Self Compacting Concrete with Chalk Filler.

Eigil V. Sørensen
Ph.D., Associate Professor
Department of Civil Engineering, Aalborg University, Denmark
E-mail: evs@civil.aau.dk

ABSTRACT

Utilisation of Danish chalk filler has been investigated as a means to produce self compacting concrete (SCC) at lower strength levels for service in non aggressive environments. Stable SCC mixtures were prepared at chalk filler contents up to 60% by volume of binder to yield compressive strengths at 28 days from about 35 MPa down to about 13 MPa. The cementing efficiency factor of the chalk filler was found to be in the range 0.21 - 0.42. The chalk filler performed equally well with a grey and a white cement; the latter opens the possibility to produce white SCC more cost effectively.

Key words: Self compacting concrete, chalk filler, slump flow, viscosity, compressive strength, cementing efficiency factor

1. INTRODUCTION

Self compacting concrete (SCC) is characterized by being able to completely fill the form and encase the reinforcement without any need of vibration. In order to attain this flow behaviour the concrete requires a high content of paste phase. Moreover, the water to binder ratio has to be kept at a relatively low level to secure that the cohesion of the paste phase is sufficient to avoid segregation of the coarser particles in the concrete. As a consequence SCC has a high binder requirement compared to traditional concrete, and if that was to be covered solely by cement, the shrinkage, heat development and cost of the concrete would become excessive. Therefore it is customary in SCC to use pozzolanic materials or less reactive fillers, such as pulverised fuel ash (fly ash), ground granulated blastfurnace slag, limestone, chalk filler, etc. Up to now fly ash has been the most commonly used mineral additive in Danish SCC.

When SCC is designed to show good stability in the fresh state using current constituent materials it appears to be difficult in practice to reach 28 day compressive strengths below about 20 MPa. Since a very large part of the Danish ready mixed concrete market is in the lower strength classes, e.g. 12 – 16 MPa for building foundations, there is a great interest in being able to produce cost effective low strength SCC.

Limestone filler has been used for many years in the production of SCC in some countries, and chalk filler has been investigated with good results [2]. Chalk filler is being produced in large quantities in Denmark and used for various purposes in agriculture and industry, but so far it has not been used in concrete production. Being readily available at reasonable cost chalk filler is interesting to study for utilization in SCC. Also, some of the problems of other fillers in terms of quality variations affecting e.g. the admixture requirement might be overcome, and, finally, due to its colour chalk filler can be used for production of white concrete.

Based on a recent study [1] the present paper describes the use of chalk filler in Danish SCC, with particular emphasis on low strength SCC, and discusses the cementing efficiency of the chalk filler.

2. EXPERIMENTAL

2.1 Materials

The cements used were a Danish rapid hardening portland cement [CEM I 52,5 N (MS/LA/≤2), computed compound composition (Bogue): C_3S = 53 %, C_2S = 19 %, C_3A = 8 %, C_4AF = 12 %] and a Danish white portland cement [CEM I/52,5 N (HS/EA/≤2), computed compound composition (Bogue): C_3S = 69 %, C_2S = 20 %, C_3A = 5 %, C_4AF = 1 %]. The particle size distributions of the two cements are shown in Figure 1.

The chalk filler was a Danish ground chalk product with a $CaCO_3$ content of about 96 % and a mean particle size of about 3 µm. The particle size distribution is shown in Figure 1.

A vinsol resin and tenside based air entraining admixture and a polycarboxylic ether based superplasticizing admixture were used. The sand was from an inland deposit, and the coarse aggregate was 4-8 mm and 8-16 mm sea dredged gravel. The particle size distributions are shown in Figure 1.

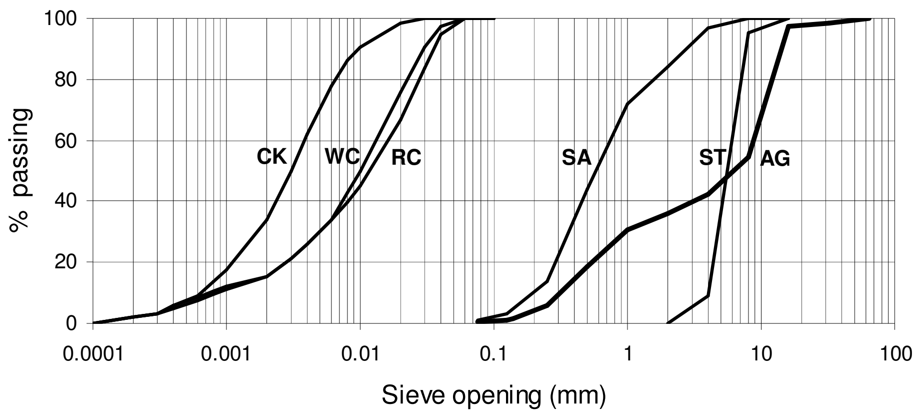

Figure 1 – Particle size distributions.(CK: Chalk filler; WC: White cement; RC: Rapid hardening cement; SA: Sand; ST: Stone; AG: Combined aggregate)

2.2 Mix design

Using a computer programme [3] to optimize the particle packing it was found that the three aggregate fractions could be combined to yield a maximum concentration of solids of about 82 % by volume. Using a slightly different combination, however, reduced the dosage sensitivity and resulted in a particle size distribution which had proven successful for SCC in general [4] while the packing efficiency was virtually unchanged. The packing efficiency of chalk filler and cement was found to be insensitive to the mutual amounts of the two components.

The mix design was based on the principle of surplus paste volume, i.e. in addition to filling the void volume between the particles at their densest packing a certain amount of extra paste is added to separate the particles and provide proper flowability of the mixture [3].

Although the type of concrete developed in this project is intended for use in a non-aggressive environment with no risk of frost attack an air content of 6 % was aimed at. The reason for this is that the air bubbles have a favourable influence on the rheology of the fresh concrete, and on the cost of the concrete.

2.3 Properties of the freshly mixed SCC

Initially the effect of various sources of chalk filler on the rheology of the SCC was studied, using an SCC mix design with a target 28 day strength of about 35 MPa in order to better being able to compare with known SCC. A relatively high content of chalk filler was chosen, corresponding to a cement/chalk ratio of 60/40 by volume, and a water/binder ratio of 0.4 by weight. The best one of the available chalk types was then selected based on minimisation of paste content and superplasticizer dosage to yield a target slump flow of 600 mm. At the same time the dosage of air entraining admixture was determined for a target air content of 6 %.

The slump flow was measured using the standard slump cone (traditionally positioned). When it had been filled with concrete the cone was removed at a prescribed (high) speed, and the slump flow was measured as the average of the maximum spread diameter and the spread diameter perpendicular to that. The time it took the SCC to reach a diameter of 500 mm was subsequently evaluated from a video recording of the test. This time was taken as an indicator of the plastic viscosity of the mix.

In order to investigate how the slump spread depends on the dosage of superplasticizing admixture a series of cement+chalk filler pastes were prepared at varying dosage of superplasticizer. Using a small cone (upper and lower diameter 40 and 90 mm, respectively, and height 75 mm) the spread of the paste was measured.

2.4 Compressive strength

The specimens used to measure the compressive strength were 200 mm high cylinders with a diameter of 100 mm. The specimens were cured 1 day in mould at 20°C, then demoulded and stored in water at 38°C until they were tested. The real time (age) at testing was converted to maturity, i.e. equivalent curing time at 20°C, using a maturity transformation function by which the rate of curing at 38°C is 2.2 times the rate at 20°C [5]. The elevated curing temperature was chosen in order to save time, and it was kept at the moderate level of 38°C to minimise variation of the microstructure compared to that obtained by room temperature curing.

Subsequent to the testing all compressive strength results were adjusted to correspond to an air content of 6 %, by changing the measured value by 4 percent for each percent change of the air content [10]. In most cases compressive strength was determined as the average of the results of three specimens.

3. RESULTS AND DISCUSSION

3.2 Mix design and rheological properties

The first series of mix compositions of grey SCC with varying paste contents and water/binder ratio (W/B) 0.4 are shown in Table 1 as mixtures G1, G2, and G3. These mixes were originally intended to contain 34, 35, and 36 vol.% paste+air to provide a basis for choosing the adequate amount of surplus paste for a stable and suitably workable mix. As can be seen, however, no clear relationship was found between the paste volume and the two parameters characterizing the rheology - the final slump flow and the time to reach 500 mm slump flow. The same was true for the white SCC as can be seen from Table 1, mixtures W1, W2, and W3. For the subsequent mixtures a paste+air volume of 35 % was chosen as the target together with a slump flow of 600 mm and an air content of 6 %.

Table 1 – Mix composition, fresh concrete properties, compressive strength, and cementing efficiency factor

Mix designation		G1	G2	G3	G4	G5	G6	W1	W2	W3	W4	W5	W6	W7
Cement/Chalk ratio	[vol./vol.]	60/40	60/40	60/40	60/40	50/50	40/60	50/50	50/50	50/50	60/40	40/60	50/50	50/50
Water/Binder ratio	[wt./wt.]	0,41	0,41	0,41	0,51	0,51	0,51	0,48	0,48	0,49	0,48	0,48	0,41	0,56
Cement (grey)	[kg/m^3]	236	252	262	224	185	148							
Cement (white)	[kg/m^3]							189	188	196	234	155	211	179
Chalk powder	[kg/m^3]	135	144	151	126	158	190	162	161	168	134	199	181	153
Water	[kg/m^3]	152	163	170	178	175	172	169	169	179	178	171	161	185
Aggregate	[kg/m^3]	1700	1731	1720	1730	1705	1689	1774	1679	1686	1758	1712	1719	1740
Superplasticizer/binder ratio	[wt.%]	1,4	1,4	1,4	1,1	0,9	0,9	1,1	0,8	1,8	0,8	1	1,1	0,7
Air content	[vol.%]	6,8	3,5	2,6	3,6	5,0	5,9	2,6	6,5	4,6	2,0	4,6	4,2	3,0
Volume of paste+air	[m^3/m^3]	0,345	0,333	0,337	0,334	0,343	0,349	0,317	0,353	0,351	0,323	0,341	0,338	0,330
Slump flow	[mm]	550	610	633	565	620	550	625	560	560	635	550	625	560
Time to 500 mm slump flow	[s]	1,5	1,2	0,9	0,5	0,3	0,8	1,2	1,0	1,1	0,6	0,7	0,9	0,8
28 day compressive strength (corresponding to 6% air)	[MPa]	36,2	36,6	33,8	25,7	17,7	13,1	25,1	22,8	22,6	27,9	16,6	32,5	16,8
Cementing efficiency factor of chalk filler	[-]	0,40	0,42	0,31	0,39	0,22	0,21	0,40	0,34	0,35	0,35	0,30	0,35	0,36

In order to evaluate the sensitivity of the mixes it was investigated how the slump flow was affected by a small change in superplasticizer dosage. Figure 2 shows the results from measurements of the paste flow as a function of superplasticizer dosage for a grey mixture at W/B = 0.41 together with three grey mixtures at W/B = 0.51. As can be seen the flow of the mixes initially increased sharply with superplasticizer dosage, but at 1.4 % as used in the low W/B mixes the flow was virtually independent of the dosage. Similarly, for the high W/B mixtures the slump flow only increased insignificantly beyond about 0.8 % superplasticizer, showing that the dosage of 0.9 – 1.1 % by weight of binder used for those mixtures was sufficient to secure proper dispersion of the solid particles in the mix, and that the mix would not be too sensitive to small variations in the superplasticizer dosage. Also, at smaller superplasticizer dosages the slump flow is seen to decrease with increasing chalk proportion of the binder which can be explained by the smaller size and higher specific surface area of the chalk particles as compared to cement, cf. Figure 1. Similar results were obtained with white cement, where stable SCC however could be prepared at slightly higher water/binder ratios.

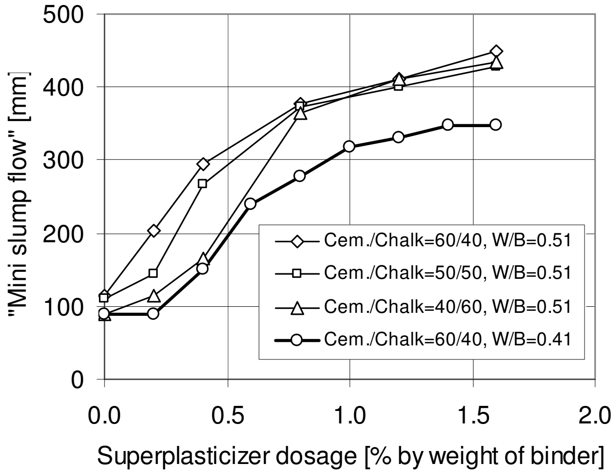

Figure 2 – Paste flow vs. superplasticizer dosage (grey cement)

The 28 day compressive strength of the grey SCC mixes G1, G2, and G3 was about 35 MPa. The next step was to reduce the compressive strength to 12 – 16 MPa. First, the 60/40 cement/chalk ratio was kept unchanged and the water/binder ratio was increased successively until W/B = 0.55 when the mix became unstable and segregation occurred. With a W/B of 0.51 stable SCCs were then prepared at cement/chalk ratios of 50/50 and 40/60 by volume. Further reduction of the cement fraction resulted in segregation. These lower strength mixes are shown as G4, G5, and G6 in Table 1. Increasing the chalk content from the original cement/chalk ratio of 60/40 to 40/60 reduced the 28 day compressive strength from about 26 to 13 MPa (Figure 3) which was the targeted compressive strength range.

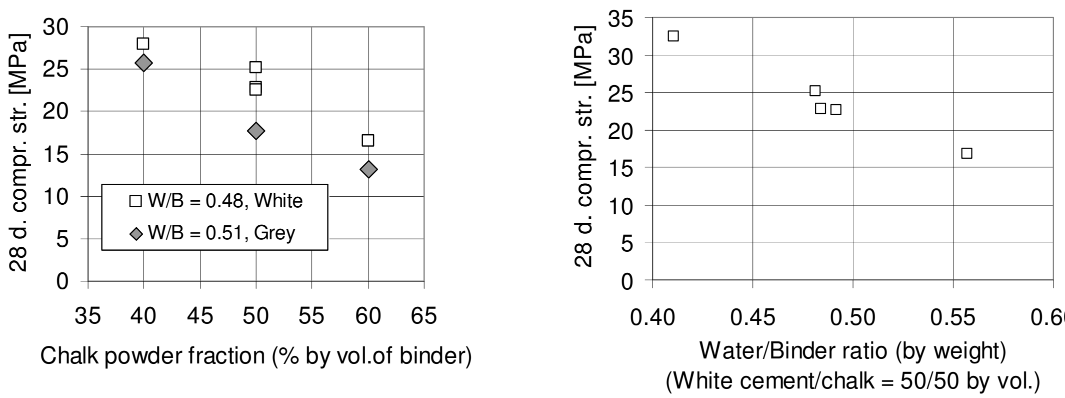

Figure 3 – Compressive strength vs. chalk filler content (left) and water/binder ratio (right)

The compressive strength of SCC with white cement was found to be of the same magnitude as with the grey cement. In Figure 3 the compressive strength is shown both as a function of chalk filler content and as a function of water/binder ratio. Obviously, increasing the chalk filler fraction of the binder and increasing the water/binder ratio both will have the effect of reducing the strength, as illustrated by e.g. mixes W5 and W7. However, other properties may develop differently. For example, a study of limestone filler [9] showed that increasing the W/B produced a coarser pore structure, and thereby a higher permeability, than did an increased limestone filler fraction.

The compressive strength development of three grey mixes G4, G5, and G6 with different contents of chalk filler is shown in Figure 4, demonstrating that the strength development pattern is similar to that known from traditional concrete.

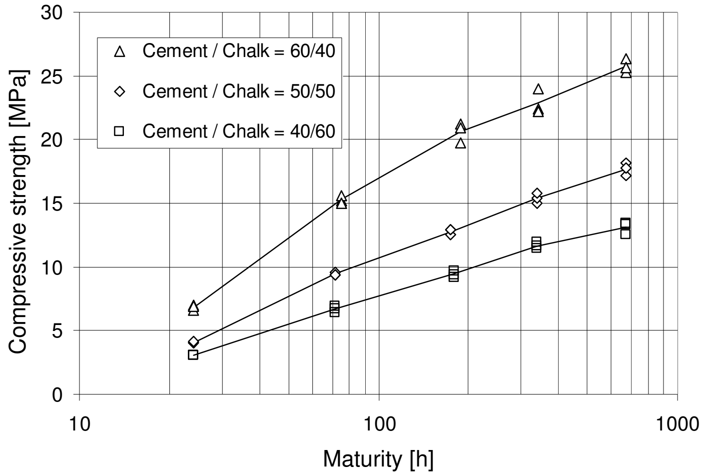

Figure 4 – Compressive strength development (grey SCC, W/B=0.51)

3.3 Cementing efficiency factor

The cementing efficiency factor of the chalk filler with regard to the 28 day compressive strength is defined as the mass of cement that can be substituted by 1 unit mass of chalk filler while the compressive strength remains unchanged.

To evaluate the cementing efficiency factor a range of plain concrete mixes without chalk filler (slump from 40 to 80 mm) were prepared at water/cement ratios ranging from 0.56 to 1.05, and thereby 28 day compressive strengths from about 10 to 34 MPa, to establish the relationship between water/cement ratio and strength of traditional concrete with the actual constituent materials used. The results are shown in Figure 5 where the 28 day compressive strength (of each individual cylinder, adjusted to 6 % air content) is plotted against the reciprocal water/cement ratio which yields a straight line relationship [10].

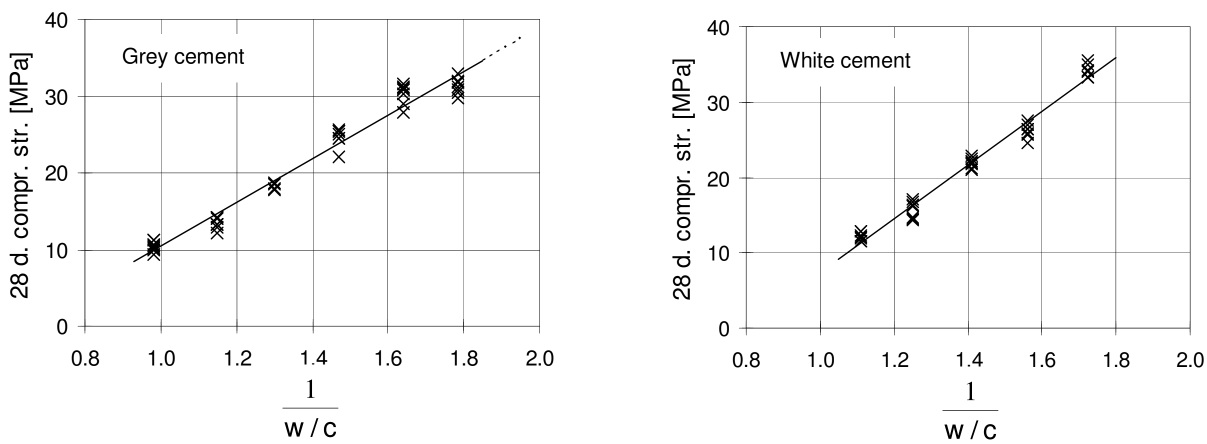

Figure 5 – 28 day compressive strength vs. reciprocal water/cement ratio of plain concrete with grey cement (left) and white cement (right)

The cementing efficiency factor of the chalk filler was then determined by means of the equivalent water/cement ratio as follows:

$$W / C_{equivalent} = \frac{W}{C + k \cdot CP} \quad (1)$$

where W = water content (kg/m^3)
C = cement content (kg/m^3)
CP = chalk filler content (kg/m^3)
k = cementing efficiency factor

At a given measured compressive strength of an SCC with chalk filler the equivalent water/cement ratio according to (1) is equal to the water/cement ratio of traditional concrete of the same strength which is found from the relationship mentioned above, and the cementing efficiency factor can then be calculated.

The results are shown in Table 1. The cementing efficiency factor of the chalk filler was found to be in the range 0.2-0.4 with a tendency towards decreasing values at increasing chalk filler content as seen in Figure 6. Due to the experimental scatter of the results it is difficult to determine if there is any difference in the cementing efficiency factor due to the type of cement. The results shown in the right hand diagram of Figure 6 suggest that there is no pronounced influence of the water/binder ratio in the range 0.41 – 0.56.

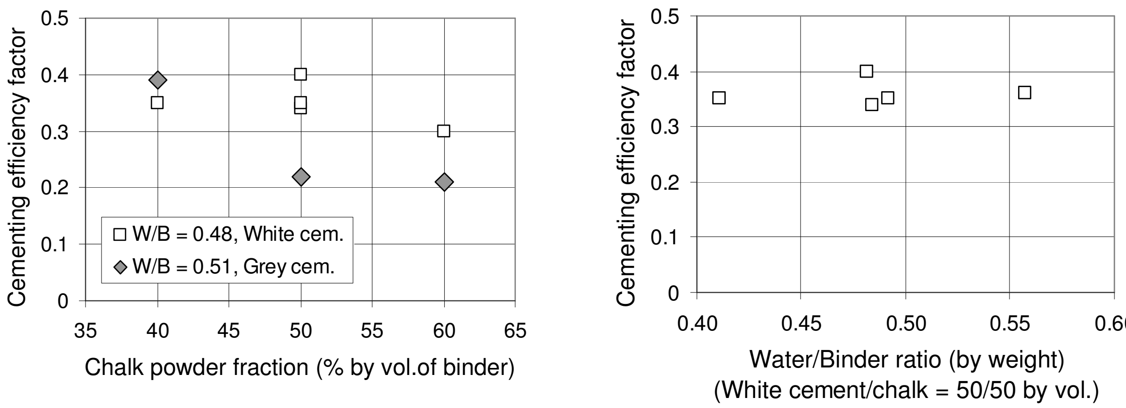

Figure 6 – Cementing efficiency factor vs. chalk filler content (left) and water/binder ratio (right)

There seems to be only few results published on SCC with chalk filler at the present time. A review paper [6] reports a cementing efficiency factor of 0.23 as the average of 6 published results. However, other data reported on compressive strength of SCC with chalk filler [2] allows further analysis to be made using the above method, whereby it was found that the cementing efficiency factor was in the range 0.10-0.35 at a water/binder ratio of 0.31, increasing with the cement/chalk ratio from 42/58 to 52/48 by volume. This is in good agreement with the results obtained in the present study.

The cementing action of the chalk filler – like limestone filler - is believed to predominantly derive from the “fine filler effect”, i.e. the fine chalk particles acting as nucleation sites for hydration products, thereby accelerating the cement hydration [6] and possibly refining the pore structure [9]. In addition to that, some chemical action may occur [6], although the extent of such reaction seems to be very modest or non-existing [7, 8].

It was beyond the scope of the present study to try to determine which mechanisms were responsible for the cementing value of the chalk filler. It was however noted that the two cement types used in the study did not give rise to significantly different cementing efficiency factors of the chalk filler.

4. CONCLUSIONS

Utilisation of Danish chalk filler in self compacting concrete (SCC) has been investigated as a means to produce cost effective SCC at lower strength levels for service in non aggressive environment.

Stable SCC mixtures could be prepared at relatively high contents of chalk filler – up to 60 % by volume of cement+chalk filler - to yield compressive strengths at 28 days from about 35 MPa down to about 13 MPa.

The cementing efficiency factor of the chalk filler was in the range 0.21 to 0.42 with a tendency to the lower values being found at the higher chalk filler contents. At constant binder composition the water/binder ratio did not seem to significantly influence the cementing efficiency factor.

The chalk filler seemed to work equally well with the grey and the white cement used. Due to its colour chalk filler opens the possibility to produce white SCC more cost effectively.

ACKNOWLEDGEMENT

The work carried out by Mr. Jeppe S. Johansen and Mr. Alex K. Høgh who successfully completed the project [1] underlying the present paper is gratefully acknowledged.

REFERENCES

1. Johansen, J.S., Høgh, A.K.: ”Lavstyrke SCC med kalkfiller” (Low strength SCC with chalk filler”. Master Thesis, Dept. of Civil Engineering, Aalborg University, Denmark, June 2007
2. Zhu, Wenzhong, Gibbs, J. C.: “Use of different limestone and chalk powders in self-compacting concrete”. *Cement and Concrete Research*, Vol. 35, 2005, pp. 1457-1462
3. Glavind, M., Sørensen, I., Thygesen, E.: ”Pakningsberegninger som hjælpemiddel ved betonproportionering” (Packing computations as a tool for concrete mix design) . Beton Teknik, 2/11, 1999. Aalborg Portland CtO, Aalborg, Denmark
4. Thrysøe, J., Rasmussen, T., Berrig, A., Hasholt, M.T., Pade, C.: “Selvkompakterende beton – SCC” (Self compacting conceret – SCC). Beton Teknik, 2/13, 2004. Aalborg Portland CtO, Aalborg, Denmark

5. Freiesleben Hansen, P., Pedersen, E. J.: ”Måleinstrument til kontrol af betons hærdning” (Maturity computer for controlled curing and hardening of concrete). *Nordisk Betong*, No. 1, 1977, pp. 21-25
6. Domone, P. L.: ”A review of the hardened mechanical properties of self-compacting concrete”. *Cement & Concrete Composites*, vol. 29, 2007, pp.1-12
7. Ye, G., Liu, X., De Schutter, G., Poppe, A.-M., Taerwe, L.: “Influence of limestone powder used as filler in SCC on hydration and microstructure of cement pastes”. *Cement & Concrete Composites*, vol. 29, 2007, pp.94-102
8. Bentz, D. P.: “Modeling the influence of limestone filler on cement hydration using CEMHYD3D”. *Cement & Concrete Composites*, vol. 28, 2006, pp.124-129
9. Boel, V., De Schutter, G.: “Porosity of superplasticised cement paste containing limestone filler”. *Advances in Cement research*, 2006, Vol. 18, No. 3, July, pp. 97-102
10. Herholdt, A. D., Justesen, C. F. P., Nepper-Christensen, P., Nielsen, A.: ”Beton-Bogen” (The concrete book), 2. ed., 1985. Aalborg Portland CtO, Aalborg, Denmark.