PLACING AND CURING SELF-COMPACTING CONCRETE IN HOT CLIMATES

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ABSTRACT

Self-compacting concrete (SCC) should present compatible quality and cost with conventional concrete (CC). Although SCC is advantageous its processability in hot climate regions is not well understood and is the main topic of this investigation. We used similar compositions of SCC and CC to study the fresh cement workability: Marsh Cone and Vicat test for different temperatures, and a Scanning Electronic Microscopy and other tests for durability study. According to the obtained results the workability is more sensitive to temperature variation which may be critical to transport and casting. The microstructure and results of durability tests were not much different from SCC and CC; it can be therefore concluded that the durability of SCC remains compatible with the CC. A real application of SCC for a large construction works was analyzed during this research. The results showed that it was feasible to apply SCC even in hot climate regions.

Keywords: self-compacting concrete (SCC), conventional concrete (CC), workability and durability.

INTRODUCTION AND OBJECTIVES

The aim of this paper is at studying the feasibility of applying self-compacting concrete (SCC) instead of conventional concrete (CC) in hot climates. The main aspects that were considered more relevant to study were those related to workability and durability. It was already demonstrated that the SCC improves and, in some cases, turns possible the construction given the technical, economic, social and environmental conditions [1]. Although SCC has advantages compared to CC, many points are not well understood that can bring difficulties to its wider application comparing to CC [2, 3]. Initially, this research compared SCC and CC using results obtained from laboratory tests related to workability of fresh and hardened concretes, measuring the compressive strength and some durability indicators. Afterwards, the tests were developed at the selected construction site – Pernambuco Arena, built to host games of the World Cup 2014 –, where both SCC and CC were used in a hot climate setting.

SCC pastes for Marsh cone test include Metakaolin addition and necessary admixtures shown in Table 1. Both SCC and CC pastes for Vicat needle test do not contain Metakaolin. Three replicates were used in each test. All pastes have the same composition and consistency except that SCC pastes were made with admixtures. Tests were conducted at different temperatures of 25^0C, 32^0C, 38^0C and 45^0C.

The motivation for using Scanning Electronic Microscope (SEM) and tomography was to clarity the following points: the absence of vibration may change the geometry aggregate/cement interface zone and the higher paste content in SCC may affect its durability. All concrete specimens were molded at 32^oC.

STUDIES OF FRESH CONCRETE

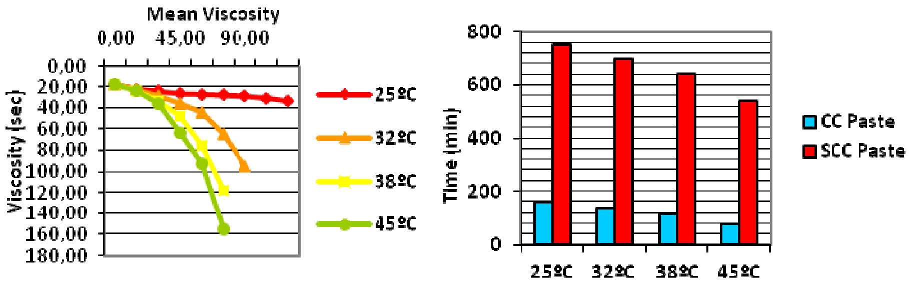
The main criteria for the composition of pastes are the ease of material availability in the construction site region, obtaining concrete plasticity and higher compactness due to a decrease in volume of voids in the mix. It was also taken into account that pastes should be equally applicable to SCC and CC. Use has been made of plasticizer Sikament 175, whose chemical composition is based on sodium lignosulphonates, and 3rd generation superplasticizer Viscocrete 3535, based on polycarboxylates. The water/cement ratio for normal consistency pastes followed the NBR NM 43 and NBR NM 65 [4 - 6]. The materials used were subjected to the temperatures 25^0C, 32^0C, 38^0C and 45^0C, before the beginning of each test, and maintained throughout the tests. Three samples were prepared for each of the four selected temperatures. The different compositions tested are presented in Table 1.

Table 1. Compositions of pastes SCC and CC

Components	Unit	Marsh cone	Vicat needle	
		SCC	SCC	CC
Cement CPV ARI	g	360	500	500
Metakaolin (10% of cement weight)	g	40	-	-
Admixture Viscocrete 3535CB (0.8%)	ml	32	32	-
Admixture Sikament PF 175 (0.8%)	ml	32	32	-
Public water utility	g	180	124.5	153
Water/cement ratio		0.45	0.249	0.306

The Marsh cone viscosity test was performed according to EN 445 [7]. The trials began at zero minute and were repeated every 15 minutes until the point where the high viscosity of the grout precluded testing. It is observed that the workability of the SCC decreases with increasing temperature, as shown in Figure 1a. It is also considered that there is a reduction of chemical admixtures performance over time, as well as accelerating of hydration reactions with increasing temperature. The Vicat needle was performed according to EN 196-3 [8] and demonstrated that the performance of the SCC is greater than the CC because of the use of admixtures. However, it is also shown that the temperature reduces the performance of SCC and CC (see Fig. 1b).

Figure 1. (a) Test results using the Marsh cone; (b) Test results using a Vicat needle.



(a) (b)

STUDIES OF HARDENED CONCRETE

Admixture 1 is a plasticizer of normal setting with a high water content reduction for concrete, while Admixture 2 is a 3rd generation superplasticizer having polycarboxylates solution in aqueous medium as the basic composition. Table 2 shows the compositions applied to the SCC and CC and the tests results of average compressive strength (f_{cm}) and durability: electrical resistivity (ρ), accelerated carbonation depth (X), voids (V), diffusion of chloride ions in Coulombs (C) and water absorption after 72 hours (W_a). The specimens were cast with concrete at a temperature of 32^0C.

Table 2. Compositions to SCC and CC and results of tests of compressive strength and durability

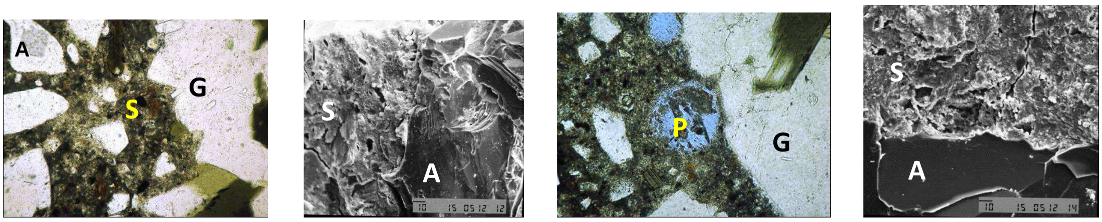
Material	Unit	SCC	CC	Material	Unit	SCC	CC
Cement CP V ARI	kg	419	416	Aggregate 2: 19.10 mm	kg	529	1028
Adding metakaolin	kg	36	36	Water	kg	205	203
Sand 2.36 mm	kg	947	661	Admixture 1: 175 Sikament	ml	3645	2260
Aggregate 1 12.50 mm	kg	227	0	Admixture 2: 5700 Viscocrete	ml	4556	0

Concrete	f_{cm} (MPa)		ρ (kΩ.cm)		X (cm)	
	7 days	28 days	28 days	90 days	28 days	90 days
SCC	36.19	45.86	37.3	64.8	0.258	0.875
CC	33.03	42.69	34.2	60.4	0.888	1.398
Concrete	**V (%)**		**C (Coulombs)**		**W_a (g/cm^2)**	
	28 days	90 days	28 days	90 days	28 days	90 days
SCC	4.31	13.07	828	900	0.821	0.425
CC	6.00	14.97	1517	1250	0.821	0.580

From the results obtained, it is observed that the SCC has in relation to CC: higher compressive strength, higher electrical resistivity which indicates lesser corrosion potential of the reinforcement; lesser depth of carbonation, lower porosity of the concrete based on the smaller voids; less chloride ions better protecting the reinforcement and lower water absorption, resulting in less porous concrete.

Scanning Electronic Microscope (SEM) tests demonstrated that, when observed closely, the concrete is not so homogeneous, making it difficult to establish a feature and characteristic morphology that represents the concrete under study. Various morphologies were observed, and even aggregate/paste interface does not always appear at the same way. Based on these results, it is understood that the absence of vibration and the greater amount of paste on SCC show no substantial differences with respect to CC, being possible to observe even higher porosity in the CC paste (see Fig. 2c). In Figures 2 (a) to (d) **A** represents sand grains, **G** aggregates, **S** paste and **P** pores. Note the higher porosity in CC paste.

Figure 2 – (a) SCC section; (b) SCC SEM images; (c) CC section; (d) CC SEM images



(a) (b) (c) (d)

As shown in Table 3, tomography test was used to identify any difference in durability between SCC and CC samples. For each sample, it was defined a VOI (volume of interest inspection), calculating then the porosity. It was found that the ratio pore volume/VOI is 80% higher in the CC compared to SCC, which indicates better durability condition to SCC. For density, both concretes have the same tendency [9-13].

Table 3. Quantitative results of tomography.

Concrete	Volume quantified (mm^3)	Pore volume (mm^3)	Pore volume / VOI (%)
SCC	119.04	0.66	0.5
CC	119.04	1.08	0.9

CASE STUDY: THE PERNAMBUCO ARENA

To evaluate the practical application of SCC, it was selected a case study: the Pernambuco Arena in Brazil (see Fig. 3) which is under construction to host games from FIFA World Cup 2014, capacity of 46.105 people, building area of 128.000 m^2 using 58.000 m^3 of concrete over six elevations. Of this total, approximately 24.000 m^3 will be SCC. The research on the construction site was developed from May to July

2012. During this period, it was consumed approximately 15,000 m^3 of concrete (26% of the total volume), from which about 6,000 m^3 were of SCC, corresponding to an average volume 2,000 m^3 per month. The concrete applied in the work was specified by the designer, with characteristic compressive strength at 28 days of 40 MPa and water/cement ratio equals to 45% wt to meet Class III of environmental aggressiveness from NBR 6118 [14], recommended for strong environmental aggression.

Figure 3. (a) Aerial view model. F. A. A. (b) Aerial view of Pernambuco Arena in July 2012.

(a)

(b)

The choice of using CAA along with CC was made by the contractor, considering as main factors: structural elements with high density reinforcement; irregular shaped forms with difficult access to vibrators for CC compaction; expected reduction in execution time of structure. The forms used for concreting SCC were of the same kind of the ones used for CC, however, they were reinforced and adapted to take into account the higher pressure of fresh SCC, type of shoring and sealing required. They were framed with steel and plywood used in the faces of contact with the concrete. The materials used in the manufacture of the SCC were not differentiated from CC, including the same type of cement and with the exception of chemical admixtures. The compositions of greater application adopted for the SCC and CC are presented below in Table 4.

Table 4. Compositions to SCC (TRU-009.12-00) and CC (TRU-012.12-00)

Material	Unit	SCC	CC	Material	Unit	SCC	CC
Cement CP-II F 32	kg	499	451	Water	kg	199	180
Sand	kg	856	815	Admixture 1: 175 Sikament	ml	2990	2710
Aggregate 1 12.50 mm	kg	0	0	Admixture 2: 5800 Viscocrete	ml	4490	1804
Aggregate 2: 19.10 mm	kg	830	917	Slumpflow / slump	mm	>700	140

Adjustments were made along time for each composition, with measurement of workability on fresh concrete directly under laboratory conditions in a suitable mixer. The workability of the concrete was around 40 to 60 minutes, according to results of tests. There was a decrease of admixtures performance over time, including acceleration of hydration reactions with temperature. It is presented in Table 5 the following results of measurements and tests carried out on fresh concrete, considering separately the compositions, and compressive strength for the hardened concrete: a)

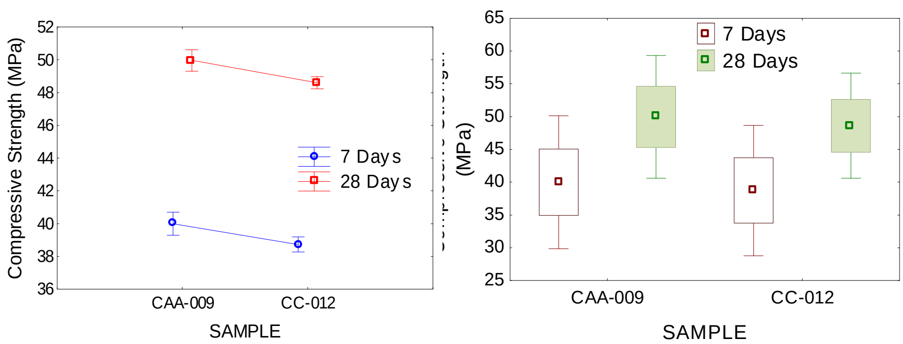
Initial temperature in the mixer (I) and final release - pump (F); b) Slump flow for SCC and slump for CC; c) Compressive strength f_{cj} at seven days (f_{c7}) and at 28 days (f_{c28}) and average compressive strength + / - standard deviation ($f_{cj,\ mean}$). The number of samples corresponds to those ones actually recorded in field.

Table 5. Results of compositions to SCC and CC and summary of the analytical results obtained

SCC - Mix: TRU-009.12-00								
Months	Number of samples	Temp. (°C)		Slump flow (mm)	Seven days		28 days	
		(I)	**(F)**		f_{cj}	$f_{cj, media}$	f_{cj}	$f_{cj, media}$
May	27	34.4	33.8	700	44.1±4.57	39.99± 5.07	48.5±3.49	49.96± 4.69
June	90	32.8	33.1	702	38.1±5.14		49.5±4.98	
July	81	32.1	32.8	705	40.7±4.13		51.0±4.53	
CC - Mix: TRU-012.12-00								
Months	Number of samples	Temp. (°C)		Slump (mm)	Seven days		28 days	
		(I)	**(F)**		f_{cj}	$f_{cj, media}$	f_{cj}	$f_{cj, media}$
May	78	33.9	37.3	159	43.1±3.70	38.7± 4.97	49.0±3.34	48.6± 4.01
June	152	32.4	32.7	160	36.5±4.60		47.5±4.14	
July	235	31.4	31.6	158	38.8±4.60		49.2±4.00	
N°	Mix	Days	Resist. Mean	Resistance Std.Err.	Resistance -95.00%	Resistance +95.00%	N	Coefficient variation (%)
1	SCC-009	07	39.99	0.3604	39.38	40.70	198	0.9013
2	SCC-009	28	49.96	0.3333	49.31	50.62	198	0.6671
3	CC-012	07	38.73	0.2306	38.28	39.19	465	0.5954
4	CC-012	28	48.60	0.1862	48.24	48.97	465	0.3830

Observing Table 5, it can be seen that the temperatures were slightly higher in SCC than in CC. This result was already expected due to SCC higher cement content. From the results obtained, a statistical analysis was performed. Also, presents a summary of the average values of analytical results obtained for the two compositions considering the ages of 7 and 28 days. We used a two-way ANOVA, considering Composition and Day as the two factors and resistance as the response variable. With a significance level of 5%, it was found that there are significant differences between the composition and days (see Fig 4).

Figure 4 – (a) Compressive strength (MPa) versus day and composition; (b) Diagram Box-Plot.



(a) (b)

The test LSD (*Least Significant Difference*, Fisher test) was used to identify individual pairs of means which are statistically different ($p \leq 0.05$). The two compositions are

statistically different for seven and 28 days. Thus, analyzing figure 4 (a) – bars refer to confidence intervals of 95% –, one realizes that in reality the compositions SCC has higher resistance than CC for both ages analyzed, confirming the trend obtained in the preliminary laboratory tests. A possible explanation may be attributed to better hydration of the SCC compared to CC for similar compositions and the same water/cement ratio. An important point to be noted is the very low coefficient of variation expressed (see Fig. 4(a)), which reflects the excellent quality of the experimental data. The bars of the confidence interval, presented (see Fig. 4(b)) emphasize this conclusion.
A comparative study of durability of the SCC (TRU-009.12-00) and the CC (TRU-012.12-00) are under development, as described: a) molding SCC and CC specimens for durability testing under laboratory conditions (see Fig. 5 (a)); (b) casting of slabs with curing by keeping the concrete wet during the first 3 days after exposure to the environment and reproducing the same conditions as applied in workplace, with concrete core extracting to apply the same durability tests performed in specimens kept in laboratory conditions (see Fig. 5(b)). The results will be reported in the near future as a continuation of this research.

Figure 5. (a) Specimens under laboratory conditions. (b) Specimens under exposure to the environment conditions

(a)

(b)

CONCLUSIONS

The results obtained in laboratory testing conditions and in the Pernambuco Arena site showed that the workability of SCC associated with the performance of forms, represented the biggest challenge for the builders, forcing them to keep careful control. Any non-compliance for SCC occurred due to rapid loss of workability or leakage of the cementitious paste from outside the form, while for CC due to deficient vibration of concrete. The test results of mechanical strength and durability indicators showed that the behavior of SCC is compatible with the CC, and even somewhat higher. The overall results of laboratory research shows consistency with applied research results of the concrete applied in the construction of the Pernambuco Arena. Workability, strength and durability were compatible, demonstrating that SCC can be applied on a large scale instead of CC in reinforced or prestressed concrete structures, even in hot climates. Note that the average temperature of 33^0C observed in the construction of Pernambuco Arena can be seen in the upper range.

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