Cedex, France, 2002.
    - [5] **The European Guidelines for Self-Compacting Concrete**, Specification, Production and Use, May 2005, SCC European Project Group, www.efnarc.org.



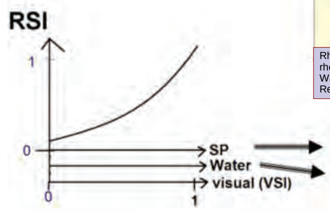
Experimental setup

- Increase in SP and water
  - Start with a stable concrete
  - The SP content is increased stepwise and **stability** is visually assessed, as well as RSI is measured with Rheometer-4SCC
  - The water content is increased stepwise and **stability** is visually assessed, as well as RSI is measured with Rheometer-4SCC

Make the SCC unstable by two different methods



Rheology as a tool in concrete science: The use of rheographs and workability boxes, Olafur H. Wallevik, Jon E. Wallevik, Cement and Concrete Research, doi: 10.1016/j.cemconres.2011.01.009.



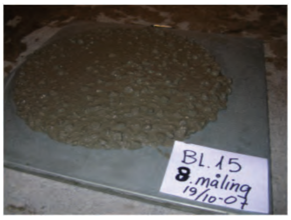
Reduced τ_0

Reduced τ_0 and μ

+ density of the matrix is reduced

"Fasitt": Actual stability of SCC is evaluated by visual observation = Visual segregation index (VSI), by Knut Lervik/SINTEF

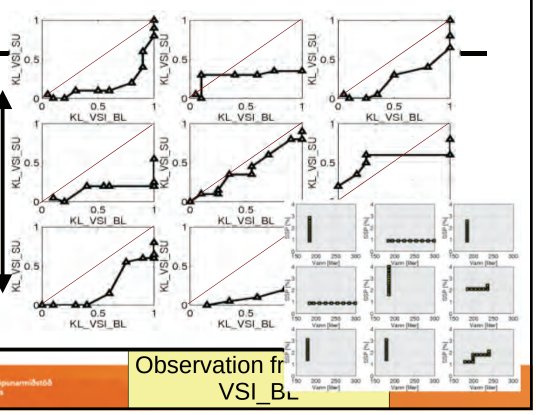
Different observations from mixer and the slump flow (the slumpflow observations could be very misleading)



Same SCC mixture!

Knut Lervik (SINTEF): KL_VSI_BL (mixer) and KL_VSI_SU (slump flow)
KL_VSI = 0 => no (i.e. zero) segregation
KL_VSI = 0.5 => borderline of being acceptable concrete
KL_VSI = 1 => complete segregation (collapse)

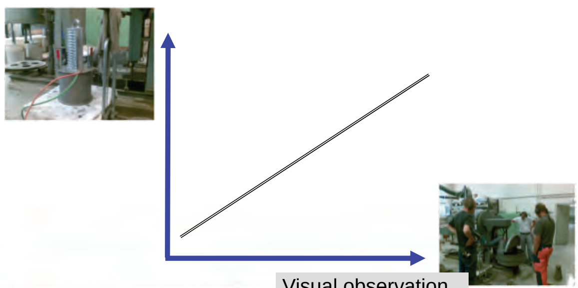
KL_VSI_SU vs. KL_VSI_BL



Observation from Slump Flow (VSI_SU)

Observation fr... VSI_BL

The aim is to get a good correlation between the RSI from Rheometer-4SCC and the concrete actual stability (Fasitt)



Visual observation (Fasitt)

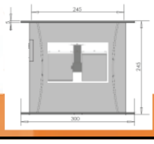
Rheological segregation index RSI by the Rheometer-4SCC

RSI = 0 => no (i.e. zero) segregation

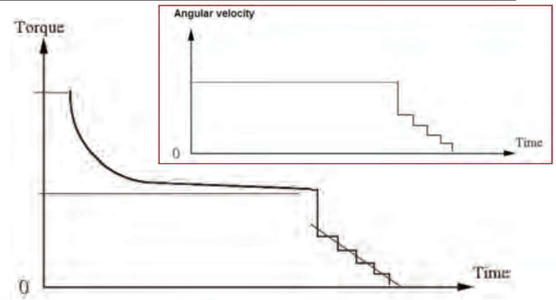
RSI = 0.5 => borderline of being acceptable concrete; (RSI > 0.5 => SCC too unstable)

RSI = 1 => complete segregation (collapse)

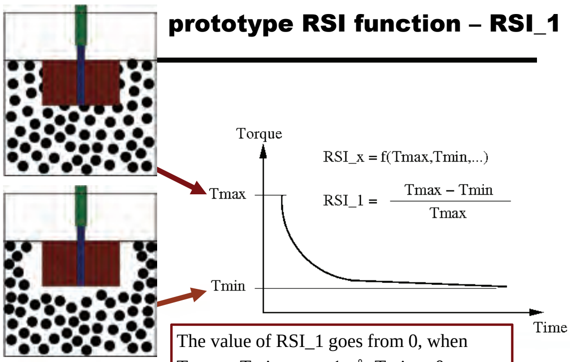
… same as for the KL_VSI



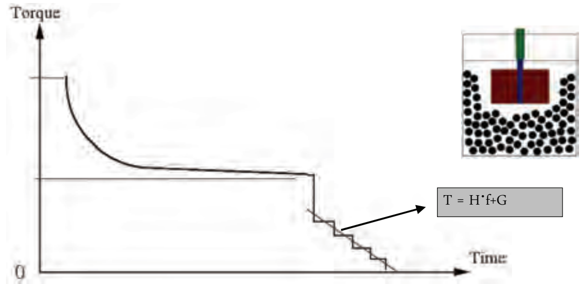
Test setup for the Rheometer-4SCC



The first version of the prototype RSI function – RSI_1



The value of RSI_1 goes from 0, when Tmax = Tmin, up to 1 når Tmin = 0.



$$\mathrm{RSI} = \frac{\alpha}{\sqrt{H \cdot f_{av} + G}} - \beta$$

$\alpha = 12.0$
$\beta = 0.25$

$f_{av} = (0.5+0.4+0.3+0.2+0.1)/5$

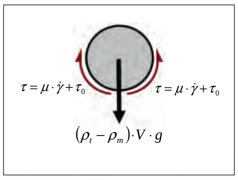
A completely stable SCC => RSI = 0

$$\mathrm{RSI} = \frac{\alpha}{\sqrt{H \cdot f_{av} + G}} - \beta = 0 \Rightarrow \frac{\alpha}{\sqrt{H \cdot f_{av} + G}} = \beta$$

$$\frac{\alpha}{\beta} = \sqrt{H \cdot f_{av} + G}$$

$$\left(\frac{\alpha}{\beta}\right)^2 = H \cdot f_{av} + G$$

$$k \cdot (\rho_t - \rho_m) \cdot \frac{V}{A} \cdot g = \mu \cdot \dot{\gamma} + \tau_0 \qquad k > 1$$

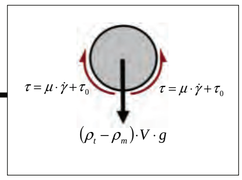


$(\rho_t - \rho_m) \cdot V \cdot g = A \cdot (\mu \cdot \dot{\gamma} + \tau_0)$
@ RSI = 0.3 (?)

$(\rho_t - \rho_m) \cdot V \cdot g < A \cdot (\mu \cdot \dot{\gamma} + \tau_0)$

Gives instability — Gives stability

$$k \cdot (\rho_t - \rho_m) \cdot \frac{V}{A} \cdot g = \mu \cdot \dot{\gamma} + \tau_0$$

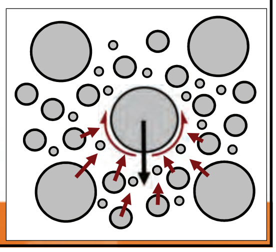


$$k \cdot (\rho_t - \rho_m) \cdot \frac{V}{A} \cdot g - \xi = \mu \cdot \dot{\gamma} + \tau_0$$

Reduced instability

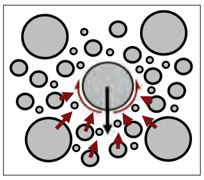
ξ → Confinement effect (“lattice effect”)

- *Grading curve*
- *Surface properties*
- *Angularity*
- *etc.*



$$\left(\frac{\alpha}{\beta}\right)^2 = H \cdot f_{av} + G$$

$$k \cdot (\rho_t - \rho_m) \cdot \frac{V}{A} \cdot g - \xi = \mu \cdot \dot{\gamma} + \tau_0$$



Point: ***α*** and ***β*** can represent divers material propeerties with respect to segregation and stability

$$\mathrm{RSI} = \frac{\alpha}{\sqrt{H \cdot f_{av} + G}} - \beta$$

Example: The larger density of Eklogitt (relative to Årdal) should bring larger segregation. But this tendency could be partial compensated by larger angularity in the Eklogitt. [?]

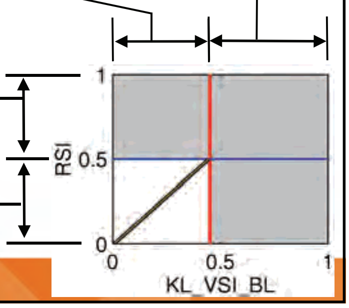
A "RSI – map" which is divided into 4 zones:

Stability is difficult to observe directly. Within the range of acceptable SCC. Gaining a good correlation in this domain is important .

Obviously segregating and thus non acceptable SCC. Instrumentation not needed to verify such. Easy to judge visually => outside of the interest of the rheometer. I.e. Gaining a good correlation in this domain is not important.

RSI from 0.5 to 1 is defined as from non-acceptable SCC to complete collapse (total sprekk).

RSI from 0 to 0.5 is the interval that correspond to an acceptable SCC. As the RSI value close up to 0.5, the SCC becomes more critical.

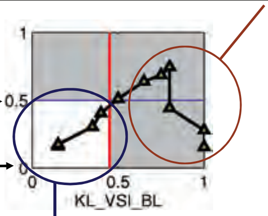


Example:

That RSI does not work in this domain is OK, since the SCC is obviously not acceptable anyway. That is, with the naked eye, one can easily see that the concrete should not be used at all.

RSI = 0,5 (KL_VSI_BL= 0,45) => SCC on borderline, a small variation in SP or water is critical here.

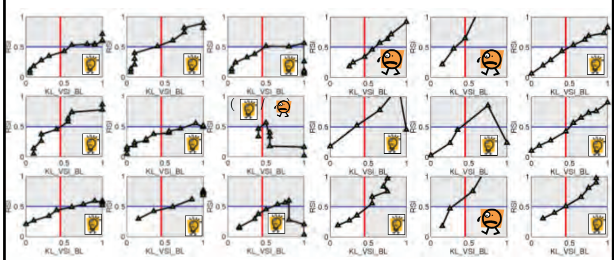
RSI = 0 (KL_VSI_BL = 0) => SCC stable! A relatively large variation in SP or water is needed to make it instable.



Here is the area of interest, which tells us how much the SCC in unstable.

RSI vs. KL_VSI_BL

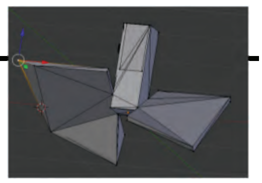
$$\mathrm{RSI} = \frac{\alpha}{\sqrt{H \cdot f_{av} + G}} - \beta$$

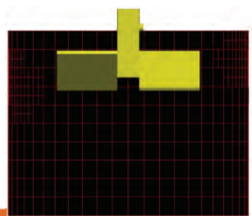


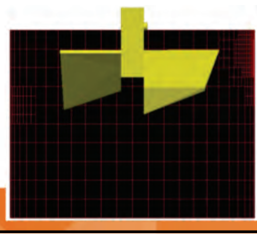
...so...

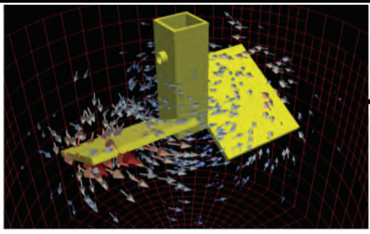
- The results shows that the current impeller system gives in about 20% false results and thus 80% correct readings
- To increase the proportion of correct readings, a new type of impeller system might be a solution to that (or new test setup in angular velocity).
- Testing a new idea is very resource demanding in terms of laboratory labor and data analysis
  - Testing new concept took minimum 4 individuals, testing for a 1 week
- As a first step of analysis, Computational Fluid Dynamics (CFD) could be used to analyze what type of impeller system would have the largest (or most desired) "*pushing mechanism*" (as in aggregates being pushed away from the impeller).
- CFD/Discrete Element Method ?

Use of computational techniques



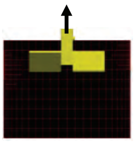


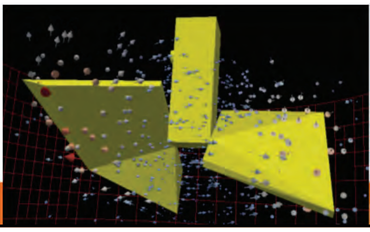




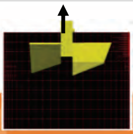
omega = 3 rad/s mu = 45 Pa.s; tau0 = 0 Pa;

vertical force = 2.9 Nm

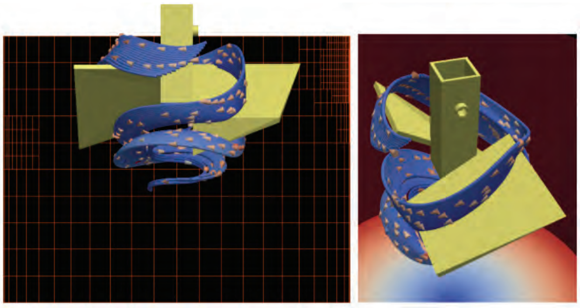




vertical force = 3.6 Nm



Examining streamlines relative to "stationary" impeller system (rotating coordinates)



Stability index for mixer (Knut Lervik, SINTEF)

0 / 0,1	Stabil og homogen betong
0,2 / 0,3	Betongen har fått en kremaktig overflate og dannelse av små luft porer, men er fortsatt stabil.
0,4 / 0,5	Begynnende separasjon, masse små porer, tendens til slamlag, dannelse av svart hinne på overflaten.
0,6 / 0,7	Tydelig tegn til separasjon, kraftig koking, slamlag, svart hinne, grovt tilslag begynner å synke.
0,8 / 0,9	Kraftig koking, klar vannhinne, 5 – 20 mm slamlag, tilslag liggende i bunn av massen.
1	Fullstendig separasjon / sprekk

Criteria for non acceptable SCC is between 0,4 and 0,5 (≈ 0,45)

Stability index for slumpflow (Knut Lervik, SINTEF)

0 / 0,1	Stabil og homogen betong. Tilslag / pasta flyter godt ut.
0,2 / 0,3	Stabil og homogen betong, flyter godt ut, men har fått en blank og glinsende overflate med evt svarte utfellinger.
0,4 / 0,5	Har nå i tillegg fått en antydning til pastarand i ytterkant av utbredelsen, men tilslag følger fortsatt godt ut. Fremdeles stabil.
0,6 / 0,7	Tydelig pastarand, grovt tilslag har tendens til å bli liggende igjen midt i utbredelsen.
0,8 / 0,9	Har nå i tillegg fått en begynnende vannseparasjon i ytterkant. Pasta / vannrand.
1	Fullstendig separasjon / sprekk

Criteria for non acceptable SCC is between 0,5 og 0,6 (≈ 0,55)

- As the rheometer is segregating the SCC by mechanical means (rotating impeller), it could be considered as a "dynamic" stability tester
- "Static" stability testers (by gravity) would then be for example the
  - *Surface settlement test* [2]
  - *Wet sieving stability* (*segregation test*) [3,4], also know as the *Sieve segregation resistance test* [5].

- [2] P.J.M. Bartos, M. Sonebi, and A.K. Tamimi (editors). Workability and Rheology of Fresh Concrete: Compendium of Tests; Report of RILEM Technical Committee TC 145-WSM, Workability of Special Concrete Mixes. RILEM Publications S.A.R.L., Cachan Cedex, France, 2002.
- [3] Association Française de Génie Civil, Bétons Auto-Plaçants – Recommandations provisoires, Documents scientifiques et techniques, July 2000, 63 p.
- [4] M.J. Rooney, Assessment of the Properties of Fresh Self – Compacting Concrete with Reference to Aggregate Segregation, PhD Thesis, University of Paisley, 2002.
- [5] The European Guidelines for Self-Compacting Concrete, Specification, Production and Use, May 2005, SCC European Project Group, www.efnarc.org.

Steel fibres in fresh concrete: packing, lubrication phase, jamming and proportioning parameters

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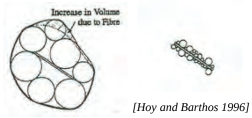
Content

- Background & objective
- Parameters
  - Particle-Matrix proportioning with calculated packing of aggregate fibre mix
  - Fibre, thickness and packing relations to rheology
- Calculating matrix- and particle volumes for SFRC
  - CPM for SFRC proportioning
  - Inverse CPM analysis fresh SFRC mixes (Årdal aggr., Dramix)
  - Further work, conclusions and acknowledgement

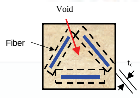
Background; Fibre effects on fresh concrete

- Particle packing and lubricating phase volume



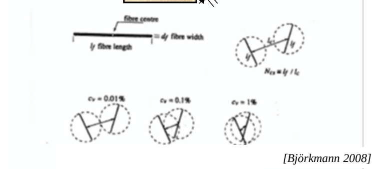
[Hoy and Barthos 1996]

- Thickness of lubricating phase



[Bui, Geiker&Shah 2003]

- Rotational overlap

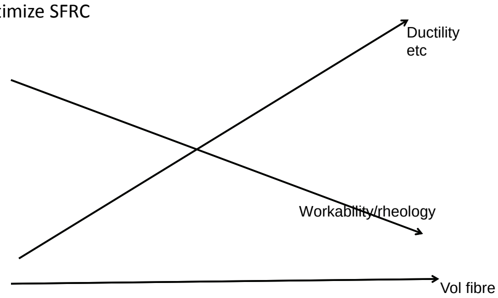


[Björkmann 2008]

0% 50% 78%

Objective

- Optimize SFRC

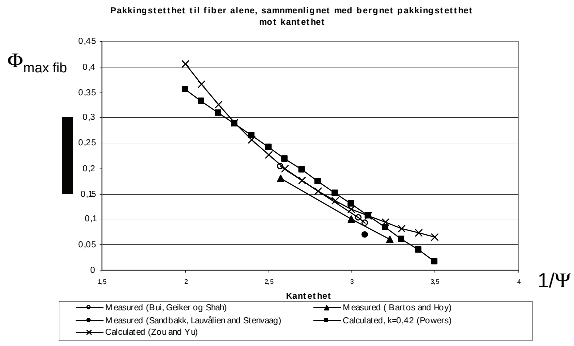


- Proportioning and rheology prediction tool for SFRC

Particle-Matrix proportioning using packing of aggregate – fibre mix

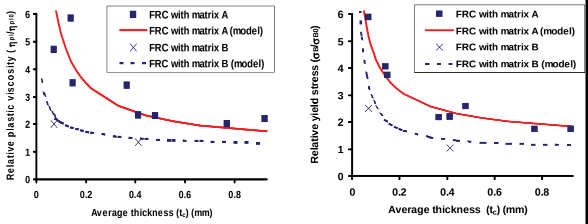
- Compressible Packing Model (CPM) for packing calculations [de Larrard 1999]
- Angularity – packing (Ψ -Φ_m) relations for fibre established (model and experiments) [Powers 1968, Zhou & Yu 1996, Berg and Jacobsen 2008]
- Fibres introduced in CPM as «Equivalent packing diameter» d_p depending on angularity and fibre volume diametre d_v => fibre interaction in CPM [Zhou & Yu 1996, Berg 2008, Berg and Jacobsen 2008,2010]
- Matrix volume calculated
- (Thickness-, packing- and fibre rotation parameters [Björkmann 2008]
- (simulated/experimental relations to rheology hopefully established)

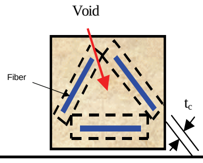
Fibre packing vs angularity



[Berg & Jacobsen 2008]

Thickness vs mortar rheology





[Bui, Geiker&Shah 2003]

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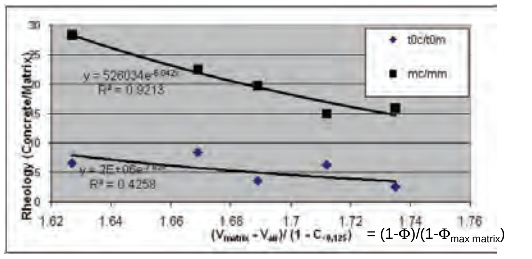
Packing vs concrete rheology (SFRC&OC)



Matrix w/b = 0.45, CSF/b = 0.05, 3.8 % Vol-% filler < 0.125mm, 1.9 % SP
0 and ≈0.9 % dramix fibre of concrete, Dmax = 16mm, Sl.Fl.=550-650mm
Concrete (with and without fibres) :BML viscometer
Matrix: BML ConTec4 viscometer

Based on [Berg (2008),Berg&Jacobsen 2010]

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CPM for SFRC proportioning - input

Maximum packing density of mix of aggregates and fibres

- Grading of aggregate fractions
- Length and diameter of fibres (1 or 2 types of steel fibre simultaneously)
- Maximum packing density of
  - Narrow fractions of aggregates (grain classes) = $\Phi_i = \beta_i = \gamma_i$
  - (Fibres – though calculated from angularity-packing model)
- Limit between matrix and particles
- Compaction index (K)

Assumptions
- Wall effect and loosening effect constant according to [deLarrard 1999] – *Can be changed to input data*

Fibre rotational overlap

- As above

Assumptions
- Cubical spacing of fibre centres

Matrix volume and Thickness of "fibre lubricating matrix" around fibres (t_c)

- As above
- Ratio matrix volume/particle void volume (= «particle dilution», «degree of matrix dominance», matrix/particle void saturation factor k)
- Maximum particle size of "fibre lubricating matrix" around fibres (d_p/X); d_p equivalent packing diameter of fibre; X

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Example Packing analysis and proportioning
Standard Årdal aggregate and Dramix 35/65 steel fibres

Aggregate fractions
- 0-8 mm washed
- 8-11 mm
- 11-16 mm

Assumptions
- Limit between martix and particles: 0.125 mm
- Maximum particle size of "fibre lubricating matrix" around fibres: d_p/X=3

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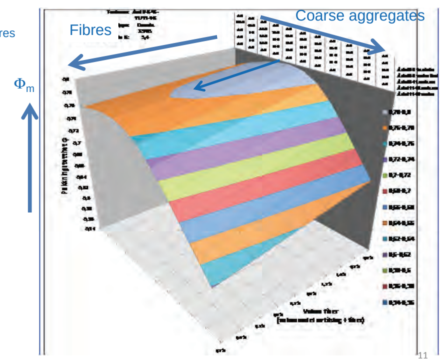
Exampe - CPM with fibre - Maximum packing Φ_m
(Årdal aggregate + 35 mm Dramix fibre mixes)

Adding approx 1% vol fibres to a mix with max. Φ_m : $\Delta\Phi_m$ < 0.02 (20 l/m³)



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Example Φ/Φ_m for matrix volume = 2 x (1-Φ_m)
(Årdal aggregate + 35 mm Dramix fibre mixes)

Årdal 0-8 vasket Stein Are	Årdal 8-11 stein are	Årdal 11-16 stein are	Volumandel fiber av tilslag+fiber									
			0.0 %	0.5 %	1.0 %	1.5 %	2.0 %	2.5 %	3.0 %	3.5 %	4.0 %	4.5 %
0%	50%	50%	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.39	0.38
10%	45%	45%	0.56	0.55	0.54	0.52	0.51	0.50	0.49	0.48	0.47	0.45
20%	40%	40%	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.53	0.52
30%	35%	35%	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.58
40%	30%	30%	0.72	0.71	0.70	0.69	0.69	0.68	0.67	0.66	0.65	0.64
50%	25%	25%	0.74	0.73	0.73	0.72	0.71	0.71	0.70	0.69	0.68	0.67
60%	20%	20%	0.75	0.74	0.74	0.73	0.73	0.72	0.72	0.71	0.70	0.70
70%	15%	15%	0.74	0.74	0.74	0.73	0.73	0.72	0.72	0.71	0.71	0.70
80%	10%	10%	0.73	0.73	0.73	0.73	0.72	0.72	0.72	0.71	0.71	0.70
90%	5%	5%	0.72	0.72	0.72	0.72	0.71	0.71	0.71	0.70	0.70	0.70
100%	0%	0%	0.71	0.71	0.71	0.70	0.70	0.70	0.70	0.69	0.69	0.69

$\Delta(\Phi/\Phi_m)$ large

$\Delta(\Phi/\Phi_m)$ small

Assumptions
- Matrix vol = 2 x (1-Φ_m)
- Air voids part of matrix

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Example - Matrix volumes (1-Φ)

Matriksvolum

Årdal 0-2 fra sindre	Årdal 0-8 vasket Stein Are	Årdal 8-11 stein are	Årdal 11-16 stein are	Årdal 11-16 vasket	Volumandel fiber av tilslag+fiber 0,0 %	0,5 %	1,0 %	1,5 %	2,0 %	2,5 %	3,0 %	3,5 %	4,0 %	4,5 %
0 %	0 %	50 %	50 %	0 %	681	690	699	708	718	727	736	745	754	763
0 %	10 %	45 %	45 %	0 %	617	627	637	647	657	668	678	688	698	708
0 %	20 %	40 %	40 %	0 %	554	564	575	586	597	608	618	629	640	651
0 %	30 %	35 %	35 %	0 %	497	507	518	529	540	551	562	573	584	596
0 %	40 %	30 %	30 %	0 %	454	464	473	483	493	503	513	524	535	546
0 %	50 %	25 %	25 %	0 %	433	440	448	455	463	472	481	490	499	509
0 %	60 %	20 %	20 %	0 %	429	435	440	446	452	459	466	473	480	489
0 %	70 %	15 %	15 %	0 %	437	441	445	450	454	459	465	470	476	482
0 %	80 %	10 %	10 %	0 %	451	454	458	461	465	469	473	477	482	487
0 %	90 %	5 %	5 %	0 %	469	471	474	476	479	482	486	489	493	497
0 %	100 %	0 %	0 %	0 %	488	490	492	494	496	499	502	504	507	511

Volum matriks [l/m^3]

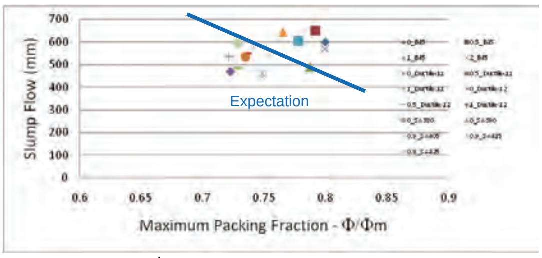
Example - Thickness of lubricating matrix for $d_{p,fibre}/3$ (Årdal aggregate + 35 mm Dramix fibre mixes)

Thickness of lubricating matrix

Årdal 0-8 vasket Stein Are	Årdal 8-11 stein are	Årdal 11-16 stein are	Volumandel fiber av tilslag+fiber 0.5 %	1.0 %	1.5 %	2.0 %	2.5 %	3.0 %	3.5 %	4.0 %	4.5 %
0%	50%	50%	2.61	1.29	0.86	0.64	0.51	0.43	0.37	0.32	0.29
10%	45%	45%	2.03	0.99	0.65	0.48	0.37	0.31	0.26	0.23	0.20
20%	40%	40%	1.60	0.77	0.49	0.36	0.28	0.22	0.18	0.16	0.14
30%	35%	35%	1.30	0.61	0.38	0.27	0.20	0.16	0.13	0.11	0.09
40%	30%	30%	1.10	0.51	0.31	0.21	0.15	0.12	0.09	0.07	0.05
50%	25%	25%	1.00	0.45	0.27	0.18	0.13	0.09	0.07	0.05	0.03
60%	20%	20%	0.98	0.44	0.26	0.17	0.11	0.08	0.05	0.04	0.02
70%	15%	15%	0.99	0.44	0.26	0.17	0.11	0.08	0.05	0.03	0.02
80%	10%	10%	1.04	0.46	0.27	0.18	0.12	0.08	0.05	0.03	0.02
90%	5%	5%	1.10	0.49	0.29	0.19	0.13	0.09	0.06	0.04	0.02
100%	0%	0%	1.17	0.53	0.31	0.21	0.14	0.10	0.07	0.05	0.03

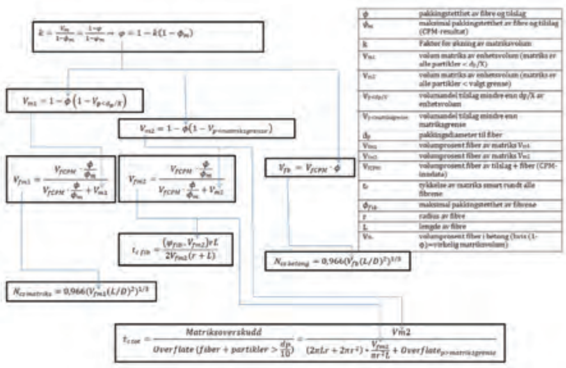
tc < 0.25mm

Existing mixes with varying matrix quality
(but constant Årdal aggregate + 65 mm Dramix fibre)
inversely analysed for rheology – maximum packing relation



Assumption: particles > 0.125 mm

Fibre(CPM) for SFRC proportioning - Flow chart



Conclusions

An extended Compressible Packing Model (CPM) for SFRC was applied

- **Maximum packing density of mix of aggregates and fibres**
- **Thickness of "fibre lubricating matrix" around fibres (t_c) and packing relations to mix rheology**
- **Fibre rotational overlap**

The model was applied to standard Årdal aggregate and Dramix 35 steel fibres to illustrate the possible predictions

Predicted packing densities and observed flow contradicted expectations – ***more extensive data are needed – suggested research is identified***

Further work (preliminary)

- Verification of CPM fibre-particle-matrix proportioning programme
- Parameter study/Sensitivity analysis
  - Aggregate grading variations
  - Air content variations
  - Definition of matrix
  - Definition of lubricating phase around fibres (or interacting aggregates) and associated particle phase
  - Matrix requirements for constant flow *Matrix vol = ? x (1-Φ)*
- Comparison to simulations of flow (collaboration with DTU)
- Comparison to observations of flow
- Optimisation of mixes / guidelines for mix design

Acknowledgements

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  - Sindre Sandbak, Sintef
- Funding from COIN TG 2

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