



STUDY OF SORPTIVITY OF SELF-COMPACTING CONCRETE WITH MINERAL ADDITIVES

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Abstract. This work presents the results of a comparative study of the sorptivity, accomplished in mixtures of self-compacting concrete with different types of additives and a normal concrete compacted by vibration. The self-compacting concrete mixtures present slump-flow of 650 ± 50 mm and have the same cement contents. In the self-compacting mixtures, were used as additives, fly ash, silica fume, hydraulic lime and a mixture of fly ash and hydraulic lime. A modified carboxylates superplasticiser was used to obtain a specific workability. The capillary absorption was carried out at 7, 14 and 28 days of age, through a methodology described in the work. The results permit to conclude that the used additives propitiate the self-compacting concrete. In terms of capillary absorption, the mixtures with fly ash have a better performance.

Keywords: capillarity, fly ash, hydraulic lime, water absorption, self-compacting concrete, silica fume, sorptivity.

1. Introduction

In recent years, there is a growing interest in the use of self-compacting concrete (SCC), which provides an overall structure durability [1, 2]. The self-compacting concrete is characterised by its capacity to flow and to fill out the most restricted places of the formwork, without losing homogeneity. On the other hand, a self-compacting concrete should have the capacity of self-densification, resulting in a material whose properties in the hardened state are at least the same achieved with concrete compacted by vibration.

One of the employed techniques to produce a self-compacting concrete is to use fine materials in the concrete, beside the cement. Those fine materials are denominated additions and they can have, or not, a chemical activity. The uses of mineral additions or powders have a purpose, beside substituting a part of the cement, it propitiate the appropriate viscosity so that the self-compaction is reached. It is expected that the addition of high fineness materials can contribute to the improvement of the properties that concern the mechanical resistance, as well as the durability. The fineness of a mineral admixture is very important for the modification of aggregate-cement interface zone, which is the weakest link in concrete [3, 4]. When the use of mineral admixtures is combined with superplasticisers, the pore structure is greatly affected and a significant reduction in the volume of pores is obtained

[5, 6]. In relation to durability, the concretes are appraised through several properties, among them the capillary sorptivity, whose importance is allied to the factor that this is the first phenomenon of transport of aggressive agents that takes place in concrete. Sorptivity, which is an index of moisture transport into unsaturated specimens, has been recognised as an important index of concrete durability, because the test method used for its determination reflects the way that most concretes will be penetrated by water and other injurious agents and it is an especially good measure of the quality of near surface concrete, which governs durability related to reinforcement corrosion [7]. Martys and Ferraris [8] have shown that the sorptivity coefficient is essential to predict the service life of concrete as a structural and to improve its performance. Gopalan [9] has demonstrated a relationship between strength and sorptivity for fly ash normal concrete. It was reported that the sorptivity of air-cured fly ash concrete, cured for 28, 90 and 180 days, increases with an increase in fly ash content. By normal concrete has been shown that the condensed silica fume, under normal curing environments, both increases strength and reduces sorptivity [10]. For normal concrete, it is clear that the pozzolanic effect on the modification of concrete porosity of silica fume is comparable to the metakaolin [11]. Durekovic [12] observed a marked decrease in capillary water suction with an increase in silica fume content for water-cured cement pastes. In contrast, some

minerals admixtures have the opposite effect on sorptivity. Sabir et al [13] found that in the water-cured mortar in which the cement was partially replaced by ground clay brick, the sorptivity increased with the increase in ground clay brick content.

The influence of different mineral additives on the durability of SCC mixtures has been investigated by testing water absorption and freeze-thaw resistance [14]. The results for the water absorption, by immersion, of SCC mixtures and the reference concrete are comparable.

This study verifies the susceptibility of the hardened self-compacting concrete to have a better, or similar, behaviour when compared to concrete, of the same strength class, compacted by vibration. This verification is accomplished through the evaluation of the sorptivity by capillary water absorption of the tested mixtures.

2. Evaluation of self-compacting ability

To evaluate the self-compacting ability of concrete, of SCC type, were accomplished, besides the slump-flow, by non-standard tests: L-box and V-funnel. These properties reflect the rheology of the mix, ie the flowability and viscosity, and also its tendency to cause blocking and segregation. There are several simple methods (Figs 1–3) designed for in situ or laboratory use.

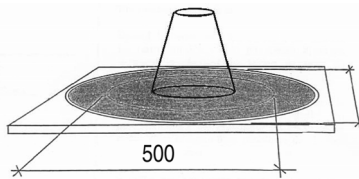


Fig 1. Slump-flow test

The most common and also simplest to perform is the slump flow test. A standard Abram’s cone is filled with concrete and then lifted. The spread diameter, D_{final} , the time of flow to reach a diameter of 500 mm, T_{500} , and the general visual appearance of the concrete is recorded. To some extent, the spread is associated with the shear yield stress and the flow time with the viscosity.

The typical values that characterise the self-compaction are between 650 and 750 mm of the final diameter and between 2 and 10 seconds for the necessary time to reach a 500 mm diameter.

The L-box test is another method that is both simple and practical to use. It consists of an L-shaped box in which the vertical part is first filled with concrete. Then, a hatch is removed and the concrete flows out between some re-bars. The height level of the concrete on each

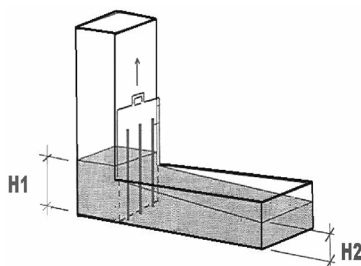


Fig 2. L-box test

side of the L-box and flow time to reach a horizontal distance of 40 cm, T_{40} , are measured. After the flowing of the concrete, inside the box’s horizontal part, the heights H_1 and H_2 are measured, H_2/H_1 rate need to be of the order of 0,8. The method is designed to capture the blocking behaviour.

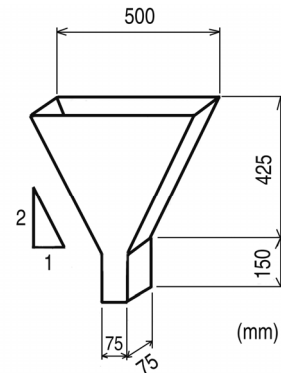


Fig 3. V-funnel test

The viscosity of the concrete can be evaluated by the V-funnel method, which consists of filling out a funnel with about 12 liters of concrete and soon after to measure the time, T, in seconds, that the concrete takes to drain of the funnel.

3. Determination of capillary sorptivity

The sorptivity tests were carried out on paralelepiped samples, with 7,5 x 7,5 x 15 cm, after drying in oven, at a temperature of 100 ± 10 °C. The samples were stored until the weight loss was negligible. The preparation of samples also included water impermeability of their lateral faces, reducing the effect of water evaporation.

The test started with the registration of samples weight and afterwards they were placed in a recipient in contact with a level of water capable to submerge them about 5 mm (Fig 4). After a predefined period of time, the samples were removed from the recipient to proceed to weight registration. Before weighing, the samples superficial water was removed with a wet cloth. Immediately after weighing, the samples were replaced in the recipient till reach the following measuring time. The procedure was repeated, consecutively, at various times such as 15 min, 30 min, 1 h, 2 hs, 4 hs, 6 hs, 24 hs, 48 hs and 72 hs until the last reading.



Fig 4. Preparation of water absorption by capillarity test

Because of a small initial surface tension and buoyancy effects, the relationship between cumulative water absorption (kg/m^2) and square root of exposure time ($t^{0.5}$) shows deviation from linearity during first few minutes [3]. Thus, for the calculation of sorptivity coefficient, only the section of the curves for exposure period from 15 min to 72 hs, where the curves were consistently linear, was used (Fig 5).

The sorptivity coefficient (k) was obtained by using the following expression:

$$\frac{W}{A} = k\sqrt{t}$$

where W = the amount of water adsorbed in (kg); A = the cross-section of specimen that was in contact with water (m^2); t = time (min); k = the sorptivity coefficient of the specimen ($\text{kg/m}^2/\text{min}^{0.5}$).

4. Experimental program

To produce the self-compacting concrete mixtures it was used a Portland-type cement II/B-L 32,5 (specific gravity $3,04 \text{ g/cm}^3$ and specific surface Blaine $4617 \text{ cm}^2/\text{g}$), a fly ash from a thermoelectric central (specific gravity $2,38 \text{ g/cm}^3$ and specific surface Blaine $4009 \text{ cm}^2/\text{g}$), a hydraulic lime (specific gravity $2,75 \text{ g/cm}^3$ and specific surface Blaine $5900 \text{ cm}^2/\text{g}$), and a silica fume Sikacrete HD (specific gravity $2,17 \text{ g/cm}^3$ and specific surface Blaine $12\,950 \text{ cm}^2/\text{g}$), as additives.

Two types of fine aggregates (sand with maximum size of 0,6 mm and 2,4 mm) and a coarse aggregate (granite crushed stone with maximum size of 9,5 mm), were used in the concrete composition. The mixture of the two fine aggregates was made of 50 % of each type of sand. A superplasticiser based on modified carboxylates (ViscoCrete 3000 from SIKA) was used to attain a suitable plastic viscosity. The maximum superplasticiser content compatible with the used cement is of 2,5 %.

To evaluate the sorptivity by capillarity, of self-compacting concrete, as well as the efficiency of different mineral additions, five mixtures were produced, being a normal concrete, compacted through a needle vibrator, the reference concrete, denominated as NC, and other four mixtures with self-compacting characteristics, denominated as SCC.

The self-compacting mixtures present a slump-flow test of $650 \pm 50 \text{ mm}$ and have approximately the same-cement content. To achieve the pretended workability, a modified carboxylates superplasticiser was used. The capillary absorption was carried out after 7, 14 and 28 days of age by the methodology described previously.

The characteristics and properties of mixtures are presented in the Table 1. Abbreviations were used in accordance with the addition material, SCCFA for self-compacting concrete with fly ash, SCCSF for self-compacting concrete with silica fume, SCCHL for self-compacting concrete with hydraulic lime and SCCFAHL for self-compacting concrete with a mixture of fly ash and hydraulic lime.

Each mixture presented in Table 1 has a cement : aggregates mass proportions equal to 1 : 4,5.

5. Results and discussion

Table 2 presents the results of tests carried out to verify the self-compacting of concrete.

The results of slump-flow test carried out in SCC concrete characterise the mixtures as being self-compacting [15]. However, the mixtures SCCSF and SCCFAHL present relationships H_1/H_0 below 0,80. This value has been recommended [1] as minimum value for this test that simulates the capacity of concrete transit inside the formwork and it depends on the steel bars density contained. For maximum superplasticizer content around 2,5 %, the SCCSF mixture (with 10 % silica fume) required the highest water/cement ratio to obtain the self compacting characteristic in the slump flow test. In the V-funnel test, the mixture SCCFAHL presented a lower fluidity; however, the recommendation for this test result has been 10 ± 3 seconds.

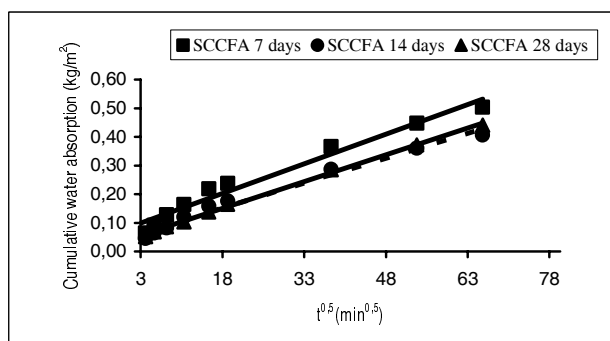


Fig 5. Typical plots of cumulative water absorption versus $t^{0.5}$ for SCCFA

The water absorption by capillarity in the age of 7 days demonstrates that the use of hydraulic lime as powder has a very similar effect to the silica fume, as it can be verified for the medium values presented in Fig 6. The most advantageous behaviour was provided by the use of fly ash, sub-product of thermoelectric industry, with a lower cost than the silica fume. The capillarity of 7 days self-compacting concrete with a mixture of hydraulic lime with fly ash, SCCFAHL, is similar to the normal concrete compacted by vibration, NC.

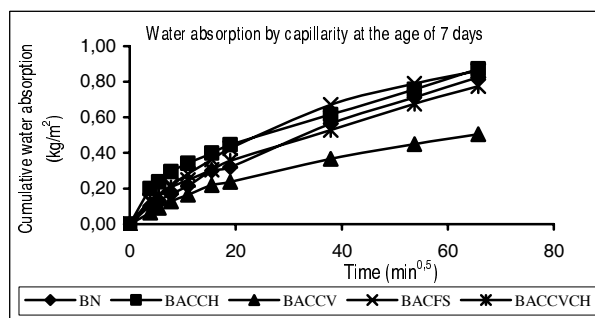


Fig 6. Evolution of water absorption by capillarity, carried out at 7 days of age

Table 1. Mixture proportions

	NC	SCCFA	SCCSF	SCCHL	SCCFAHL
Cement (kg/m ³)	410	390	384	384	384
Fly ash (kg/m ³)	xx	58	xx	xx	38
Silica fume (kg/m ³)	xx	Xx	38	xx	xx
Hydraulic lime (kg/m ³)	xx	Xx	xx	77	38
Sand 0,15–0,6 mm (kg/m ³) Mf*= 2,8	360	437	418	418	418
Sand 0,3–2,4 mm (kg/m ³) Mf*= 4,5	360	437	418	418	418
Aggregate 6–15 mm (kg/m ³)	1127	881	863	891	891
Water/cement	0,40	0,40	0,55	0,48	0,48
Superplasticiser Viscocrete 3 000 (%)	1,50	2,5	2,4	2,4	2,4
Water/powder materials (kg/kg)	0,40	0,35	0,36	0,33	0,33

* Fineness module

Table 2. Results of slump-flow, L-box, V-funnel and compressive strength tests

		NC	SCCFA	SCCSF	SCCHL	SCCFAHL
Slump	(mm)	35	–	–	–	–
Slump flow	Time (sec)	–	4'81''	1'34''	2'53''	3'29''
	Final average diameter (mm)	–	650	680	675	650
L-box	T ₄₀ (sec)	–	5' 46''	3' 93''	2' 81''	4' 00''
	H ₁ /H ₀ (cm)	–	0,86	0,60	0,86	0,50
V-funnel	Time (sec)	–	10' 00''	13' 00''	12' 29''	15' 00''
Compressive strength at 28 days	(MPa)	40,0	25,5	29,0	26,0	34,4

Analysing the evolution of water absorption, by capillarity, of mixtures, in the age of 14 days (Fig 7), it is noticed, with the evolution of the cement hydration, a modification of the microstructure, that hydraulic lime as the smallest efficiency as fine material to fill the capillary pores. The mixture with silica fume additions behaviour is similar to a normal vibrated concrete. At 14 days, the fly ash continues to develop a larger efficiency given to the SCCFA the lowest results of water absorption by capillarity.

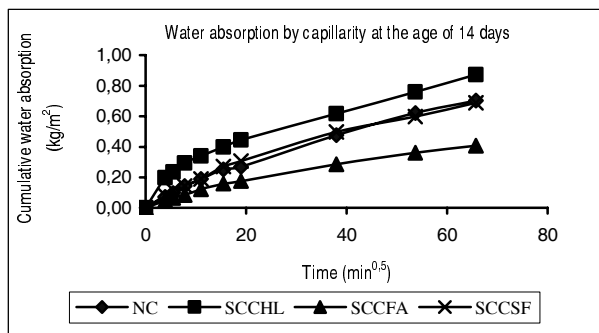


Fig 7. Evolution of water absorption by capillarity, carried out at 14 days of age

At the age of 28 days, the results are practically confirmed (Fig 8). However, it is verified that the addition of fly ash to the mixture containing hydraulic lime is quite beneficial, bringing a substantial improvement of the behaviour of SCCFAHL concrete. It is observed that this mixture, in the tests that characterises the self-compact ability of concrete, presented results expressing a smaller filling capacity and fluidity than other mixtures.

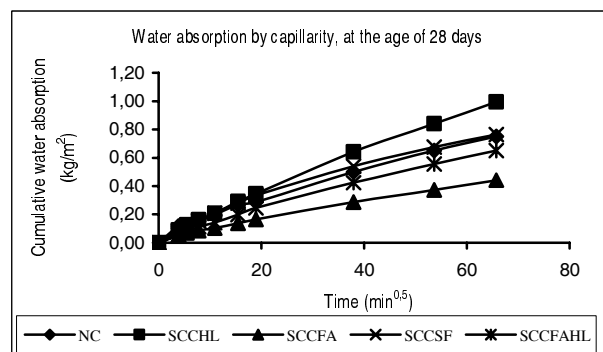


Fig 8. Evolution of water absorption by capillarity, carried out at 28 days of age

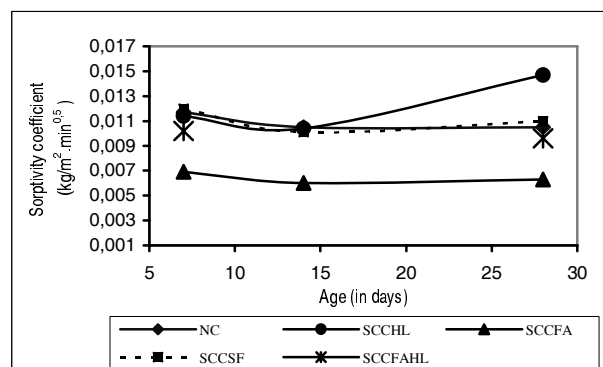


Fig 9. Sorptivity coefficient versus the age of different self-compacting concrete

The change in sorptivity with age of the NC, SCCHL, SCCFA, SCCSF and SCCFAHL cured up to 28 days is shown in Fig 9. It is apparent that sorptivity decreases systematically with an increase in the curing pe-

riod. However, SCCHL sorptivity at 28 days deviates from this pattern. Apparently, this may be due to the influence of heterogeneity of the specimens used to obtain these data. The sorptivity coefficients of SCCFA are low for all ages. Since the FA is very fine, pores in the bulk paste or in the interfaces between aggregate and cement paste are filled by this mineral addition; hence, the capillary pores are reduced. This effect can be observed in the sorptivity coefficient values obtained with the SCCFAHL with 10 % of HL and 10 % FA cement replacement.

Recently, a study developed in Laboratory of the University of Beira Interior presented some results of SCCSF properties obtained with 5 % and 10 % cement replacement [16]. These results indicate a rapid loss of self-compactability properties when the silica fume content is increased up to 10 %. It seems may be due to the non-compatibility between the carboxylates based superplasticiser and silica fume.

In this experimental program the silica fume, a material considered more expensive, when compared to others here employed, induced in the SCCSF mixture a similar behaviour to the one of the vibrated concretes.

Therefore, it can be inferred that the improvement of the characteristics that increase durability of a hardened concrete, is obtained with the employment of a self-compacting concrete, in which an addition of fly ash is used.

6. Conclusions

The behaviour of self-compacting concretes, in relation to the water absorption by capillarity, represented by the sorptivity coefficient (one of the parameters used to foresee durability) is equal or better than the one of a normal concrete compacted by vibration.

The addition of fly ash, used in this work, resulted in a better performance of the self-compacting concrete appraised through the water absorption by capillarity. The same additive mixed with hydraulic lime also improved the concrete performance at the age of 28 days.

The silica fume, a more expensive additive, imparts in the self-compacting concrete a similar behaviour to the one of normal concrete compacted by vibration. Apparently this behaviour is caused by an incompatibility between the silica fume and superplasticiser requiring an increase of water/cement ratio for the same concrete workability.

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References

1. French Association of Civil Engineering (AFGC). Self-compacting concrete: provisional recommendations (Bétons Auto-Plaçants: recommandations provisoires). Scientific and Technical Documents, 2000. 63 p. (in French).
2. Skarendahl, A. Early age and hardened properties. In: Self-Compacting Concrete: State-of-the-Art Report of Rilem Technical Committee 174-SCC, Rilem Publications S.A.R.L., 2000, p. 43–46.
3. Tasdemir, C.; Tasdemir, M. A.; Mills, N.; Barr, B. I. G. and Lydon, F. D. Combined effects of silica fume, aggregate type and size on postpeak response of concrete in bending. *ACI Material Journal*, 96(1), 1999, p. 74–83.
4. Bai, J.; Wild, S. and Sabir, B. B. Sorptivity and strength of air-cured and water-cured PC-PFA-MK concrete and the influence of binder composition on carbonation depth. *Cement and Concrete Research*, 32(11), 2002, p. 1813–1821.
5. Wee, T. H.; Matsunga, Y.; Watanabe, Y. and Sahai, E. Production and properties of high-strength concrete containing various mineral admixtures. *Cement and Concrete Research*, 25(4), 1995, p. 709–714.
6. Khatib, J. M. and Clay, R. M. Absorption characteristics of metakaolin concrete. *Cement and Concrete Research*, 34(1), 2004, p. 19–29.
7. Dias, W. P. S. Reduction of concrete sorptivity with age through carbonation. *Cement and Concrete Research*, 30(8), 2000, p. 1255–1261.
8. Martys, N. S. and Ferraris, C. F. Capillary transport in mortars and concrete. *Cement and Concrete Research*, 27(5), 1997, p. 747–760.
9. Gopalan, W. J. Sorptivity of fly ashes. *Cement and Concrete Research*, 26(8), 1996, p. 1189–1197.
10. Tasdemir, C. Combined effects of mineral admixtures and curing conditions on the sorptivity coefficient of concrete. *Cement and Concrete Research*, 33(10), 2003, p. 1637–1642.
11. Oliveira, L. A. P.; Jalali, S.; Fernandes, J. M. and Torres, E. The use of metakaolin to produce the eco-efficient concrete. *Materials and Structures*, Vol 38, No 277, 2005, p. 403–410.
12. Durekovic, A. Cement pastes of low water to solid ratio: An investigation of the porosity characteristics under influence of a superplasticiser and silica fume. *Cement and Concrete Research*, 25(2), 1995, p. 365–375.
13. Sabir, B. B.; Wild, S. and O’Farrel M. A water sorptivity test for mortar and concrete. *Materials and Structures*, Vol 31, No 213, 1998, p. 568–574.
14. Heirman, G. and Vandewalle, L. The influence of fillers on the properties of self-compacting concrete in fresh and hardened state. In: Proc of 3rd International RILEM Symposium on Self-Compacting Concrete, Reykjavik, Iceland, 17–20 Aug 2003. Ed by O. Wallevik and I. Nielsson, RILEM Publications, 2003, p. 606–618.
15. Neto, G., Morete, N. and Cardoso, A. M. Self-compacting concrete: physical and mechanical properties (Betão auto-compactável: propriedades físicas e mecânicas). Research Report, University of Beira Interior, Covilhã, 2003. 68 p. (in Portuguese).
16. Nepomuceno, M. S., Oliveira, L.A.P. Self-compacting concrete properties (Propriedades do betão auto-compactável). Partial report of SCC mix subproject, University of Beira Interior, Covilhã, 2004. 53 p. (in Portuguese).

SAVAIME SUSITANKINANČIO BETONO SU MINERALINIAIS PRIEDAIS ĮGERTIES TYRIMAI**L. A. Pereira de Oliveira, J. P. de Castro Gomes, C. N. Gonilho Pereira****S a n t r a u k a**

Straipsnyje pateikti įvairių savaime susitankinančio betono mišinių su skirtingos rūšies priedais įgerties lyginamųjų tyrimų rezultatai. Pastarieji lyginti su analogiškais rezultatais, gautais įprastuoju vibravimu sutankintam betonui. Savaime susitankinančio betono mišinio slankumas yra 650 ± 50 mm. Skirtingiems betono mišiniams parinktas vienodas cemento kiekis. Mišiniams naudoti šie priedai: pelenai, silicio dulkės, gesintosios kalkės ir pelenų bei gesintųjų kalkių mišinys. Betono mišinio technologiškumui užtikrinti naudotas modifikuotasis superplastifikatorius. Įgertis matuota praėjus 7, 14 ir 28 paroms nuo kietėjimo pradžios, taikant darbe aprašytą metodiką. Nustatyta, kad įgerties požiūriu mišiniai su pelenais yra veiksmingiausi.

Reikšminiai žodžiai: kapiliarumas, pelenai, gesintosios kalkės, vandens sugėrimas, savaime susitankinantis betonas, silicio dulkės, įgertis.

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