

### **CODE 2.3.43**

## **A REVIEW OF THE DURABILITY ASPECTS FOR SELF-COMPACTING CONCRETE**

**Marian, Sabau<sup>1\*</sup>; Yamith, Cantillo Mier<sup>2</sup>; Traian, Onet<sup>3</sup>**

1: Department of Civil Engineering  
Universidad de la Costa

e-mail: [marian.sabau@gmail.com](mailto:marian.sabau@gmail.com), web: <http://www.cuc.edu.co/>

2: Department of Civil Engineering  
Universidad de la Costa

e-mail: [yamith.cantillo@gmail.com](mailto:yamith.cantillo@gmail.com), web: <http://www.cuc.edu.co/>

3: Department of Civil Structures  
Technical University of Cluj-Napoca

e-mail: [traianonet@gmail.com](mailto:traianonet@gmail.com), web: <http://constructii.utcluj.ro/>

**KEYWORDS:** self-compacting concrete, carbonation, chloride penetration, sulphate attack, frost durability and salt scaling, fire resistance.

### **ABSTRACT**

This article presents a literature review concerning the durability of self-compacting concrete (SCC), making a comparison between this new type of concrete and the vibrated concrete (VC). The degradation mechanisms that have been considered are: carbonation, chloride penetration, sulphate attack, frost durability and salt scaling, and fire resistance. The carbonation of SCC is not significantly deviating from the carbonation of VC. Cyclic wetting and drying in a chloride containing solution shows significantly lower chloride diffusion in SCC in comparison with VC. The initiation time for sulphate attack is prolonged in SCC compared with an equivalent VC due to a denser microstructure in SCC. Frost action in combination with de-icing salts is leading to similar mass losses in SCC as in VC. SCC has a high probability of spalling when exposed to fire even in a dry environment, so precautions shall be taken when SCC shall be used in situations where no fire spalling is accepted.

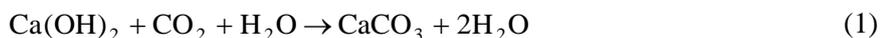
### **1. INTRODUCTION**

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement [1]. SCC was developed in Japan in the 1980's. The aim was to develop concrete that could be placed without vibration. In this way, some health risks as well as environmental problems could be avoided. Figure 1 illustrates the relative volume fractions of vibrated concrete (VC), SCC with viscosity modifying agent (SCC VMA type), and SCC with increased powder content (SCC powder type).

### **2. DEGRADATION MECHANISMS**

#### **2.1. Carbonation**

Carbonation is the chemical reaction of the hydrated cement paste with CO<sub>2</sub> molecules, diffusing from the air into the concrete:



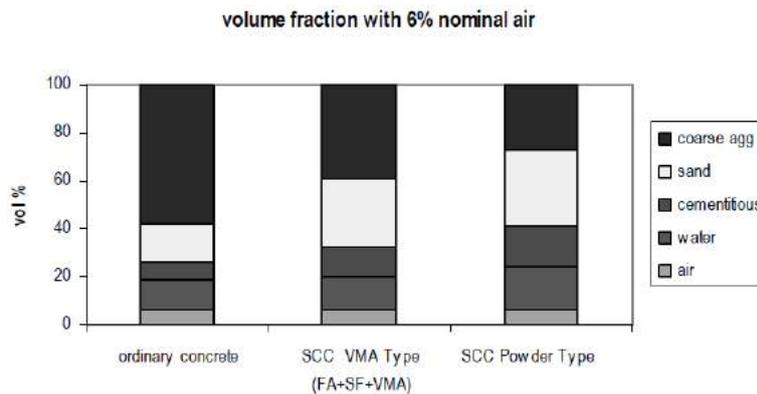


Figure 1: Typical volume fractions of the major constituents of VC and VMA and powder type SCC with about the same compressive strength [2]

Sideris et al. [3] produced four SCC mixes (SCC, SCC-V, SCC1-S, SCC2-S) and four VC mixes (NCC, NCC-V, NCC1-S, NCC2-S). After initial water curing of 3 days, cylindrical specimens from all SCC and VC mixes were cured in an accelerating carbonation chamber with 10% CO<sub>2</sub>, R.H. = 65% and T = 20°C. Specimens remained in this chamber for 6 weeks. After this age the carbonation was measured according to RILEM CPC-18 [4]. The carbonation depth of all mixes is presented in table 1. The carbonation depth of the SCC mixes is in general lower than the one measured on VC mixes with the same cement and water content. The reduction ranged between 20% and 50%. Only in the case of the SCC mix produced with silicate filler (SCC), the carbonation depth was slightly increased by 5%.

Assié [5] has made a comparison between four types of SCC (BAP15, BAP20, BAP40, BAP60) and three VC (BV20, BV40, BV60) in different strength classes. The carbonation tests were carried out at a CO<sub>2</sub> concentration of 50% and a R.H. = 65%. The carbonation depth was measured with phenolphthalein. The value of the carbonation depth after 28 days of carbonation is also given in table 1. The general conclusion is that the SCC mixes are carbonating a little faster than the VC mixes, for all concrete strength classes. It is explained that this higher carbonation rate is caused by a higher water accessible porosity. Nevertheless, this higher carbonation rate is still acceptable.

Cioffi et al. [6] studied the influence of three types of filler material: blast furnace slag, silica fume and limestone powder in four SCC (SCC, SCC-L, SCC-SF, SCC-BSF) and one VC (TC). As can be seen in table 1, the SCC mix with silica fume (SCC-SF) has the lowest carbonation depth, the SCC mix with blast furnace slag (SCC-BFS) has a higher carbonation depth, and the VC mix (TC), the SCC without additional filler material (SCC) and the SCC with limestone (SCC-L) have the highest carbonation depth.

Sideris [7] produced four SCC mixes (SCC20/25, SCC25/30, SCC30/37, SCC45/55) and four VC mixes (NCC20/25, NCC25/30, NCC30/37, NCC45/55) belonging in four different strength classes: C20/25, C25/30, C30/37 and C45/55. After initial water curing of 3 days cylindrical specimens from all SCC and VC mixes were cured in an accelerating carbonation chamber with 10% CO<sub>2</sub>, R.H. = 65% and T = 20°C. Specimens remained in this chamber for 6 weeks. After this period the carbonation depth was measured according to RILEM CPC-18 [4] and is presented in table 1. It is clear that SCC mixes are leading to a lower carbonation depth. The reduction is higher in the lower strength class C20/25. SCC-C25/30 showed a slight increase, but since it is very small and corresponds to the mean value of several measurements, the conclusion is that SCC and VC mixes behave the same. The same could be said for the upper strength class C45/55.

Audenaert [8] studied two SCC (C35-SCC, C60-SCC), two VC (C35-Ref, C60-Ref) and one SCC with steel fibers (C60-FSCC). The carbonation depths are given in table 1. The concrete specimens (concrete beams and columns) were not sheltered from rain and placed in normal Scottish weather conditions.

Table 1: Results of the carbonation depth for SCC and VC mixes

Reference	Mix	Compressive strength at 28 days (MPa)	Exposure time	Carbonation depth (mm)
Sideris et al. [3]	NCC	52.0	6 weeks	9.3
	NCC-V	49.8	6 weeks	9.7
	NCC1-S	69.7	6 weeks	3.0
	NCC2-S	48.0	6 weeks	15.0
	SCC	60.7	6 weeks	9.8
	SCC-V	51.0	6 weeks	6.5
	SCC1-S	68.3	6 weeks	2.0
	SCC2-S	47.3	6 weeks	12.0
Assié [5]	BAP15	18.8	28 days	24.6
	BAP20	25.5-30.0	28 days	19.8
	BV20	20.0-25.4	28 days	18.1
	BAP40	44.3-49.6	28 days	4.7
	BV40	45.2-50.8	28 days	4.0
	BAP60	69.2	28 days	0.7
	BV60	68.6	28 days	0.3
Cioffi et al. [6]	TC	-	1 year	1.95
	SCC	-	1 year	1.91
	SCC-L	-	1 year	1.99
	SCC-SF	-	1 year	0.81
	SCC-BSF	-	1 year	1.22
Sideris [7]	NCC20/25	29.5	6 weeks	31.0
	NCC25/30	39.6	6 weeks	12.0
	NCC30/37	45.2	6 weeks	3.0
	NCC45/55	67.0	6 weeks	1.5
	SCC20/25	33.7	6 weeks	23.0
	SCC25/30	43.4	6 weeks	13.0
	SCC30/37	53.5	6 weeks	2.5
	SCC45/55	73.2	6 weeks	1.2
Audenaert [8]	C35-Ref	37	38-44 months	4.5
	C35-SCC	47	38-44 months	1.5
	C60-Ref	61	38-44 months	0.5
	C60-SCC	79	38-44 months	0.5
	C60-FSCC	63	38-44 months	0.5

## 2.2. Chloride penetration

Chloride itself in normal cases does not directly result in any damage of concrete, but it can induce corrosion of steel in concrete. Chloride-induced reinforcement corrosion is the most important degradation process for reinforced concrete structures.

Zhu and Bartos [9] published results of chloride migration coefficient at the concrete age of 7-10 days for three SCC (SCC1, SCC2, SCC3) and two VC (REF1, REF2) given in table 2. The results clearly indicated that the chloride diffusivity was very much affected by the type of powders used in the concrete as well as the concrete strength. Particularly, the concrete mixes containing fly ash (REF2 and SCC2) showed a much lower migration coefficient compared to the other mixes, especially for the C40 mixes. The results in table 2 also showed that the SCC3 mixes which contained no additional powder but a viscosity agent had the highest chloride diffusivity at both concrete strengths. While the data in the C40 mixes showed similar migration coefficient for REF1 and SCC1 mixes, the migration coefficient of SCC1 was found to be higher than that of REF1 in the C60 strength concretes [9].

Table 2: Results of the chloride migration coefficient for SCC and VC mixes [9]

Mix	Average values of chloride migration coefficient ( $10^{-12} \text{ m}^2/\text{s}$ )	
	C40 mixes	C60 mixes
REF1	43.6	9.4
REF2	12.9	6.6
SCC1	41.9	12.7
SCC2	8.4	6.3
SCC3	54.6	16.2

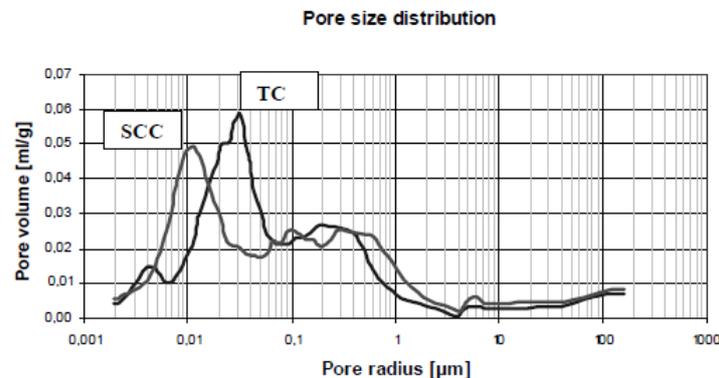
Audenaert et al. [10] carried out an extended experimental study on chloride penetration of sixteen SCC and four VC. Based on the chloride penetration results obtained through cyclic immersion (under combined action of capillary suction and chloride diffusion), they concluded that the depth of chloride penetration was strongly influenced by the water/cement and water/(cement + filler) ratios. Decreasing one of these ratios or both would lead to a decreasing penetration depth. Furthermore, the chloride penetration depth in SCC by cyclic immersion was lower than that in the corresponding VC [10]. It was also found that for SCC mixes with the same mix proportion but different cement types, using high strength class cement (CEM I 52.5 against CEM I 42.5R) or a blast furnace slag cement (CEM III A 42.5LA) resulted in lowering the rate of chloride penetration, while using a sulphate resistant cement could have the opposite effect due to its reduced chloride binding capacity.

From the results in the literature it can be seen that the property of SCC regarding to chloride penetration varies more than the VC, additionally depending on the dispersion of filler [11], the content of cementitious material [12], the types of filler and admixture such as viscosity agent [9], and the ratio of water to (cement+filler) [10].

### 2.3. Sulphate attack

Ettringite ( $\text{C}_3\text{A} \cdot 3\text{CaSO}_4 \cdot 32\text{H}_2\text{O}$ ), thaumasite ( $\text{CaCO}_3 \cdot \text{CaSO}_4 \cdot \text{CaSiO}_3 \cdot 15\text{H}_2\text{O}$ ), and gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) are three minerals, which are found among the deterioration products of cementitious materials exposed to sulphate attack [13,14,15,16,17,18].

The influence which the incorporation of limestone filler in SCC may have on the capillary pore size distribution is exemplified by figure 2. Compared with a VC specimen, the SCC specimen containing  $200 \text{ kg/m}^3$  limestone filler showed a reduction of the pore size. The samples had the same  $w/c = 0.45$  and total porosity measured by mercury intrusion porosimetry (MIP).


 Figure 2: Capillary pore size distribution in SCC compared with VC at  $w/c = 0.45$  [8]

An example of the heat development in a SCC and a comparable VC is given in figure 3 from two field concrete mixes for civil engineering purposes, where the maximum hydration heat production and heat production rates are shown. It is concluded that the SCC has a faster hydration heat

development which is in accordance with results obtained by Poppe et al. [19]. In thinner wall geometries (0.2-0.8 m) a slightly higher maximum heat production is calculated in SCC, but when the concrete mass is further enlarged due to an increased wall thickness of 3.2 m the VC shows a higher maximum heat production than the SCC. This is explained by the higher cement content in the VC. The example shows that the difference in maximum heat production between a SCC with limestone filler and a performance-based equivalent VC is marginal in the region of 65 °C (max. 66 °C for VC and max. 64.5 °C for SCC).

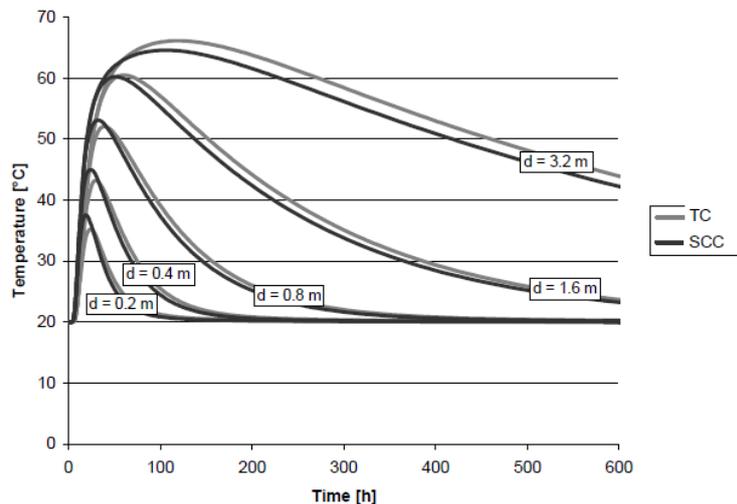


Figure 3: Heat production rate in two comparable SCC and VC mixes, exemplified by five different thicknesses of a wall geometry (0.2 – 3.2 m) [8]

## 2.4. Frost durability and salt scaling

The degree of expansion of concrete due to frost action is usually determined by measuring the elongation of test prism subjected to freeze-thaw cycles. Persson [12] proposed that the following relationship between linear expansion of concrete and the loss in fundamental resonance frequency (FRF) exists:

$$\Delta\text{FRF} = -\Delta\varepsilon(58.4 \times \Delta\varepsilon + 42.4) \quad (2)$$

where  $\Delta\text{FRF}$  and  $\Delta\varepsilon$  denote the change of FRF and elongation of the sample, both in percent.

SCC made with polypropylene fibers showed an increase of the spacing factor and low salt frost resistance compared to VC. The main reasons for low salt frost resistance in the fibrous SCC were associated with probable loss of unstable air system [20]. The author suggested that polypropylene fibers in concrete seemed to prohibit the movement of water in the air-void system so that a sudden collapse could occur, as shown in figure 4. At low air content, an inner breakdown occurred in the SCC made with polypropylene fibers. The SCC made with polypropylene fibers was damaged by salt frost attack if the air content was too low, which is associated with high spacing factor [20].

## 2.5. Fire resistance

In a study by Sideris et al. [21] the effect of temperature on compressive strength, splitting tensile strength and pulse velocity of SCC and VC have been studied. Mixes of different strength classes were used (C20/25, C25/30, C30/37, C50/60). The experiments showed that for temperatures up to 700 °C the residual mechanical properties were affected in the same way for SCC and VC belonging to the same strength class. However the influence of elevated temperatures was more detrimental to residual splitting tensile strength.

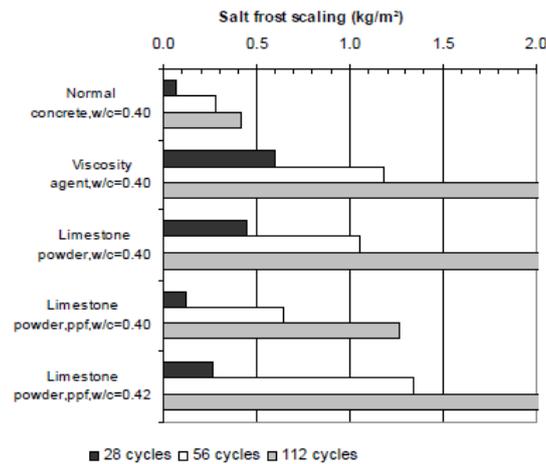


Figure 4: Salt frost scaling of VC and SCC made with and without polypropylene fibers [20]

A general observation is that most fire tests on SCC result in spalling [22], [23], [24], [25], [26]. In a study concerning the mechanism of polypropylene fibers in preventing explosive spalling in SCC and high performance concrete (HPC) [27] the residual permeability, after heating and cooling down, has been shown to be much higher after heat treatment of 200-300 °C. In the study it was also shown that the melted fibers were absorbed by the surrounding pores.

### 3. CONCLUSIONS

The following conclusions can be made regarding the durability of self-compacting concrete:

- SCC has sometimes a larger and sometimes a smaller carbonation depth in comparison with VC with the same water and cement content, although the differences are small.
- The chloride diffusivity is very much dependent on the type of cement and additional powder used in concrete. Equal strength grade or equal w/c ratio alone cannot ensure different SCC mixes to have equal or lower chloride diffusivity in comparison with VC.
- The increased risk concerning delayed ettringite formation in SCC with limestone filler is small.
- Internal frost resistance and salt frost scaling of SCC do not differ much from the analogous properties of VC provided that the concrete is prepared with sound aggregate, proper air-void system, adequate resistance to segregation and bleeding, and proper strength.
- The effect on strength of SCC when exposed to high temperatures may differ slightly from VC, SCC having a high probability of spalling when exposed to fire.

### 4. BIBLIOGRAPHY

- [1] BIBM, CEMBUREAU, EFCA, EFNARC, and ERMCO. *The European Guidelines for Self-Compacting Concrete. Specification, Production and Use*. 2005.
- [2] Bonen, D. and Shah, S.P. Fresh and hardened properties of self-consolidating concrete. *Progress in Structural Engineering and Materials* 7, 1 (2005), 14–26.
- [3] Sideris, K.K., Kiritsas, S., and Haniotakis, E. Mechanical characteristics and durability of self-compacting concretes produced with Greek materials. *Proceedings of the 14th Greek Concrete Conference*, (2003), 187–193.
- [4] RILEM. CPC-18 Measurement of hardened concrete carbonation depth. *Materials and Structures* 21, 6 (1988), 453–455.
- [5] Assié, S. *Durabilité des bétons auto-plaçants*. PhD thesis, Institut National des Sciences Appliquées de Toulouse, France, 2004.
- [6] Cioffi, R., Colangelo, F., and Marroccoli, M. Durability of self-compacting concrete. *Proceedings of the Eight Convegno Nazionale AIMAT, Palermo*, (2006).

- [7] Sideris, K.K. *Durability of Self-compacting concretes of different strength categories*. Internal Report, Laboratory of Building Materials, Democritus University of Thrace (in Greek), 2006.
- [8] De Schutter, G. and Audenaert, K. *Durability of Self-Compacting Concrete-State-of-the-Art Report of RILEM Technical Committee 205-DSC*. RILEM publications, 2007.
- [9] Zhu, W. and Bartos, P.J.M. Permeation properties of self-compacting concrete. *Cement and Concrete Research* 33, 6 (2003), 921–926.
- [10] Audenaert, K., Yu, Z., Shi, C., Khayat, K.H., and Xie, Y. Chloride penetration in self compacting concrete by cyclic immersion. *SCC'2005-China: 1st International Symposium on Design, Performance and Use of Self-Consolidating Concrete*, (2005), 355–362.
- [11] Tang, L., Andalen, A., Johansson, J.O., and Hjelm, S. Chloride diffusivity of self-compacting concrete. *Proceeding of First International RILEM Symposium on Self-Compacting Concrete (PRO 7)*, Stockholm, Sweden, (1999), 187–198.
- [12] Persson, B. *Assessment of the chloride migration coefficient, internal frost resistance, salt frost scaling and sulphate resistance of self-compacting concrete*. Division of Building Materials, Lund University, 2001.
- [13] ACI. *201.2R-08: Guide to Durable Concrete*. 2008.
- [14] Collepardi, M. Ettringite formation and sulfate attack on concrete. *Proceedings of the Fifth CANMET/ACI International Conference on Recent Advances in Concrete Technology (ACI SP-200)*, (2001), 21–37.
- [15] Collepardi, M. Thaumassite formation and deterioration in historic buildings. *Cement and Concrete Composites* 21, 2 (1999), 147–154.
- [16] Hartshorn, S.A., Sharp, J.H., and Swamy, R.N. Thaumassite formation in Portland-limestone cement pastes. *Cement and Concrete Research* 29, 8 (1999), 1331–1340.
- [17] Hime, W.G. and Mather, B. “Sulfate attack,” or is it? *Cement and Concrete Research* 29, 5 (1999), 789–791.
- [18] Barnett, S.J., Halliwell, M.A., Crammond, N.J., Adam, C.D., and Jackson, A.R.W. Study of thaumasite and ettringite phases formed in sulfate/blast furnace slag slurries using XRD full pattern fitting. *Cement and Concrete Composites* 24, 3 (2002), 339–346.
- [19] Poppe, A.-M. and De Schutter, G. Analytical hydration model for filler rich binders in self-compacting concrete. *Journal of Advanced Concrete Technology* 4, 2 (2006), 259–266.
- [20] Persson, B. On the internal frost resistance of self-compacting concrete, with and without polypropylene fibres. *Materials and structures* 39, 7 (2006), 707–716.
- [21] Sideris, K.K. Mechanical characteristics of self-consolidating concretes exposed to elevated temperatures. *Journal of materials in civil engineering* 19, 8 (2007), 648–654.
- [22] Noumowé, A., Carré, H., Daoud, A., and Toutanji, H. High-strength self-compacting concrete exposed to fire test. *Journal of materials in civil engineering* 18, 6 (2006), 754–758.
- [23] Boström, L. *Innovative self-compacting concrete - Development of test methodology for determination of fire spalling*. SP Report 2004, 2004.
- [24] Bostrom, L. and Jansson, R. Spalling of self-compacting concrete. *Proceedings of 4th International Workshop Structures in Fire*, (2006).
- [25] Persson, B. Fire resistance of self-compacting concrete, SCC. *Materials and Structures* 37, 9 (2004), 575–584.
- [26] Horvath, J., Hertel, C., Dehn, F., and Schneider, U. Einfluß der Vorlagerung auf das Temperaturverhalten von selbstverdichtendem Beton. *Beton-und Stahlbetonbau* 99, 10 (2004), 813–815.
- [27] Liu, X. *Microstructural investigation of self-compacting concrete and high-performance concrete during hydration and after exposure to high temperatures*. These de doctorat, Université de Ghent, Belgique, 2006.