THE INFLUENCE OF FILLER CHARACTERISTICS ON THE WORKABILITY OF SELF-COMPACTING CONCRETE

Ir.-arch. G. Heirman[1] and Prof. dr. Ir. L.Vandewalle[2]

Department of Civil Engineering, Catholic University Leuven, Kasteelpark Arenberg 40, 3001 Heverlee, Belgium.
[1]Email: Gert.Heirman@bwk.kuleuven.ac.be
[2]Email: Lucie.Vandewalle@bwk.kuleuven.ac.be

1 INTRODUCTION

Self-compacting concrete (SCC) is considered more and more as the "concrete of the future". Its high workability not only improves the labour conditions and the speed of working, also the uniformity and quality of the end product is increased. To reach this high workability, the amount of coarse aggregates has to be reduced and replaced by fine material. Since cement is quite expensive and a too high amount of cement causes a strong hydration reaction, with possible problems of shrinkage cracks, fillers are added.
This paper presents the results of an investigation on the suitability of different fillers to be used for SCC. An experimental test program has been executed with 12 different SCC mixtures, each mix with another type of filler.[1] The other mix parameters (water/cement ratio, sand and aggregates) were the same for all mixes. The different mixes were investigated with respect to workability (slump-flow, V-funnel and U-test), compressive strength, shrinkage and freeze-thaw resistance. These properties were sometimes very different if only another type of filler was used.
Each filler has been characterised with different tests: water demand (β_p), Blaine, activity index, grain distribution (by means of laser diffraction) as well as the roundness, sphericality and surface structure of the grains which were observed through a scanning electron microscope (SEM).
An effort has been made to link the measured properties of the SCC with the characterising parameters of the fillers. Especially the microscopic properties play a determining role. This has to a great extent increased the understanding of the mechanisms that play, when it comes down to achieving a good workability.

2 THE EXPERIMENTAL TEST PROGRAM

2.1 Mixing

Twelve different SCC mixtures are made according to the CBR mix design method.[2]
The used materials are:

- Rounded coarse aggregates 4/14, whereby the maximal volume is determined by 50% of the maximal compacted coarse aggregate volume starting from $1m^3$.
- River sand 0/4, whereby the maximal volume is determined by 40% of the mortar volume.
- Cement: CEM III/A 42.5 N LA, commonly used cement in Belgian concrete manufactures.
- Fillers: 12 fillers, available on the Belgian market, were selected:
    - 7 limestone fillers (number 1 to 7)
    - 1 dolomite filler (number 8)
    - 2 fly ashes (number 9 and 10)
    - 2 silica fillers (number 11 and 12)

  Filler 5 is a non-ground filler; it concerns a desagglomerated, chalk filler.
- Water, whereby the water/cement ratio is kept constant (W/C = 0.5).
- Superplasticizer: a high range water reducing, polycarboxylate-based (3rd generation) superplasticizer with 20% dry material.

All concrete mixtures were firstly made with:

- a constant water/cement ratio = 0.5
- a constant cement content = 350 kg and therefore, together with a constant water/cement ratio,
- a constant water content =175 l. The small variations are the result of the 80% water content of the superplasticizer, which is adjusted for each mixture.
- a constant volume filler/cement ratio = 0.9.

Secondly, all mixtures that could not be defined as SCC (according to slump flow, V-funnel and U-flow) were adapted by adapting the κ_p-correction to the water content (Table 1), as used by Prof. Okamura in the Japanese Mix Design Method.[2] Since the water/cement ratio and the mortar volume were kept constant, adapting the water content has an influence on the filler and cement content as well. It was not possible to obtain a self-compacting concrete with a water/cement ratio = 0.5 for filler 9.

2.2 Characterisation of the fillers

2.2.1 Water demand (β_p).[2] β_p is the volume water/powder ratio whereby all the water is "kept" by the powder. The measurements of spread are converted to relative flow area.

$$\Gamma_p = \frac{\text{final area - initial area}}{\text{initial area}} \quad (1)$$

To determine the β_p-value, at least 4 mortar mixes with a different water/powder-ratio and a r^2 of at least 0.99 must be made (Figure 1). The theoretical water/powder ratio according to a $\Gamma_p = 0$ is by definition the β_p-value.

Table 1 *Mix proportions*

concrete		1 (175)	2 (175)	3 (175)	4 (175)kp1	5 (175)	6 (175)kp1	7 (175)kp1	8 (175)kp1	10 (175)kp1	11 (175)kp1	12 (175)kp1	REF.
coarse aggr. 4/14	[kg/m³]	875	875	875	875	875	875	875	875	875	875	875	1046
fine aggr. 0/4	[kg/m³]	696	696	696	696	696	696	696	696	696	696	696	829
filler 1	[kg/m³]	275	-	-	-	-	-	-	-	-	-	-	-
filler 2	[kg/m³]	-	271	-	-	-	-	-	-	-	-	-	-
filler 3	[kg/m³]	-	-	276	-	-	-	-	-	-	-	-	-
filler 4	[kg/m³]	-	-	-	222	-	-	-	-	-	-	-	-
filler 5	[kg/m³]	-	-	-	-	278	-	-	-	-	-	-	-
filler 6	[kg/m³]	-	-	-	-	-	236	-	-	-	-	-	-
filler 7	[kg/m³]	-	-	-	-	-	-	228	-	-	-	-	-
filler 8	[kg/m³]	-	-	-	-	-	-	-	228	-	-	-	-
filler 10	[kg/m³]	-	-	-	-	-	-	-	-	168	-	-	-
filler 11	[kg/m³]	-	-	-	-	-	-	-	-	-	196	-	-
filler 12	[kg/m³]	-	-	-	-	-	-	-	-	-	-	208	-
cement	[kg/m³]	350	350	350	374	350	368	372	376	385	383	378	350
water	[kg/m³]	175.9	175.8	175.4	187.0	176.4	184.5	185.9	189.0	193.0	191.5	188.5	175.0
superplasticizer	[kg/m³]	4.7	4.6	4.1	3.9	5.3	4.3	3.8	5.0	4.7	3.9	3.4	0.0

concrete		1 (175)	2 (175)	3 (175)	4 (175)kp1	5 (175)	6 (175)kp1	7 (175)kp1	8 (175)kp1	10 (175)kp1	11 (175)kp1	12 (175)kp1	REF.
filler	[kg/m³]	275	271	276	222	278	236	228	228	168	196	208	-
cement	[kg/m³]	350	350	350	374	350	368	372	376	385	383	378	-
ρ (filler)	[kg/l]	2.69	2.65	2.70	2.70	2.72	2.71	2.71	2.84	2.30	2.63	2.63	-
ρ (cement)	[kg/l]	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	-
filler	[l/m³]	102.1	102.1	102.1	82.3	102.1	87.1	84.0	80.3	73.1	74.6	79.1	-
cement	[l/m³]	116.7	116.7	116.7	124.6	116.7	122.6	123.9	125.4	128.2	127.7	125.8	-
F/C	[-]	0.9	0.9	0.9	0.7	0.9	0.7	0.7	0.6	0.6	0.6	0.6	-

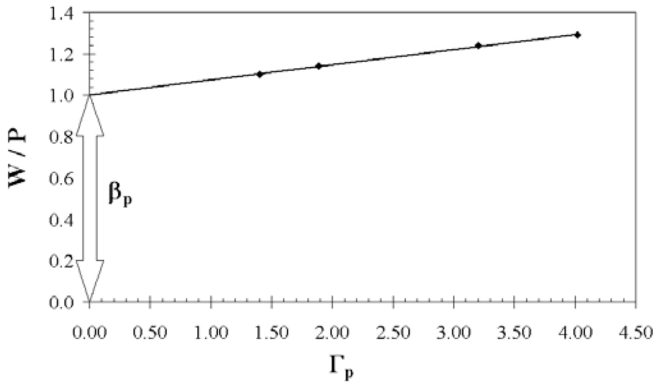


Figure 1 *Determination of the β_p-value*

2.2.2 Blaine (EN 196-6). The Blaine describes the fineness, indicated as a specific surface, of the filler by measuring the time that a specific volume of air needs to escape through a filler specimen with known dimensions and porosity. It should be noted that the obtained results only have a relative character. They can be used to compare the different fillers, but they don't give information about the absolute specific surface. For instance, possible pores in the filler grains aren't taken into account. Therefore, a Brunauer Emmet Teller (B.E.T.) test is necessary. This test measures the inert gas content that is absorbed in vacuum on the surface of the filler grains.

2.2.3 Activity index. The activity index of the filler is measured by determining the compression strength of, on the one hand, mortar based on pure cement and, on the other hand, mortar wherein 25% of the cement is replaced by the filler.
The compression strength N, according to EN 196-6, is determined on n = 1, 2 and 28 days. The corresponding activity index is defined as:

$$\text{activity index} = \frac{N_{n,\,\text{cement + filler}}}{N_{n,\,\text{cement}}} .100 \quad [\%] \tag{2}$$

2.2.4 Grain distribution. The grain distribution between 1.8 and 350 μm can be determined by means of laser diffraction. This method is based on the relation between the diameter of the grains and the diffraction of a laser beam through a filler suspension in alcohol. To make it possible to link the measured properties of the SCC with the grain distribution, only one parameter to describe the distribution is desirable. Some possibilities are:

- the filler amount y_x with a grain diameter $d \leq x$ (x = an assumed grain diameter), e.g. y_{10}, y_{50} and y_{90}.
- the maximal grain diameter d_y by a certain filler amount y, e.g. d_{10}, d_{50} and d_{80}. (d_{80} is the maximal grain diameter according to the definition of a filler).

2.2.5 Microscopic examination. The roundness, sphericality and surface structure of the filler grains were observed through a scanning electron microscope (SEM).[3] The roundness is defined as "the mean of the radii of all inscribed circles in a cross-section of the grain, divided by the radius of the greatest inscribed circle drawn in the cross-section". The calculation is mostly a difficult and time-consuming assignment. Therefore, the use of a visual scale (Figure 2) makes the assessment much easier.

Next subdivision can be made: very round, round, semi round, semi angular, angular and very angular.
The sphericality is defined as "the volume of the grain divided by the volume of the circumscribed sphere". Here also, a visual scale (Figure 2) is more recommended and a subdivision between a respectively low, average and high sphericality can be made.

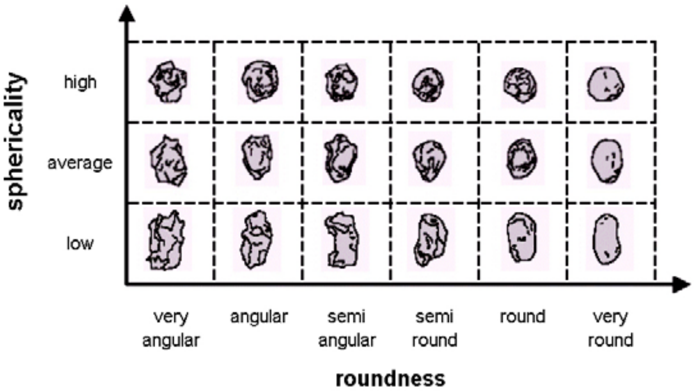


Figure 2 *A visual scale to determine the sphericality and the roundness of a grain*

2.3 Properties of fresh concrete

2.3.1 Mixing procedure. All mixes in the laboratory were prepared in 55 litre batches and mixed in a pan mixer. First, all the dry material was put in the mixer. Then mixing was started. Water was added after 15 seconds, the superplasticizer 120 seconds later. After adding the superplasticizer, the mixing continued for 55 seconds.

2.3.2 Slump flow test.[4] The slump flow test consists of the determination of the mean diameter of the concrete sample spread on a base plate after performing a slump test without any compaction. With the same test, the t_{500} slump flow time was also measured. The t_{500} is the time necessary to reach a spread of 500 mm. A slump flow of at least 630 mm and a t_{500} of 7 seconds or less are considered appropriate.

2.3.3 V-funnel test.[4] The V-funnel test consists of the determination of the time necessary for the concrete to flow out of a V-funnel with a rectangular cross-section. The top dimensions are 515 mm by 75 mm and the bottom opening is 70 mm by 75 mm. The total height is 600 mm with a 150 mm long straight section. The concrete is poured into the funnel with a gate blocking the bottom opening. The time necessary for the concrete to flow out is measured as the time taken for light to appear at the bottom of the V-funnel (when viewed from above). A flow time between 5 and 15 seconds is considered appropriate.

2.3.4 U-flow test.[4] The U-flow test consists of the determination of the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall in two compartments (with the same cross-section). An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 12 mm are installed at the gate with a clear spacing of 35 mm between the bars. The left hand section has a height of 680 mm and is completely filled with concrete. Then the gate is lifted and the filling height of the concrete in the right hand section is measured. A filling height of at least 300 mm (or 79% of the maximum height possible) is considered appropriate.

2.4 Properties of hardened concrete

2.4.1 Compressive strength (NBN B15-220). Standard cubes measuring 150 mm were demoulded one day after casting and cured at 20°C and 60% RH until testing was carried out at 1, 2, 7, 28 and 90 days.

2.4.2 Shrinkage (NBN B15-216). Cylinder specimens (∅ 113 mm x 300 mm) were demoulded one day after casting and cured at 20°C and 60% RH. Directly after demoulding, 3x2 Demec measuring points were evenly stuck on the cylinder surface. A Demec gauge with an initial length of 100 mm is used. In that way the influence of the two ends of the cylinder can be avoided. Measurements are done five and three times a day on the first, respectively second day, twice a day for the rest of the first week, once a day the second week and twice a week after one month.

2.4.3 Freeze-thaw resistance (NBN B15-231). Standard prisms measuring 100 x 100 x 500 mm^3 were demoulded one day after casting and cured at 20°C and more than 90% RH for 14 days and at 20°C and 60% RH for 28 days. Afterwards the prisms were saturated until their mass stabilized. After saturation, the prisms were subjected to 3 x 14 freezing and thawing cycles (which is more than the 1 x 14 cycles required by the NBN B15-231). After every 14 cycles, possible damage is evaluated by measuring the dynamic, longitudinal elastic modulus, according to NBN B15-230.

2.4.4 Freeze-thaw and de-icing salt resistance (T 98/0343 N). Cylinder specimens (∅ 113 mm x 100 mm) were demoulded one day after casting and cured at 20°C and 60% RH for six weeks. The preparation of the specimens included the lateral and bottom sealing (by epoxy resin) and thermal insulation. The test surface is subjected to a 3% NaCl solution and 28 freezing and thawing cycles. After 7, 14 and 28 cycles, the amount of scaled material related to the test surface is measured, using a trickle of water to catch up the material in a paper filter, which is dried at 105°C afterwards.

3 RESULTS AND DISCUSSION

3.1 Characterisation of the fillers

3.1.1 Water demand (β_p). The β_p-value for the cement used is β_{cement} = 1.0004. The β_p-value for each filler (= β_{filler}) is given in Table 2.
β_{powder} can be calculated volumetrically proportional to β_{filler} and β_{cement}. This means that the knowledge of both is sufficient to calculate β_{powder} as a function of the volumetric proportion of cement (X) and filler (Y).

Table 2 *β_{filler} and the determination of β_{powder} for the SCC mixtures*

filler	1	2	3	4	5	6	7	8	10	11	12
β_{cement}	1.0004										
β_{filler}	0.8357	0.7826	0.6845	0.7565	1.4122	0.7032	0.7367	0.7802	0.8759	0.8550	0.7944
X [%]	53	53	63	63	63	63	63	63	64	63	63
Y [%]	47	47	37	37	37	37	37	37	36	37	37
β_{powder}	0.9235	0.8987	0.8839	0.9104	1.1523	0.8908	0.9031	0.9192	0.9552	0.9468	0.9244

3.1.2 Blaine The results of the Blaine S of each filler are given in Table 3. According to the Dutch 'CUR-Aanbeveling 93'[5], a Blaine of less than 700 m^2/kg is required, since an increased risk of spalling caused by fire is seen by high strength concrete using very fine fillers.

Table 3 *Determination of the Blaine S of each filler*

filler	1	2	3	4	5	6	7	8	10	11	12
S [m^2/kg]	559	517	443	338	1115	503	294	236	388	457	268

3.1.3 Activity index The activity index of the filler is given in Table 4. The compressive strength for cement at 1d, 2d and 28 d is 7.09 N/mm², 20.07 N/mm² and 66.15 N/mm² respectively.

Table 4 *Determination of the activity index of each filler*

filler		1	2	3	4	5	6	7	8	10	11	12
N_n [N/mm²]	1d	4.54	4.47	4.66	4.74	6.71	5.31	4.11	4.39	4.53	5.03	4.29
	2d	13.03	13.18	12.97	12.74	13.78	14.22	12.43	12.48	11.92	12.67	12.05
	28d	45.75	45.28	44.31	44.18	44.3	46.74	42.41	43.52	44.72	45.12	44.34
act. index [%]	1d	64	63	66	67	95	75	58	62	64	71	61
	2d	65	66	65	63	69	71	62	62	59	63	60
	28d	69	68	67	67	67	71	64	66	68	68	67

3.1.4 Grain distribution. The weight percent passed is given in figure 3. The according grain distribution parameters are given in Table 5.

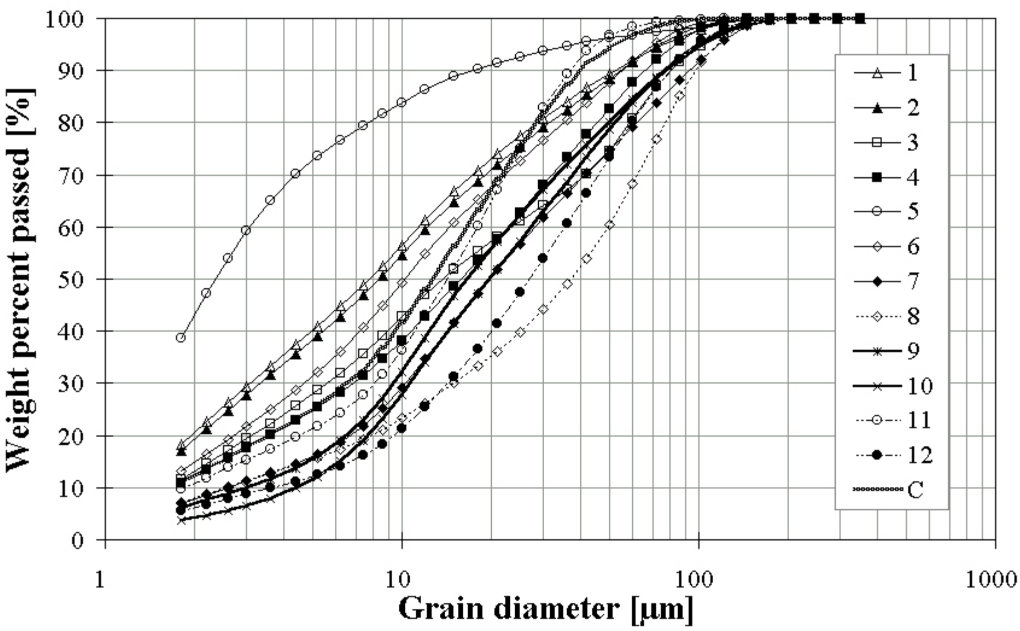


Figure 3 *Grain distribution (weight percent passed) of each filler and cement*

Table 5 *Grain distribution parameters of each filler and cement (C)*

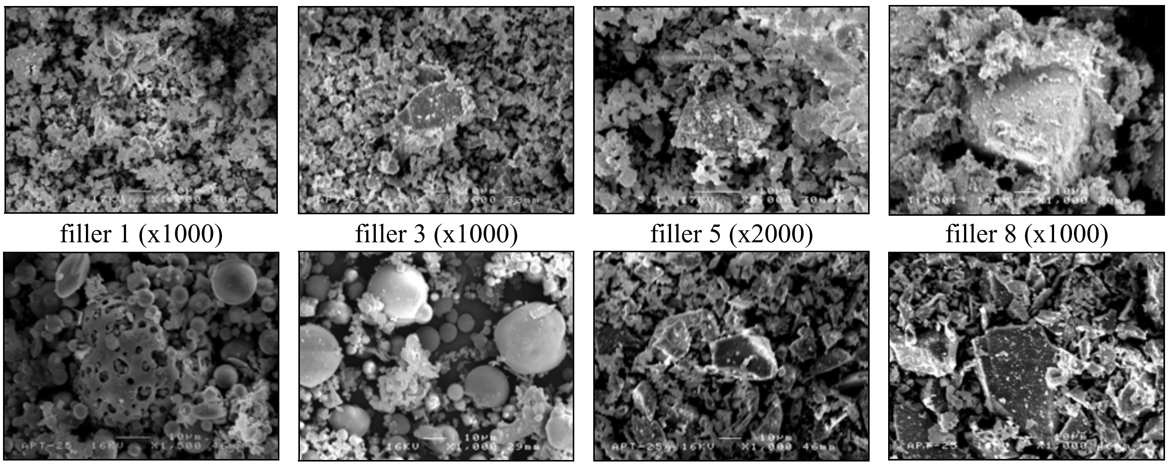
filler	1	2	3	4	5	6	7	8	9	10	11	12	C
x_{10} [%]	56.6	54.6	42.7	38.2	83.9	49.4	29.2	23.3	32.1	27.8	36.2	21.2	41.6
x_{50} [%]	89.4	88.5	74.6	82.7	96.3	87.8	74.7	60.3	80.1	78.7	96.8	73.3	94.5
x_{80} [%]	95.5	96.0	89.7	94.1	97.7	96.9	86.3	81.6	90.7	90.6	99.4	89.9	99.1
d_{10} [μm]	1.2	1.3	1.6	1.7	0.8	1.5	2.6	2.5	3.0	4.4	1.9	3.7	1.7
d_{50} [μm]	7.8	8.4	13.9	15.8	2.4	10.2	19.8	37.1	16.7	19.8	14.3	27.0	12.7
d_{90} [μm]	52.3	54.7	80.8	66.3	17.4	55.5	93.3	97.9	77.3	77.8	36.8	80.2	40.1

3.1.5 Microscopic examination The fillers can be placed in the visual scale to determine the sphericality and the roundness (Figure 2) as shown in Table 6. Figure 4 gives an idea of the roundness, sphericality and surface structure as seen through the scanning electron microscope

Table 6 *Determination of the sphericality and roundness of each filler*

filler	1	2	3	4	5	6	7	8	9	10	11	12
sphericality	low	av.	av.	av.	high	av.	low	low	high	high	low	low
roundness	semi ang.	semi ang.	semi round	ang.	round	semi round	ang.	ang.	very round	very round	very ang.	very ang.

(av. = average; ang. = angular)



filler 1 (x1000) filler 3 (x1000) filler 5 (x2000) filler 8 (x1000)
filler 9 (x1500) filler 10 (x1000) filler 11 (x1000) filler 12 (x1000)

Figure 4 *Microscopic shots, using the SEM*

3.2 Properties of fresh concrete

3.2.1 Slump flow test. The mean diameter of the concrete and the t_{500} slump flow time are given in Table 7.

Table 7 *Slump flow (SF) and t_{500}*

concrete	1 (175)	2 (175)	3 (175)	4 (175) kp1	5 (175)	6 (175) kp1	7 (175) kp1	8 (175) kp1	10 (175) kp1	11 (175) kp1	12 (175) kp1
SF [mm]	650	635	630	665	635	678	642	640	643	643	660
t_{500} [s]	2	2	2	2	1	1	2	1	1	2	3

3.2.2 V-funnel test. The time necessary for the concrete to flow out of a V-funnel is given in Table 8.

Table 8 *Funnel time (t)*

concrete	1 (175)	2 (175)	3 (175)	4 (175) kp1	5 (175)	6 (175) kp1	7 (175) kp1	8 (175) kp1	10 (175) kp1	11 (175) kp1	12 (175) kp1
t [s]	11	10	9	7	5	7	9	6	8	9	11

3.2.3 U-flow test. The filling height of the concrete in the right hand compartment is given in Table 9.

Table 9 *Filling height (h)*

concrete	1 (175)	2 (175)	3 (175)	4 (175) kp1	5 (175)	6 (175) kp1	7 (175) kp1	8 (175) kp1	10 (175) kp1	11 (175) kp1	12 (175) kp1
U-test [mm]	320	311	304	323	310	328	317	329	323	311	299

3.3 Properties of hardened concrete

3.3.1 Compressive strength (NBN B15-220). The results for the compressive strength at 1, 2, 7, 28 and 90 days of the SCC and the reference (vibrated) concrete are given in Table 10.

3.3.2 Shrinkage (NBN B15-216). The shrinkage of SCC mixtures 2(175), 4(175)kp1, 5(175), 8(175)kp1, 10(175)kp1, 11(175)kp1 and of the reference concrete is reproduced in Figure 5.

Table 10 *Compressive strength ($f_{c,cub}$) at 1, 2, 7, 28 and 90 days*

concrete	1 (175)	2 (175)	3 (175)	4 (175) kp1	5 (175)	6 (175) kp1	7 (175) kp1	8 (175) kp1	10 (175) kp1	11 (175) kp1	12 (175) kp1	REF
$f_{c,cub,1d}$ [MPa]	-*	13.0	12.9	15.1	16.2	13.1	12.5	10.0	8.5	11.0	8.1	9.2
$f_{c,cub,2d}$ [MPa]	25.3	24.9	24.5	22.3	29.0	25.4	23.9	22.0	19.8	22.2	20.4	21.1
$f_{c,cub,7d}$ [MPa]	46.9	46.3	45.0	43.7	50.6	48.4	44.6	44.4	40.7	41.4	41.9	42.1
$f_{c,cub,28d}$ [MPa]	58.5	60.0	57.4	56.8	63.7	62.6	61.7	59.7	54.0	55.5	53.0	54.9
$f_{c,cub,90d}$ [MPa]	66.6	69.3	70.1	66.4	69.2	66.9	65.8	69.4	59.3	62.3	59.1	63.8

(* = not measured)

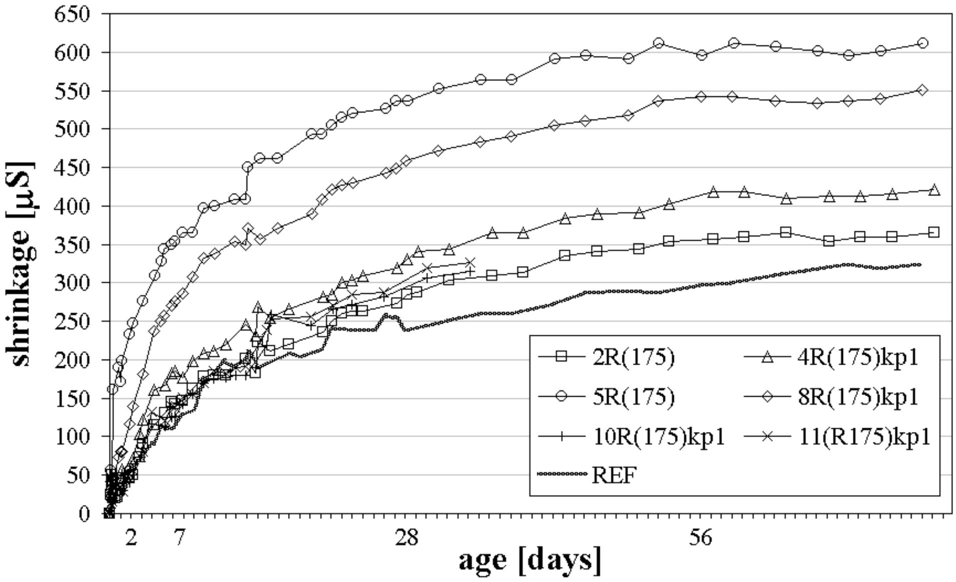


Figure 5 *Shrinkage of SCC mixtures*

3.3.3 Freeze-thaw resistance (NBN B15-231). The results of the freeze-thaw resistance for SCC and the reference concrete are given in Table 11.

Table 11 *Evaluation of the dynamic, longitudinal elastic modulus (E_{dL}) to determine possible damage caused by freeze-thaw cycles*

concrete	1 (175)	2 (175)	3 (175)	4 (175) kp1	5 (175)	6 (175) kp1	7 (175) kp1	8 (175) kp1	10 (175) kp1	11 (175) kp1	12 (175) kp1	REF
$E_{dL,0c}$ [MPa]	42480	41598	42689	40438	41591	43301	43046	43114	40974	38995	40626	43622
$E_{dL,14c}$ [MPa]	42703	41522	42547	40775	41348	42950	43113	43356	38443	41884	41340	43205
$E_{dL,28c}$ [MPa]	43041	41365	43133	41247	41572	43137	42772	43652	38491	41904	41423	43717
$E_{dL,42c}$ [MPa]	43156	40736	42535	40905	41213	43187	43437	43305	38700	41724	41440	43575
$E_{dL,0c}$ [%]	100	100	100	100	100	100	100	100	100	100	100	100
$E_{dL,14c}$ [%]	100.5	99.8	99.7	100.8	99.4	99.2	100.2	100.6	93.8	107.4	101.8	99.0
$E_{dL,28c}$ [%]	101.3	99.4	101.0	102.0	100.0	99.6	99.4	101.2	93.9	107.5	102.0	100.2
$E_{dL,42c}$ [%]	101.6	97.9	99.6	101.2	99.1	99.7	100.9	100.4	94.5	107.0	102.0	99.9

3.3.4 Freeze-thaw and de-icing salt resistance (T 98/0343 N). The results of the freeze-thaw and de-icing salt resistance for the SCC mixtures and the reference concrete are given in Table 12.

Table 12 *Determination of the amount of scaled material related to the test surface (M) after 7, 14 and 28 freeze-thaw cycles*

concrete	1 (175)	2 (175)	3 (175)	4 (175) kp1	5 (175)	6 (175) kp1	7 (175) kp1	8 (175) kp1	10 (175) kp1	11 (175) kp1	12 (175) kp1	REF
M_{7c} [kg/m²]	0.34	0.43	0.31	0.28	0.52	0.40	0.29	0.27	0.06	0.29	- *	0.43
M_{14c} [kg/m²]	1.20	1.29	1.24	1.22	1.99	1.19	0.95	1.01	0.13	1.19	- *	1.35
M_{28c} [kg/m²]	2.99	3.32	3.08	3.10	5.14	3.11	2.55	2.71	0.18	2.99	- *	2.53

(* = not measured)

3.4 Discussion of test results

For some fillers, it was necessary to apply the κ_p-correction to obtain a self-compacting concrete. It was even not possible to obtain a SCC with a water/cement ratio = 0.5 for filler 9, although there is not a great, even not microscopic, difference between filler 9 and filler 10. It was not possible to find an unequivocal relationship between the filler-characteristics and the results of the workability (slump-flow, V-funnel and U-test) of self-compacting concrete. Reason for this is the high sensitivity of the mixtures to the superplasticizer. Besides, the use of the superplasticizer is based on experience, what sometimes led to segregation due to an overdose.

Table 10 shows that a difference in compressive strength can be noted, when a different filler is used. The finest filler (filler 5) has the greatest compressive strength at 1, 2, 7 and days. The compressive strength of 7 limestone fillers and the dolomite filler has a likewise development. The compressive strength of the two fly ashes and the silica fillers follow the development of the reference concrete and stays in that way below the strength of the limestone fillers and the dolomite filler.

Figure 5 shows that self-compacting concrete has a much greater shrinkage than the reference concrete. Another conclusion that can be made is that the finest filler (filler 5) has the greatest shrinkage.

Self-compacting concrete has a good freeze-thaw resistance in comparison with the reference concrete (Table 11). But a somewhat greater amount of scaled material is found when de-icing salts were added (Table 12). It is remarkable that SCC 10(175)kp1 has an inferior freeze-thaw resistance but also a lot less scaled material when de-icing salts were added in comparison with the other investigated SCC mixtures.

4 CONCLUSION

This paper has shown that totally different properties of self-compacting concrete were found if only another type of filler was used. Fillers 9 and 10 (both fly ashes) have shown that microscopic differences are not sufficient to explain all. Although there is almost no microscopic difference between the 2 fillers, it was not possible to obtain a self-compacting concrete (with a water/cement ratio = 0,5) for filler 9. Possibly, only a nanoscopic difference must be able to explain it. This subject is worthy further investigations.

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