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SINTEF Building and Infrastructure

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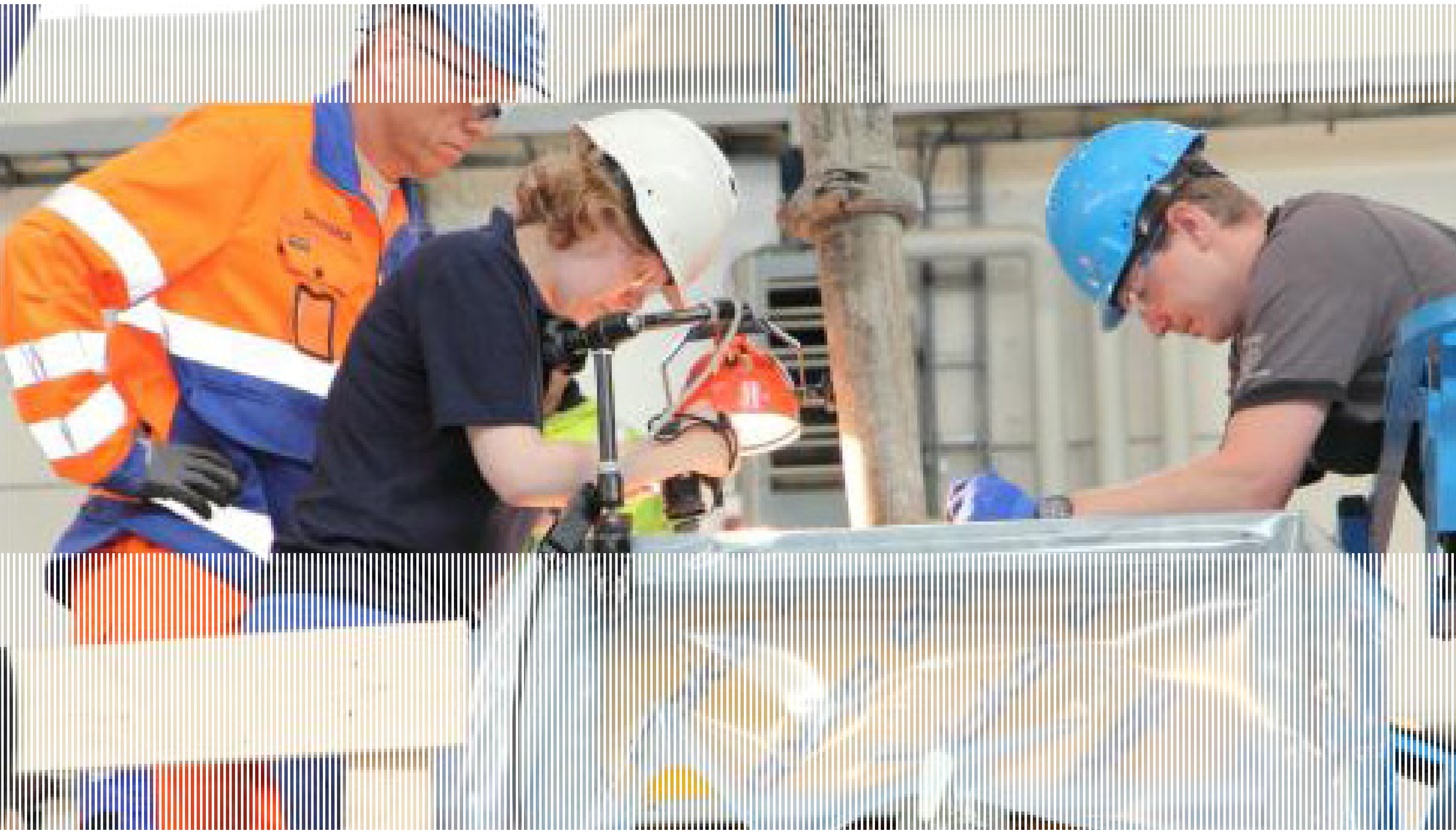
The effect of stabilization with either filler or chemical stabilizer on the surface quality of concrete elements

COIN Project report 39 – 2012



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FA 2 Competitive constructions

SP 2.1 Robust highly flowable concrete

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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 eight projects in three focus areas:

- Environmentally friendly concrete
- Economically competitive construction
- Aesthetic and technical performance

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

Summary

Three full scale wall elements were cast with three different concretes: an unstable SCC, one stabilized by adding filler, and one stabilized by adding chemical stabilizer. The aim of this study was to investigate the effect of the stabilization on the rheology of the SCC and on the final surface quality.

All delivered SCC's were rather stone rich and unstable, even the stabilized ones. This was most likely caused by a change in the fines and water content of the sand for which the concrete recipe was not corrected. Even though the SCC's were not as expected certain conclusions could be drawn.

All three mixes had a low viscosity and relatively high yield stress indicating segregation. The questionable stability was confirmed by the sieve segregation test, but not by the visual segregation index on the flow board. Stability assed on a hardened concrete cylinder indicated good stability for the unstable and filler stabilized SCC. However, the chemically stabilized concrete showed clear signs of bleeding.

Regarding the surface quality of the wall elements, it can be concluded that all surfaces had a similar grey level independent of the type of SCC used or whether or not formwork agent was applied. It is not possible to come to clear conclusions as to how the SCC type or the surface treatment affects the amount of pores. However, there is an indication that the chemical stabilizers can lead to large bleeding pores in the lower part of the surface of the concrete wall, whereas filler stabilization can gives rise to the formation of very fine pores.

The fact that all SCC's were on the verge of instability, did not allow for clear rheological differences nor clear differences in final surface quality.

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1 Introduction

Self Consolidating Concrete (SCC) is a category of concrete which is able to flow under its own weight, fill the required space or formwork completely and produce a dense and adequately homogeneous material without the need for compaction (De Schutter et al. 2008). Although the use of SCC can provide an improved working environment, and better form filling and surface finishing, SCC currently holds less than 5% of the cast-in-place concrete in Norway. One of the major reasons leading to the limited acceptance of SCC by the building industry is the relatively high cost/benefit ratio when using SCC compared to ordinary concrete. Problems related to the lack of robustness of SCC regarding stability can for example result in rejection of concrete batches and dead-time on the construction site (Kristiansen 2011). This is especially the case for low grade concrete e.g. NS-EN 206-1 B30M60 (Kristiansen 2011). This type of SCC is generally more sensitive to variations in production e.g. water content of sand, resulting in the need for stricter quality control and possibly rejection of concrete on-site.

There are two common ways to improve the stability of SCC, either by adding chemical stabilizers or by adding filler. In a previous study, the effect of the different methods of stabilization on the rheological properties was investigated (Vikan and De Weerdt 2010).

The aim of the current study is to investigate the effect of the rheological properties of the stabilized SCC on the surface quality of concrete wall elements. Two stabilization methods were selected, based on these results of the previous study (Vikan and De Weerdt 2010): stabilization with a chemical stabilizer, and stabilization with limestone powder.

A higher filler content increases the matrix volume and reduces the water/powder ratio, which in turn results increases the plastic viscosity of the resulting SCC. Chemical stabilization does not increase the matrix volume significantly, but tends to increase the yield stress and the thixotropy of the matrix. The higher the viscosity of the concrete, the more difficult it is for the entrapped air to travel through the concrete, thereby resulting in more pores at the surface. The hypothesis for this study has been that the unstable concrete will result in the best surface finish and the filler stabilized (most viscous SCC) the worst.

2 Experimental set-up

2.1 Concrete proportioning

The aim was to design a reference SCC which was on the verge of instability at a Slump Flow (SF) of 675±25 mm1. This unstable SCC was then stabilized in two different ways, chemical stabilizer and limestone powder respectively. Trial batches were performed at the ready mix plant, in order to have the required slump flow (675±25 mm) and stability.

Table 1and Table 2show the concrete recipe of the SCC commercially produced at the concrete plant and the recipe of the unstable SCC. The following changes were made to the commercial SCC in order to obtain an SCC at the verge of instability at a SF of 675±25 mm:

- Exclusion of the fine sand (0/2 mm)
- Exclusion of the silica fume
- Increase of the coarse aggregate content
- Increase of the water/cement ratio

The recipes of the unstable reference SCC and the filler and chemically stabilized SCC are given in Table 3 and Table 4.

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The materials used are:

- EN 197-1 CEM II/A-V 42.5 R Portland fly ash cement (Blaine = 450 m^2/kg, density = 3010 kg/m^3)
- Limestone powder (Blaine = 360 m^2/kg, density = 2700 kg/m^3)
- Silica fume (density = 2200 kg/m^3)
- Air entrainer (AE)
- Superplasticizer (SP): Acrylic polymer with 30% dry solid, splitting type admixture, normal dosage = 0.3-1.2% of cement weight.
- Chemical stabilizer: polymer with high molecular weight, dry solids = 2.2%, active ingredients = 5.5%, normal dosage = 1-4 l/m^3.
- Retarder: a set retarder based on gluconate.
- Aggregates: sieve curves of the used aggregates can be found in the appendix.

The super plasticizer content was adapted in order to achieve the required slump flow (675±25 mm). The dosage given in Table 3 is the total amount of SP added. Table **5** shows the SP dosage added at the ready mix plant and upon arrival with the respective slump flow spreads.

Table 1: Mix design parameters, commercial SCC and unstable SCC

Initial parameters	Commercial SCC	Unstable SCC
w/c	0.56	0.65
w/p	0.53	0.49
s/c (silica fume) [%]	4.8	0.0
Admixtures	% of C	% of C
AE	0.65	0.65
SP(*)	1.5	0.75
Matrix	l/m^3	l/m^3
Matrix volume	320	310
Volume cement paste	286	276

(*) a different type of SP was used for the commercial and the unstable SCC

[1] This is within recommended consistency range (K2) for wall casting (580 mm < SF < 700 mm) according to NB29.

Table 2: Detailed recipes, commercial SCC and unstable SCC

Materials [kg/m^3]	Commercial SCC	Unstable SCC
CEM II/A-V 42.5 R	310.4	278.3
Silica fume	14.9	0.0
Free water	173.8	178.2
0/8 mm aggregate (*)	713.2	1035.7
0/2 mm aggregate	348.7	0.0
8/16 mm aggregate	751.0	847.4

(*) a different type of 0/8 mm sand was used for the commercial and the unstable SCC

Table 3: Mix design parameters, of the three different SCC's used in the full scale laboratory investigation

Initial parameters	Unstable SCC	Filler stabilized	Chemically stabilized
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
AE	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
Volume cement glue	276	299	276

(*) 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

Table 4: Detailed recipes of the three different SCC's used in the full scale laboratory investigation

Materials [kg/m^3]	Unstable SCC	Filler stabilized	Chemically stabilized
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
0/8 mm Søberg aggregate	1035.7	1001.2	1035.7
8/16 mm Ramlo aggregate	847.4	819.2	847.4
AE	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

Table 5: Dosage of SP added at ready mix plant and upon arrival with corresponding slump flow (SF) spread

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

The concretes delivered for the full scale test differed a lot from the concretes obtained during the trail batches performed a couple of weeks prior at the ready-mix concrete plant, even though the same recipe was used. This difference can be attributed to the new sand batch used for the full scale test which contained a considerably lower filler content compared to the sand used during the trail mixing. This results in a lower matrix volume (estimated to 15 l /m^3) and a higher water/powder ratio, which on its turn gives rise to reduced stability. This was most evident for the reference concrete which was supposed to be on the verge of instability, but was actually fully separating. Even though the delivered concretes differed from the trail batches performed in advance, it was opted to carry though the full scale testing.

2.2 Concrete placing

The concrete for the full scale experiment was mixed at the ready mix plant, and was transported with a concrete mixer to the laboratories of NTNU/SINTEF (approx.15 minutes drive).

Straight after mixing the slump flow of the concrete is determined at the ready mix plant before loading the concrete truck. Upon arrival at the laboratory the concrete was mixed full speed for 3 minutes. The first 100-200l of concrete coming out of the concrete truck is stone rich and was poured in barrels for disposal. Then a sample was taken with a wheelbarrow to evaluate the slump flow. If necessary additional SP was added to obtain the required slump flow spread (see Table **5**). The concrete was then remixed for 3 minutes and evaluated again.

When the concrete was accepted, three wheelbarrows were filled and taken to the laboratories for testing.

The concrete was pumped into the moulds. The pump truck was positioned in the laboratory besides the formwork. Concrete trucks with the different concrete batches were backed into the lab to feed the pump truck. A 3” pump hose was lowered into the formwork, and lifted up as the formwork filled with concrete. The outlet of the pump was kept approx. 200 mm above the free surface of the concrete. It took about 3-4 minutes to fill the formwork.

2.3 Formwork

The formwork of the three wall elements was delivered by DOKA Norge AS and had the following dimensions: 0.70×2.50×0.25m. The three wall units were assembled together as shown in Figure 1.

The walls are reinforced by two steel reinforcement nets (type K131) that are welded together with 6 mm steel rods to form reinforcement cages (see Figure 1). Reinforcement spacers were used to obtain a 45 mm concrete cover of the reinforcement. This resulted in a 14 cm gap between the two reinforcement nets which leaves enough space for the 3 " pump hose (outer diameter 10.5 cm).

Brand new, plastic coated plywood formwork was used. Of each wall element one surface was treated with a demolding agent and one surface was kept clean. The demolding agent used was an organic demolding oil (1l /40 m^2).

Figure 1: The reinforcement and formwork for the three wall elements.

2.4 Rheological testing

The fresh concrete was characterized regarding density EN 12350-6:2009 and air content EN 12350-7:2009. The compressive strength was measured after 28 days on concrete cubes (100×100×100 mm) according to EN 12390-3:2009. The cubes were cast without compaction or vibration. The first 24 hours they are covered with plastic and left in the laboratory atmosphere. The cubes were thereafter demoulded and cured in a water bath until the time of testing.

The following rheological measurements were preformed:

- Slump flow and T500 according to EN 12350-8, were T500 is related to the viscosity of the concrete, and the slump flow to the yield stress (Roussel et al. 2005).

Figure 2: Slump flow and T500 measurement.

- The ConTec Rheometer 4SCC (ConTec 2011) was used to study the rheology of the concrete. The 4SCC rheometer decreases the rotational speed of the rotor (f) stepwise and measuring the torque (T) needed (see Figure 3). By plotting the steady state torque in function of the rotational speed, a linear function of the form T=H.f+G is obtained. This curve is referred to as a flow curve. The parameters G (A) and H (A.s) are related respectively to the yield stress and the viscosity of the concrete. However, due to the complex geometry of the rotor of the 4SCC it currently not possible to calculate the yield stress τ_y and the plastic viscosity μ_p.

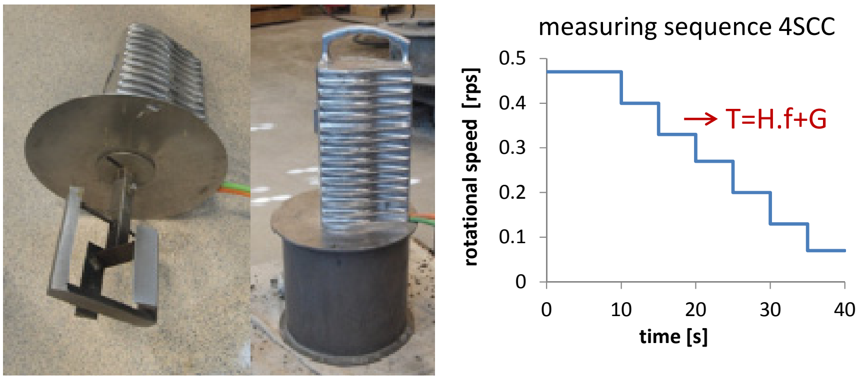

Figure 3: 4SCC rheometer and the measuring sequence applied.

- The downwards flow curve was also measured with the ConTec BML Viscometer 3 (ConTec 2011) as shown in Figure 4. Due to the axial geometry of the viscometer, the yield stress τ_y and the plastic viscosity μ_p can be calculated based on the measured H and G, and the geometrical parameters (Ri = 10 cm ,Ro = 14.5 cm ,h = 18 cm), using the Reiner-Riwlin equation:

$$T = \frac{4\cdot\pi\cdot\mu_p\cdot h}{\frac{1}{R_i^2}-\frac{1}{R_o^2}}\cdot f + \frac{4\cdot\pi\cdot\tau_y\cdot h}{\frac{1}{R_i^2}-\frac{1}{R_o^2}}\cdot \ln\left(\frac{R_o}{R_i}\right) = H\cdot f + G$$

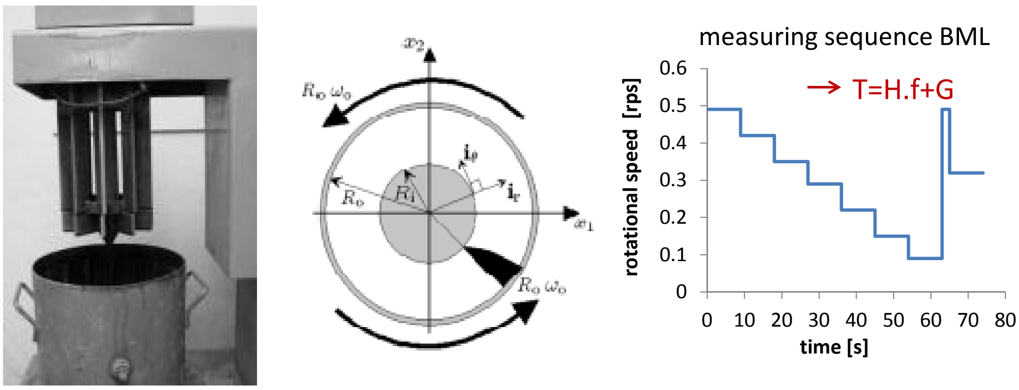

Figure 4: ConTec BML Viscometer 3 and the measuring sequence applied.

- The concrete was sieved through a 6.3 mm sieve in order to remove the coarse aggregates. The mortar obtained by sieving was tested using the ConTec Viscometer 4 (see
- Figure **5**) to obtain the downwards flow curve. As the Contec Viscometer 4 has a co-axial geometry, the Reiner-Riwlin equations can be applied to obtain the yield stress τ_y and the plastic viscosity μ_p (Ri = 8.5 cm ,Ro = 10.1 cm ,h = 11.6 cm) .

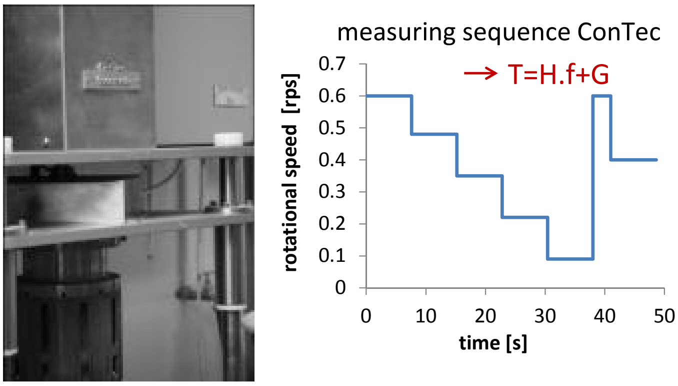

Figure 5: ConTec Viscometer 4 and the measuring sequence applied.

- The inclined plane test according to (Khayat et al. 2010) was used to evaluate the yield stress of the concrete and the sieved mortar (6.3 mm sieve). The plane was covered with sand paper and moistened by spraying water on it. The mortar or concrete sample was poured into a cylinder with diameter 62 mm and up to a height of 100 mm for the mortar and 120 mm for the concrete. Then the cylinder was lifted slowly. The resulting spread was covered with a wide cylindrical container to avoid evaporation and left for 10 minutes. The height of the spread was determined by averaging 5 measurements near the central area. The plane was then slowly tilted until the sample started to flow. The angle of inclination at that point was measured using a protractor. The static yield stress was calculated according to the following formula: $\tau_0 = \rho \cdot g \cdot h \cdot \sin\theta$.

Figure 6: The inclined plane test with SCC

2.5 Stability testing

- *Visual segregation index* (VSI) on the flow board according to (Lervik and De Weerdt 2011).
  The VSI was measured on the fresh concrete on the flow board after determination of the slump flow.
  Table 6 shows the characteristics used for rating the VSI. A castable concrete has a VSI between 0 and 0.5-0.6.

Table 6: Characteristics used to rate the VSI of the concrete on the flow board.

VSI	Characteristics of the concrete
0-0.1	Stable and homogeneous concrete. Aggregate and paste flow towards the rim of the sample.
0.2-0.3	Stable and homogeneous concrete that flows well, but has a shiny surface with possible black spots (usually unburned coal residue liberated by the fly ash.
0.4-0.5	Has additionally a hint of a paste rim at the outer edge of the spread, but aggregates

	follow the flow towards the edge. Still stable.
0.6-0.7	Clear rim of paste at the outer edge of the spread. Coarse aggregates tend not to flow outwards and are left in the middle of the spread.
0.8-0.9	Additionally separation of water/paste at the out rim of the spread
1	Complete separation

- *Sieve segregation test* according to EN 12350-11.
  For this test about 10 l of concrete is filled into a container. The container is put on a height, covered and left standing without being shaken for 15 minutes (see Figure 7). A sieve and a receiver are put on the balance. The weight of the receiver alone is m_p. After the required time is elapsed, about 5 kg of concrete from the container is poured upon the sieve (5 mm). The exact mass of the concrete poured onto the sieve is recorded, m_s. The concrete is left for about 2 minutes on the sieve, after which the mass of the concrete passed through the sieve is determined (m_{ps}). The sieve segregation index is then:

$$SI = \frac{(m_{ps} - m_p) \times 100\%}{m_c}$$ for

$0 < SI < 15$ the SCC has a satisfactory segregation resistant;
$15 < SI < 30$ the segregation resistance is questionable;
$30 < SI$ the segregation resistance is inadequate and the SCC is ranged unstable.

Figure 7: Sieve segregation test

- *Segregation test on hardened concrete.*
  PVC columns with a diameter of 0.20 m and a height of 0.60 m were filled with fresh concrete and covered with plastic. The concrete was left to harden for about 1 week, after which the columns were cut in two along the axes by saw. The distribution of the aggregates in the cross section was studied to evaluate the stability.

Figure 8: Filling of the PVC columns with fresh concrete

2.6 Surface properties

In total 6 different surfaces were analysed as schematically shown in Table 7. Each surface 2.50×0.70 m was divided into three zone of 0.60×0.60 m. One positioned in the top, the middle and the bottom of the surface as shown in Figure 9.

Figure 9: Positioning of the bottom, middle and top zone of the surface of a wall element. (left to right)

Table 7: Schematic overview of the analyzed surfaces

	Unstable SCC	Filler stabilized	Chemically stabilized
Treated with demolding agent	U-t	F-t	C-t
Untreated	U-u	F-u	C-u

The surface quality was assessed by analysing a combination of pictures taken from each of the three zones and processing them with the matlab based BetongGUI software which is under development by SINTEF Building and Infrastructure and SINTEF ICT.

A procedure for taking pictures of concrete surfaces to analyse greyscale and greyscale distribution has been proposed in (Eide et al. 2011). For the set-up two tripods are used: one for the camera and one for flash covered in a soft-box in order to have a diffuse light source. Figure 10 shows the four steps of the procedure. First a picture is taken of the test area, then a white paperboard is placed in front of the test area and a second picture is taken. This image is used to adjust for the flash distribution. The third picture includes a greyscale calibration tool. Finally, a picture of the test area alone is taken once again.

The procedure for analysing greyscale and greyscale distribution has also been applied to assess the surface and size of pores on the concrete surface, as there is currently no procedure for taking pictures to analyse pores.

Figure 10: Example of the procedure for taking pictures

The parameters that will be discussed in this report are the following:

- Grey scale: where 0 stands for black and 1 for white.
- Pores:
    - Total area of the pores in mm^2 per marked area (approx. 0.6 m × 0.6 m)
    - Total amount of pores
    - Pore size distribution according to Table 8

Table 8: Classes of pores

Class	Pore diameter [mm]	Pore area [mm^2]
1	1-5	1-20
2	5-10	20-79
3	10-15	79-177
4	>15	>177

The pore classes used in this report are given in pore area. The corresponding pore diameters given in Table 8 are approximate values.

The greyscale distribution is not discussed in this report as all concrete surfaces assessed where too even regarding greyscale. For the greyscale distribution, the BetongGUI software tries to divide the image into two areas with distinct greyscale levels. This could however not be done in a reproducible way as the greyscale difference in the entire image was to low.

3 Results

3.1 Rheology

The fresh concrete properties measured on the three tested SCC's are shown in Table 9. It can be seen that the slump flow of all tested SCC's is within the targeted interval namely, 675±25 mm. The T500 value is rather low for all of them, and lowest for the filler stabilized SCC which is in contradiction with the expected increase of viscosity when increasing the filler content. However, the viscosity might be slightly reduced due the relatively higher water to cement ratio and higher air content of the filler stabilized SCC compared to the other SCC's. These two factors might also be the reason for the lower compressive strength and lower density of the filler stabilized SCC compared to the others.

Table 9: Properties of the different SCC’s

	Unstable SCC	Filler stabilized	Chemically stabilized
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
28d compressive strength [MPa]	34.7±1.1	31.9±1.0	34.7±1.1

The rheological results have limited value as all tested concretes were unstable to a certain extent, and the rheological tests used are not designed to investigate segregating concrete. Nevertheless, certain observations can be made.

Table 10 shows the rheological properties measured on the SCC's using the ConTec Rheometer 4SCC, the ConTec BML Viscometer 3 and the inclined plane test. Due to an error of measurement the filler stabilized SCC was not tested with the 4SCC. The low plastic viscosity or G value measured on the concretes is in line with the low T500 values. The rather high yield stress or H values measured with the rheometers can be caused by the sedimentation of aggregates in the bottom of the measuring bucket, making it hard to shear the concrete.

Table 10: Rheological properties of the different SCC's

	Unstable SCC	Filler stabilized	Chemically stabilized
4SCC			
G [A.s]	0.88	-	0.43
H [A]	3.96	-	3.91
R^2	0.93	-	0.98
BML			
G [Nm]	0.03	0.26	0.38
H [Nm.s]	1.47	1.47	0.86
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
Inclined plane			
Density [kg/m^3]	2427	2368	2408
Spread [mm]	148	205	312
Angle [°]	23	26	13
Static yield stress [Pa]	428	295	101

The inclined plane test gives a much higher static yield stress than the rheometers. It should be noted that it was difficult to determine the angle at which the first movement occurs. The first movement was typically tipping over of one of the larger aggregates. In addition, only a small test volume of concrete was used to perform the inclined plane test (cylinder with diameter 62 mm and height 120 mm) making it questionable whether this is a representative concrete sample. This indicates all together a limited applicability of the inclined plane test for stone rich and unstable SCC's.

Table 11 shows the rheological properties of the mortars sieved out of the SCC's using the ConTec Viscometer 4 and the inclined plane test. The plastic viscosity or G values of the mortar are considerably higher than the ones measured on the concrete. The yield stress of the mortar, on the other hand, is in the same order of magnitude as for the concrete, but the trends do not seem to correlate. It should be noted that it is strange to observe a higher viscosity and higher yield stress on the mortar than on the concrete. One would expect the opposite as aggregates would increase these parameters by inter-collision. However, instability of the concrete might explain this observation. For mortar, the inclined plane test gives similar results compared to the one obtained by the ConTec Viscometer 4 for the unstable and filler stabilized mortar, but not for the chemically stabilized one. This indicates that the inclined plane test is more suitable for mortar than for concrete.

Table 11: Rheological properties of the sieved out mortar of the different SCC's

	Unstable SCC	Filler stabilized	Chemically stabilized
ConTec			
G [Nm]	0.97	0.62	2.54
H [Nm.s]	0.83	0.52	0.73
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
Inclined plane			
Density [kg/m^3]	2360	2241	2356
Spread [mm]	200	228	261
Angle [°]	17	15	11
Static yield stress [Pa]	102	68	31

3.2 Stability

The stability of the fresh concrete was evaluated in two ways: the VSI and the sieve segregation test. The VSI indicated that all SCC's were stable enough to be accepted on site, and that the chemically stabilized SCC was the most stable one. The sieve segregation index (SI), on the other hand, ranged the chemically stabilized SCC to be inadequately segregation resistant (SI>30), and the unstable SCC and filler stabilized one as questionably segregation resistant (15<SI<30). The contradictory results between the visual segregation index and the sieve segregation test might be due to the fact that the former one is measured on a thin layer of concrete immediately after pouring, whereas the later one evaluates the segregation of concrete in a bucket after a time of rest (15 min).

Table 12: Stability assessment of the three different SCC's

	Unstable SCC	Filler stabilized	Chemically stabilized
VSI_{board}	0.4-0.5	0.3-0.4	0.2-0.3
Segregated fraction [%]	23.3	16.5	38.4

The stability of hardened concrete was assessed by examining the cut surface of hardened cylinders as shown in Figure 11. It can be seen that the course aggregates are well distributed over the height of the cylinder for all tested concretes. However, the chemically stabilized concrete showed a top layer of paste of about 1 cm thick, as well as, bleeding channels in the concrete. This indicates that for the high w/c ratio used in this experiment, the chemical stabilizer provoked bleeding.

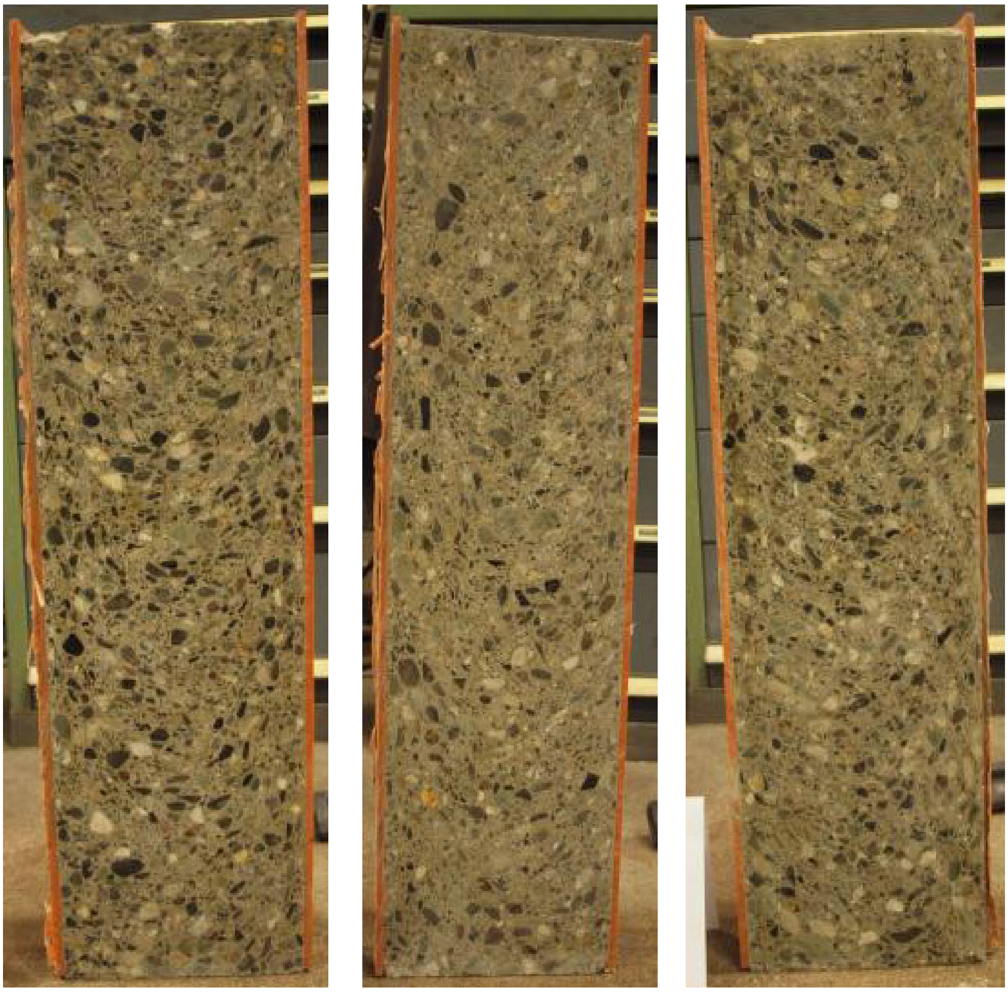

Figure 11: The cross sections of the hardened concrete cylinders; from left to right: unstable SCC, filler stabilized and chemically stabilized.

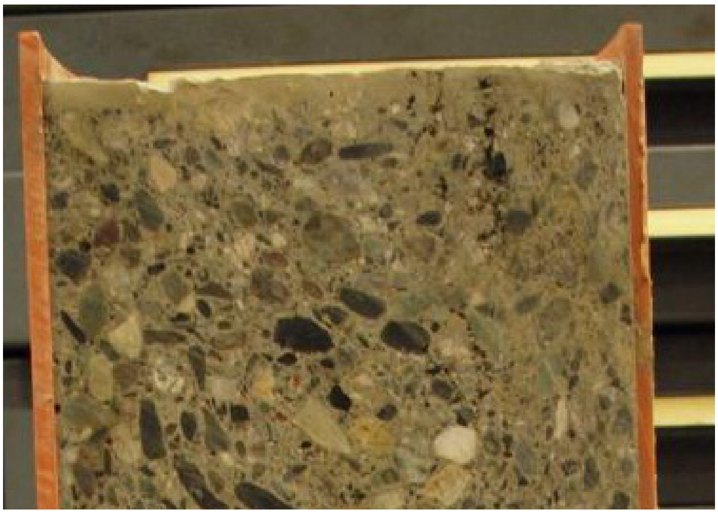

Figure 12: Part of the cross section of the hardened concrete cylinders of the chemically stabilized SCC, showing the top paste layer and bleeding channels.

3.3 Surfaces

In the report the results of the analysis of the concrete surfaces will be presented in graphs. The data is tabulated in the appendix. It should be noted that no results are shown for the bottom surface of C-u, as the pictures could not be processed by the software. In addition, the flash did not go off when taking the pictures of the middle surface of C-t, giving rise to erroneous results for this surface. These results are however included in the report to demonstrate the impact of variations in lighting on the results.

3.3.1 Greyscale

The greyscale of the different tested areas of the concrete surfaces are shown in Figure 13, where 0 stands for black and 1 for white. A standard deviation was included in the graph as the greyscale was analysed twice, once on the first picture taken and once on the last picture (see Figure 10).

It can be concluded that all surfaces had a similar grey level (0.5-0.6) independent of the type of SCC used or whether or not formwork agent was applied. There are also no great differences between the top, middle and bottom part of each surface. The middle C-t surface is rated brighter than the other surfaces due to a problem with the lighting.

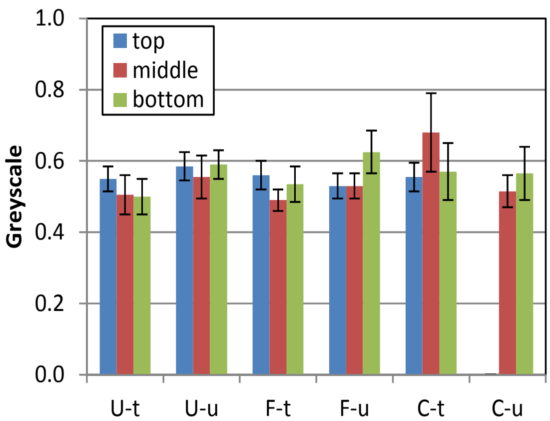

Figure 13: The grey tone of the top, middle and bottom part (indicated with colours) of both the side of the wall which was treated with formwork agent (t) and the untreated side (u) of the walls cast with unstable (U), filler stabilized (F) and chemically stabilized (C) SCC, with 0 for black and 1 for white.

3.3.2 Pores

The procedure used to photograph the surfaces has been developed to analyse the greyscale of the surfaces, but not the pores. Even though the procedure is not specially adapted for analysing the pores, the results obtained by processing these pictures can give a fair indication about the pores present at the surface (see Figure 14).

From Figure 15 and Figure 16 it can be seen that the top part of the concrete walls contains the least pores. The area and the amount of pores are higher for the middle part of the wall, but appear to be the highest for the bottom part of the walls. This might be due to the fact that it is more difficult for air bubbles or water pockets in the lower part of the wall to travel to the free surface, and that due to the pressure of the overlaying concrete smaller but more pores are formed in the lower part of the surface.

There are no clear trends as to how the SCC type or the use of formwork agent affect the amount of pores on the different surfaces tested. Formwork agent appears to reduce the amount of pores for the stabilized SCC's, but tends to increase it for the unstable SCC. There is also a slight trend which indicates that the unstable SCC has the least pore area, followed by the filler stabilized. The largest pore area was found for the chemical stabilized SCC (Figure 15). However, Figure 16 shows that the filler stabilized surfaces have a higher amount of pores in the bottom part than the chemically stabilized one, indicating that filler stabilization gives rise to more fine pores whereas chemical stabilization gave rise to fewer but larger pores.

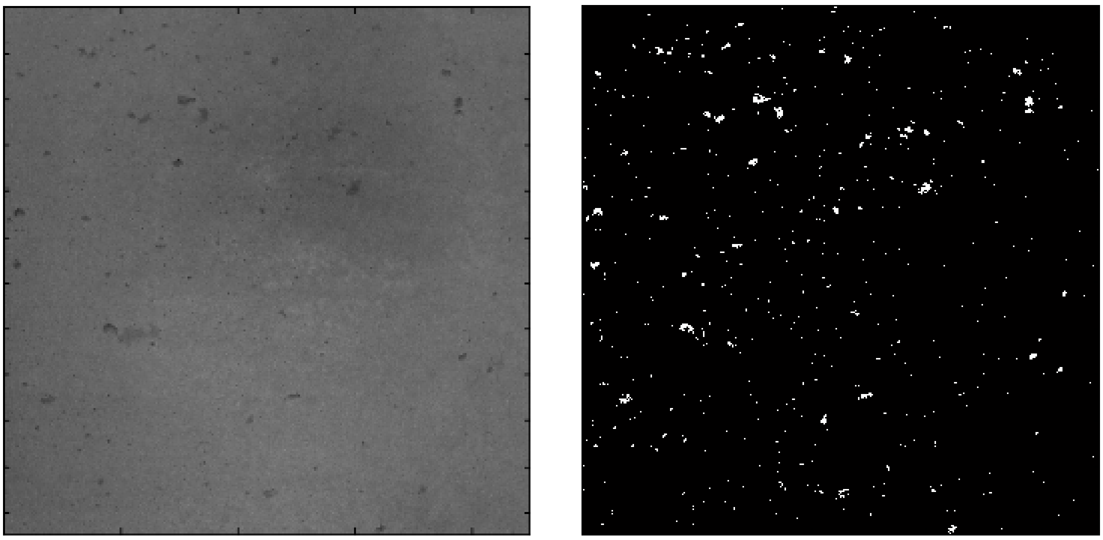

Figure 14: Left: a picture of the concrete surface. Right: the pores selected by the BetongGUI software.

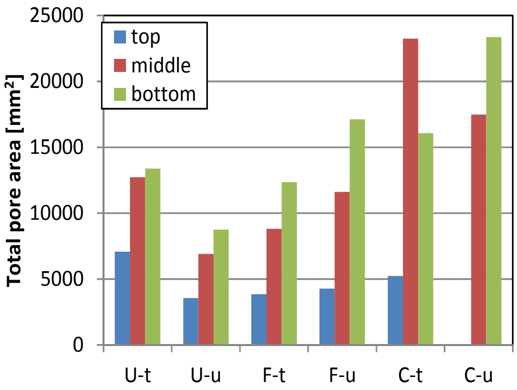

Figure 15: The total pore area of the tested zones.

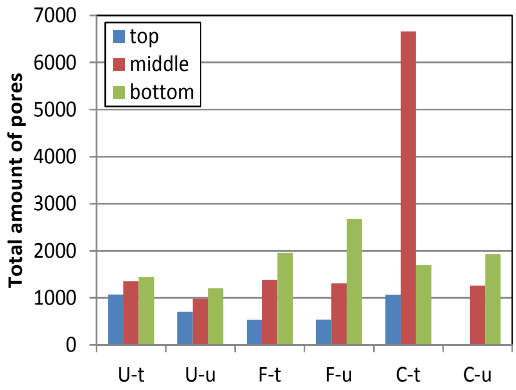

Figure 16: The total amount of pores of the tested zones.

Figure 17shows the amount of pores in the different pore categories given in Table 8. Note that the y-axis has a logarithmic scale.

It can be seen that for each of the categories that most of the pores are located in the bottom part of the concrete wall surfaces, a bit less in the middle and the least in the top part of the surface, with the exception of the unstable SCC in the 20-78.9 mm^2 category where most of the pores are found in the middle. This is in agreement with the total pore area measurements and total amount of pores shown in respectively Figure 15 and Figure 16.

For all tested surfaces the greatest amount of pores can be found in the category of the smallest pores, 1-19.9 mm^2. The amount of pores in this category varies between 501 and 2539, not taking into account the erroneous values of the C-t middle. The highest amount of fine pores was found in the bottom part of the wall casted with filler stabilized SCC, whereas the surface of the unstable SCC cast against untreated formwork showed in general the least fine pores.

In the category 20-78.9 mm^2, the bottom part of the filler or chemical stabilized SCC against untreated formwork resulted in the highest amount of pores, respectively 117 and 126. The unstable SCC against untreated formwork appears to perform the best regarding this pore category, with 41 pores in the middle. The amount of pores in this category for the other tested concrete surfaces lay in between these values.

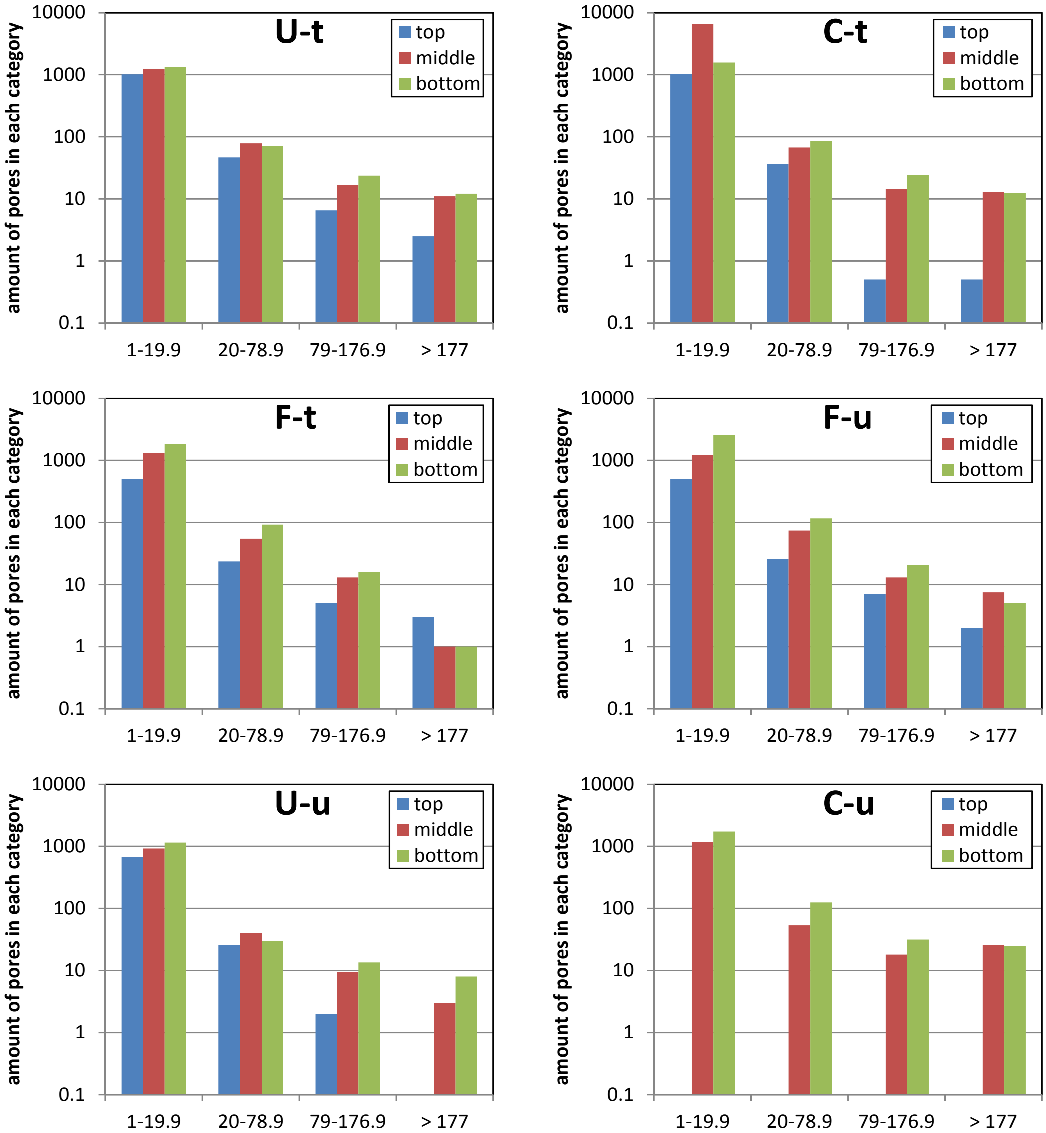

Figure 17: The amount of pores in each category given in mm^2 (see Table 8) of the top, middle and bottom part of treated (t) and untreated (u) concrete surfaces of the walls cast with unstable (U), filler stabilized (F) and chemically stabilized (C) SCC.

When observing the larger pore categories 79-176.9 mm^2 and >177 mm^2, the chemical stabilization of the SCC seems to result in a high amount of larger pores in the bottom part of concrete wall surface, up to respectively 32 and 26 for the two classes, but there were hardly any pores observed at the top section. The larger pores appeared to be shallow, indicating that they are caused by bleeding, in contrast to pores resulting from air voids which are generally deeper. The higher amount of large, shallow bleeding pores for the surfaces of the walls poured with chemically stabilized SCC is in line with the stability observations which indicated enhanced bleeding in the chemically stabilized SCC (see Figure 12).
It should be noted that pores in the category >177 mm^2 (ϕ 15mm) are more considered to be a casting error than a pore. The filler stabilized SCC's and the unstable SCC against untreated formwork had relatively few of these large pores.

It is not possible to come to clear conclusions as to how the SCC type or the surface treatment affects the amount of pores. However, there is an indication that the chemical stabilizers can lead to large bleeding pores in the lower part of the surface of the concrete wall, whereas filler stabilization can gives rise to the formation of very fine pores in the bottom part.

It should also be noted that in this study the same formwork was used for all surfaces. The type of formwork plays however a very important role of the quality of the final concrete surface. On the back and the front surface of the wall elements (0.7 m × 2.5 m) new formwork elements with new plastic covered plywood delivered by DOKA were used. However, on the sides of the wall elements (0.2 m × 2.5 m) plywood of the wood workshop was used. On the side surfaces hardly any large pores were observed. This might be due to the fact that most of the larger pores were caused by bleeding and that the plywood from the workshop was more permeable than the plywood from the new formwork. Another factor which might play a role regarding the formation of pores, is the difference in concrete flow in the vicinity of the shorter side surfaces compared to the larger front and back surface as the concrete is pumped in the middle of the formwork.

4 Conclusion

Three full scale wall elements were cast with three different concretes: an unstable SCC, one stabilized by adding filler, and one stabilized by adding chemical stabilizer. The aim of this study was to investigate the effect of the stabilization on the rheology of the SCC and on the final surface quality. One side of each wall element was treated with formwork agent.

All delivered SCC's were rather stone rich and unstable, even the stabilized ones. This was most likely caused by a accidental change in the fines and water content of the sand for which the concrete recipe was not corrected. Even though the SCC's not were as expected certain conclusions can be drawn.

The slump flow of the three tested SCC's was within the targeted range 675±25 mm. All three mixes had a low T500 and apparent viscosity, even for the filler stabilized one which would be expected to have a higher viscosity. The BML measured a relatively high yield stress on all three SCC's this might be caused by the segregation of stones in the bottom of the rheometer.

The fact that the stability of all three concretes was questionable was confirmed by the sieve segregation test. However, the visual segregation index determined on the flow board rated all concretes as acceptable stable. The stability was also assessed by examining the cut surface of hardened cylinders. It could be seen that the course aggregates are well distributed over the height of the cylinder for all tested concretes. However, the chemically stabilized concrete showed clear signs of bleeding. This indicates that for the high w/c ratio used in this experiment, the chemical stabilizer might provoke bleeding.
Regarding the surface quality of the wall elements, it can be concluded that all surfaces had a similar grey level (0.5-0.6) independent of the type of SCC used or whether or not formwork agent was applied. There are also no great differences between the top, middle and bottom part of each surface.

It is not possible to come to clear conclusions as to how the SCC type or the surface treatment affects the amount of pores. However, there is an indication that the chemical stabilizers can lead to large bleeding pores in the lower part of the surface of the concrete wall, whereas filler stabilization can gives rise to the formation of very fine pores in the bottom part.

The fact that all SCC's were on the verge of instability, did not allow for clear rheological differences nor clear differences in final surface quality.

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A Appendices

A.1 Sieve curves of the different aggregates used

Sieve [mm]	Søberg 0/8	Kneppet 0/8	Ramlo 0/8	Ramlo 8/16
16	-	-	-	4
11.2	-	-	-	54.5
8	0.4	0.4	0.9	98.0
5,6	6.6	-	-	99.0
4	16.7	11.1	13.5	100
2	36.7	27.9	29.0	100
1	57.7	45.6	44.4	100
0.5	73.2	64.7	61.7	100
0.25	84.8	82.0	79.4	100
0.125	91	92.1	91.2	100
0.063	95	96.9	97	100

A.2 Pictures of the concrete surfaces

<table>
<tr><th>Unstable SCC - treated formwork</th><th>Unstable SCC - untreated formwork</th></tr>
<tr><td>Bottom

</td><td>Bottom
</td></tr>
<tr><td>Middle

</td><td>Middle

</td></tr>
<tr><td>Top
</td><td>Top

</td></tr>
</table>

Chemically stabilized SCC - treated formwork	**Chemically stabilized SCC – untreated formwork**
Bottom 	Bottom 
Middle 	Middle 
Top 	Top 

Filler stabilized SCC – treated formwork	**Filler stabilized SCC – untreated formwork**
Bottom 	Bottom 
Middle 	Middle 
Top 	Top 

A.3 Result of the image analysis of the concrete surfaces

	Greyscale (0 black -1 white)					
	average			standard deviation		
	top	middle	bottom	top	middle	bottom
U-t	0.55	0.51	0.50	0.04	0.06	0.05
U-u	0.59	0.56	0.59	0.04	0.06	0.04
F-t	0.56	0.49	0.54	0.04	0.03	0.05
F-u	0.53	0.53	0.63	0.04	0.04	0.06
C-t	0.56	0.68	0.57	0.04	0.11	0.08
C-u	0.00	0.52	0.57	0.00	0.05	0.08

	Total pore area [mm^2]			Total amount of pores		
	top	middle	bottom	top	middle	bottom
U-t	7071	12724	13389	1071	1354	1442
U-u	3560	6902	8740	707	976	1201
F-t	3864	8818	12349	533	1384	1955
F-u	4270	11612	17107	537	1311	2681
C-t	5236	23244	16079	1069	6662	1694
C-u	0	17483	23368	0	1264	1929

		Amount of pores in each category [mm^2]			
wall side	zone	1-19.9	20-78.9	79-176.9	> 177
U-t	top	1015	47	7	3
	middle	1248	79	17	11
	bottom	1336	70	24	12
U-u	top	679	26	2	0
	middle	923	41	10	3
	bottom	1150	30	14	8
F-t	top	501	24	5	3
	middle	1316	55	13	1
	bottom	1845	93	16	1
F-u	top	502	26	7	2
	middle	1218	75	13	8
	bottom	2539	117	21	5
C-t	top	1031	37	1	1
	middle	6568	67	15	13
	bottom	1573	85	24	13
C-u	top	0	0	0	0
	middle	1166	54	18	26
	bottom	1747	126	32	25

SINTEF Building and Infrastructure is the third largest building research institute in Europe. Our objective is to promote environmentally friendly, cost-effective products and solutions within the built environment. SINTEF Building and Infrastructure is Norway's leading provider of research-based knowledge to the construction sector. Through our activity in research and development, we have established a unique platform for disseminating knowledge throughout a large part of the construction industry.

COIN – Concrete Innovation Center is a Center for Research based Innovation (CRI) initiated by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and constructions. The primary goal is to fulfill this vision by bringing the development a major leap forward by long-term research in close alliances with the industry regarding advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.