# BETON AUTOCOMPACTANT ŞI OBIŞNUIT PENTRU STADIONUL PERNAMBUCO: STUDIU COMPARATIV AL INDICATORILOR DE DURABILITATE ŞI FEZABILITATE ECONOMICĂ

# SELF-COMPACTING CONCRETE AND CONVENTIONAL CONCRETE IN THE ARENA PERNAMBUCO: COMPARATIVE STUDY OF DURABILITY INDICATORS AND ECONOMIC FEASIBILITY

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***This study addressed the application, strength and durability of self-compacting concrete (SCC) in a large-scale construction site, comparing its performance with vibrated conventional concrete (CC) with similar characteristics, assessing its economic feasibility.***

***The studies were undertaken in the Arena Pernambuco project and involved the concreting during May, June and July 2012, for data collection, accompanying the routine concrete control tests and performing specific strength and durability tests.***

***The SCC compressive strength was on average 4% higher than the CC one, and its formwork reinforced to withstand greater lateral pressure of the fresh concrete. The durability indicators results were in favour of SCC, which cost was 13% higher than CC.***

***Keywords:*** *self-compacting concrete (SCC), durability and applicability on a jobsite*

## 1. Introduction

Although conventional concrete (CC) was regularly used first, since the start of the 20th century, self-compacting concrete (SCC) was developed later and its first application occurred around ninety years later. It is, therefore, necessary to learn more about SCC and validate this relatively new material in its different aspects in order to make possible for designers and builders to specify and apply SCC as an alternative to CC. Rich *et al* [1] studied the acceptance of SCC among UK civil construction entrepreneurs and concluded that the research developed at that time is mainly focused on specific scientific studies related to SCC. However, for taking decisions in the planning phase, the builders are more interested in finding answers for simpler issues, for example, how, when and where to use SCC. In other words, the SCC should be regarded as a method and not just as a material.

Accordingly, the purpose of this study herein presented was to investigate SCC and CC on a real jobsite, examining the actual behaviour of the two types of concrete in large-scale application. The study was developed in order to obtain answers regarding the effective use of SCC instead of CC in hot and wet climate regions, considering a more aggressive environment due to the marine influence and based on the possible economic and technical feasibility of SCC compared to CC. Arena Pernambuco was the site chosen to undertake the study since it is located in the metropolitan region of Recife, which meets the study's desirable environmental requirements. The project was built between 2011 and 2013 to host games of the Confederations Cup 2013 and the 2014 World Cup. It is understood that the competitive edge of SCC will depend on being technically feasible, associated with the broader aspects of workability when applying fresh concrete and the strength and durability of the hardened concrete. But it will also depend on the economic feasibility, which shall be observed either for materials, manufacture and application of SCC [2]. Performance between SCC and CC was also compared based on the test results made on specimens moulded with concrete from different mix-designs used on the site.

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The rheological behaviour of the fresh concrete shows fluidity, unlike the hardened concrete that shows plastic deformation and creep. The yield stress is related to the slump-flow that can physically be interpreted as the stress required to be surpassed, in order to start the flow of the fluid mixture. Accordingly, the more the stress, the harder it will be for the SCC to start flowing, which means less workability. The progressive physical-chemical interaction and subsequent alterations of the fresh behaviour of the composite material is time depend [3].

The available time is a major challenge that must be accomplished, involving the start of the batching and its conclusion, including the compaction into the formwork and the beginning of curing phase. The stages considered when applying the fresh concrete are: batching, transportation, pouring, compacting and finishing the concrete in the formwork. Each stage requires compatible workability. In order to assure the SCC's self-compactness, one may be concerned with its fluidity, filling capacity, viscosity, pouring capacity and yield stress. The initial curing time, together with the consistency and cohesiveness of the fresh concrete, determines how long the batching remains plastic and workable, and may be handled and applied on the jobsite. For regions with higher temperatures, as the case of Recife, the time available for applying the fresh SCC could be shorter than in regions with a cooler climate. The batching operation requires a minimum time in order to produce an uniform concrete composition to fulfil the specified mechanical strength, taking into consideration the type of batching equipment, number of rotations and applied energy [4 - 6].

Some factors may affect workability by reducing it: cement content, cement properties, aggregate conditions, prolonged batching time, performance of plasticizing and super-plasticizing chemical admixtures and temperature. Plasticizers are water-reducing admixtures that modify viscosity and it is expected that they stabilize the cementitious paste by increasing the viscosity of the aqueous solution. Super-plasticizers have effects on the dispersion of cement particles by steric or electrostatic repulsion, with strong water-reducing characteristics. The adsorption of the chemical admixture may extend the maintenance of the fluidity by dispersing the cement particles. However, the concentration of sulphate ions in the solution may help reducing the intensity of the steric effect of the polymer, causing an exponential increase in the flow resistance of the mixture, which may explain the admixture's loss of efficiency in the jobwork, reducing workability and restricting concreting operations. This effect is particularly, noted at high temperatures where the internal reactions of the concrete occur sooner. It is found that curing time takes a much longer time when high contents of chemical admixtures are used, regardless of the type of cement applied. Moreover, the consistency of the cementitious paste, its performance and cost, leads to an attempt to determine the ideal super-plasticizer content to be specified in a composition based on its saturation content. The cement and super-plasticizer are bonded by physical and chemical interactions that lead to characteristics different to both the fresh and hardened concrete, including the hydration process. The higher temperature causes an initial fast hydration rate retarding the subsequent hydration and producing an uneven distribution of the hydration products within the paste. This is due to a high initial hydration rate that reduces the available time required for diffusing the hydration products far from the cement particles and for uniform precipitation in the interstitial spaces, as occurs at low temperatures. So, the concrete applied and cured at a high temperature hardens faster but has less strength than that applied and cured at lower temperatures [4, 7, 8 - 13].

Other executive aspects worth mentioning are the formwork, design and implementation and the pouring process, such as pumping, for example. To improve the pumping of the concrete De Schutter [14] studied the topic and provided the following recommendations: enhancement of the grading curve; paste and fines content; increase in the cement content; seeking a low water/cement ratio associated with the fluid consistency; application of viscosity modifying agent. Improving the pumpabiliity is understood to be a reduction in pumping pressure, in friction and mechanical wear of the components, increase in productivity, reduction in line blockage and energy saving. The pouring process affects the SCC lateral pressure on formwork. Based on the studies carried out by Torgal and Jalali [15], it is found that to reduce the costs of special formwork for SCC, the following should be considered: influence between thrust, composition and consistency of SCC; concreting from the top or bottom; reinforcement density; material used in the manufacture and assembly of formwork; control of pouring velocity and ongoing monitoring of thrusts on the formwork. Khayat and Omran [16] undertook studies and concluded that the thixotropic level and pouring rate of the SCC have significant influence on the lateral pressure exerted by the SCC on the formwork. The higher the level of the SCC thixotropy the lower the lateral pressures, the higher the pouring rate, the greater the lateral pressures. Silva and Brito [17], based on the formers studies, noted that for initial higher temperatures there was a reduction in the SCC pressure on the formwork as a result of the hydration process and faster hardening, due to the development of greater cohesion and consequent diminished pressure.

In relation to the curing methods, Girish *et al* [18] had performed a comparison of compressive strength of the concrete for different curing methods, such as wet curing, with air, with membrane and self-curing. Immersion, mist or spraying, jute or wet cloth are considered water-adding techniques, while plastic sheets, delayed removal of the formwork and curing membranes are water-retention techniques. The results showed that the wet curing method led to higher compressive strengths for both seven (7) and 28 days of curing.

The strength and elasticity modulus of SCC were studied by Desnerck [19] from a database obtained from more than 250 publications in which, when comparing SCC and CC, it was found that SCC strengths were around 10% higher, possibly due to the greater density of the microstructure of the self-compacting concrete. It was also found that the type of aggregate and volume of paste have a slight influence for the elasticity modulus. For the creep coefficient, there is an increase of 5-10% when the powder content increases, which will require closer attention when controlling the deformations for SCC, such as when stressing cantilever bridge constructions [20].

The durability of the concrete is adversely influenced by the transportation of fluids such as pure water or carrying chloride ions, carbon dioxide and oxygen, in addition to possible mechanical damage. These fluids can penetrate and move inside the concrete through pores, by permeation, diffusion, capillary suction and absorption. The interconnected pores increase the permeability. Carbon dioxide leads to the carbonation of the hydrated paste and the oxygen permits the advance of the corrosion of reinforcements embedded in concrete. The result is that dense and only slightly permeable concrete greatly reduces the penetration of aggressive agents, restricting corrosive attacks only on its surface. The water/cement ratio, temperature, degree of hydration, mineral additions, capillary porosity, permeability and other factors influence the durability of the self-compacting concrete and vibrated conventional concrete [5, 21, 22].

## 2. Experimental procedure

The research studies were carried out on the Arena Pernambuco jobsite during its construction, along three different phases: (a) first phase of the survey on the structural design, executive methodology adopted, materials used and application of a questionnaire to obtain information about the partial progress of the work with identification of the achievements, problems encountered and corrective actions taken; (b) second phase of the survey on the worksite to accompany the executive stages with data collection onsite and undertaking specific tests on the survey, in May, June and July 2012 and (c) assessment of the information gathered and results of the tests done in order to obtain possible answers to the objectives of the applied survey.

To respond to a possible feasibility of applying fresh SCC on a large scale, the survey concentrated on the following aspects: studies to determine the compositions to be adopted; choice of classes of slump-flow (SCC) and slump (CC); available workability time for the transportation, pouring, thickening and finishing operations; type of pouring adopted to place the SCC in the formwork; behavior of the formwork given the expected greater lateral pressure of the fresh SCC and performance of chemical admixtures for maintaining the SCC workability during concreting and finishing operations. The slump-flow tests were based on european standard EN 12350-8:2010 [23]; slump tests were based on standard EN 12350-2:2009 [24].

To develop the experimental programme on the jobsite one has selected the most representative compositions. Thus, SCC-009 and CC-012 (see Table 1) were chosen. Both had the same water/cement ratio (0.40); the same type of cement (CEM II/A-L); the same type of aggregates and admixtures and larger volumes of this two selected concretes were applied on site. The studies were performed equally for both chosen compositions of SCC and CC, to enable a comparison of performance between them, from two types of samples: type 1, moulded test samples in accordance with the standard recommendations, with storage in laboratory conditions (CP) (see Figure 1); type 2, test samples taken from moulded and cured concrete blocks simulating the same environmental conditions of the moulded concrete in the project's structural elements, called test cores (TE) (see Figure 2). Compressive strength, elasticity modulus and durability tests, were carried out in the laboratory, on the Arena Pernambuco jobsite.

Fig. 1 - Standard test samples (CP).

Fig 2 - Core test samples (TE).

The durability tests applied to the test samples (CP) and test cores (TE) were: chloride ion diffusion; water absorption by capillarity; calculation of the void ratio.

The compressive strength test was performed based on standard EN 12390-3:2009 [25]. The elasticity modulus test was based on standard EN 12390-13:2013 [26]. All CP and TE samples were tested at 33 days old. Chloride ion diffusion test was based on standard ASTM C1202:2012 [27]. Water absorption by capillarity was based on standard ASTM C1585-13:2013 [28]. Calculation of the void ratio was based on standard ASTM C642-13:2013 [29].

It should be mentioned that the study on the jobsite was not restricted to taking results from the systematically developed work on site but the performance of both SCC and CC concretes was also studied by means of durability and mechanical strength tests on the hardened concrete, simulating actual situations of exposure of these concretes to the real environment where they were applied.

The economic feasibility study was made for comparing selected materials's costs in each SCC and CC compositions, in order to be able to compare among the two concretes and with the existing bibliographic references.

The Arena Pernambuco project was a major onsite research laboratory, with a built-up area of 128,000 $m^2$ with capacity for 46,105 people, its structure being built in reinforced concrete at all levels, including the stand areas. The designed volume of concrete was 58,000 m³, distributed over six levels, 40% (23,200 $m^3$) being SCC and 60% (34,800 $m^3$) CC. The foundations consisted of slabs laid directly on the ground and root piles casted on site. The local environment has the following annual average statistics: temperature 26°C; relative humidity of the air 80%; rainfall 2,418 mm; sunlight equal to 2,551 hours and marine influence since it is a city by the sea accordingto National Weather Institute (INMET) [30].

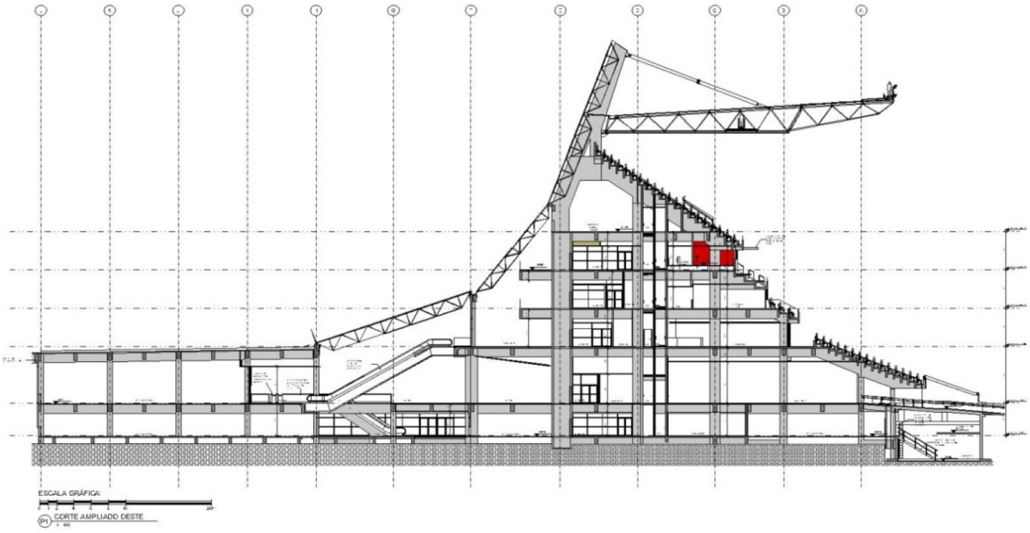

Fig. 3 – Vertical section showing six floor levels and cable-stayed metal structure overhang.

**Table 1**

SCC and CC compositions applied in the survey

| | Compositions | | | | |
|---|---|---|---|---|---|
| | SCC - 009 | SCC - 017 | SCC - 024 | CC - 012 | CC - 019 |
| Type of cement | CP-II F 32 | CP-IV 32 RS | CP-II F 32 | CP-II F 32 | CP-IV 32 RS |
| Cement consumption | 499 | 525 | 532 | 451 | 476 |
| Sand | 856 | 778 | 732 | 815 | 681 |
| Crushed stone 19 mm | 830 | 798 | - | 917 | 946 |
| Crushed stone 12.5 mm | - | - | 778 | - | - |
| Water | 199 | 236 | 215 | 180 | 214 |
| Ratio (W/C) | 0.40 | 0.45 | 0.40 | 0.40 | 0.45 |
| Plasticizer | 3.44(1) | 4.83(2) | - | 3.12(1) | 4.38(2) |
| Super-plasticizer | 4.94(3) | 5.78(4) | 4.13(3) | 1.98(3) | 2.09(4) |
| Strength $f_{ck,28}$ (MPa) | 40 | 40 | 40 | 40 | 40 |
| Slump flow/Slump (mm) | > 700 | > 700 | > 700 | 140 ± 20 | 140 ± 20 |
| Applications | Walls & pillars | Walls & pillars | Precast | Beams | Foundations |

Cements: CP-II F 32 equivalent to CEM II/A-L; CP-IV 32 RS equivalent to CEM IV/B 32.5
Unit: kg/$m^3$
Plasticizer: (1)SIKAMENT PF 175; (2)VIAMIX 261R
Super-plasticizer: (3)VISCOCRET 5800; (4)VIAFLUX 2200

Figure 3 shows the vertical section drawing representing the structure, showing the six floor levels and the cable-stayed metallic roof.

From the group of concrete compositions used during the stages of the work, three SCC and two CC were adopted, chosen for their larger volume applied in during the research period on the site, with the same strength $f_{ck}$ of 40 MPa. In all of these compositions, the same components were used. SCC-009, SCC-024 and CC-012 had a water/cement ratio of 0.40. SCC-017 and CC-019 had a water/cement ratio of 0.45.

Characterization data of the fresh concrete were collected: slump-flow for SCC and slump for CC as well as compressive strength for the hardened concrete. These results and details of the five selected compositions, plus the type of structural element where each composition was applied, are provided in Table 1.

## 3. Results and discussions

Between May and July 2012 the construction of Arena Pernambuco was at the stage of implementing the superstructure and beginning to erect the precast structures of the top and bottom stands (see Figure 4). The use of self-compacting concrete at this stage was intensified; all precast structures of the stands, support beams and stairways were built in SCC, plus the pilllars and walls of the access ramps (see Figure 5). During the aforementioned period approximately 15,000 m³ of concrete were applied, around 26% of the total expected for the project; around 40% of this (6,000 m³) was SCC, corresponding to a monthly average volume of 2,000 m³. The decision to study and apply SCC in the Arena Pernambuco project was taken by the technical division of the building company, considering principally the existence of structural elements with high reinforcement density, which difficult the access for the vibrators to compact the CC, a requirement for pouring the concrete at higher free heights and shorter completion deadlines. This aspect was in accordance with the one referred by Rich *et al* [1], where the decision to apply SCC instead of CC was not included in the planning stage of the project.

Concrete plants were installed on the jobsite. The concrete was transported in truck mixers and poured by pumping. The setting time required to carry out the operations from the production to completing compaction and finishing in the formwork, was no more than 90 minutes. Therefore, this maximum time for the SCC to achieve the necessary workability was one of the key variables for establishing the compositions to be applied. It is worth mentioning the following in relation to the concrete components: Binders: two types of cement were applied: CP-IV 32 RS (equivalent to CEM IV/B 32.5), Portland pozzolanic cement applied to the foundation elements, the pozzolana being metakaolin, a clay thermally activated at 600°C-700°C; CP-II F 32 (equivalent to CEM II/A-L), compound Portland cement with limestone filler applied to the superstruture elements. Aggregates: the aggregates were selected considering their potential reactivity with alkali. The approved deposits were monitored and alkali-aggregate reactivity and petrographic tests were performed every six months to accompany the supply. Admixtures: the initial difficulty was the compatibility of chemical admixtures to meet the requirement of the compositions, especially regarding pouring time and maintenance for both types of cement used. The task was the workability of the concrete to stay within the necessary maximum time of 90 minutes with an average gauged temperature of 34°C. Thirteen experimental compositions were tested with an application of 20 plasticizer and super-plasticizer chemical admixtures supplied by seven different manufacturers, with a dosage varying between 0.8% and 1.4%, a slump-flow of 700-745 mm and slump-flow an hour later varying between 630 mm and 685 mm. Five of the 13 compositions studied met the technical requirements (see Table 1). Composition SCC–024 was applied to the precast elements of the stands, which were moved from the production line yard to supporting cradles all along the parts, until removed for transportation and pouring into the final supports, 24 hours after concreting.

The industrialized formwork adopted needed to be adapted to withstand the lateral pressures created by the fresh SCC and also to

Fig. 4 – Stands.

Fig. 5 - Access ramps.

enable better finishing of the concrete surfaces. They were structured with steel and plywood was used on the concrete-concrete sides, with better insulation of the panel joints to prevent fines leaking from the mortar.

Table 2 shows the results collected on the jobsite from the technological control of concrete between May and July 2012. The average values of each group of results are presented, based on the number of samples considered. The initial temperature was measured in the concete plant, while the final temperature was measured in the pump during the pouring operation. The slump-flow was measured for the SCC and the slump for the CC.

Table 3 displays the results collected on the jobsite for the technological control of the concrete from May to July 2012. The average values of each group of results are presented based on the number of samples considered. The results consider the five analyzed compositions, with the results obtained in May, June and July 2012. The total SCC and CC volume applied to each composition in the three above months is also indicated.

The statistical analysis confirmed the excellent quality of the experimental data, since the variation coefficients (standard-error/average) had a low value (below 10%). The confidence interval bars, shown in Figure 6, reinforce this conclusion. It can be said that the repetitiveness of the experiments was excellent, despite the fact that the experimental data were obtained on the jobsite, without the sophistication of a research laboratory.

**Table 2**

Results of temperatures and slump-flow/slump

| Month (2012) | No. of samples | Initial temperature (°C) | Final temperature (°C) | Slump-flow/slump (mm) |
|---|---|---|---|---|
| Composition: SCC – 009 (Applied volume = 2763 $m^3$) | | | | |
| May | 27 | 34.4 | 33.8 | 700 |
| June | 90 | 32.8 | 33.1 | 702 |
| July | 81 | 32.1 | 32.8 | 705 |
| Composition: SCC – 017 (Applied volume = 1084 $m^3$) | | | | |
| May | 22 | 34.2 | 35.0 | 699 |
| June | 30 | 33.1 | 33.9 | 703 |
| July | 34 | 31.8 | 31.9 | 706 |
| Composition: SCC – 024 (Applied volume = 2198 $m^3$) | | | | |
| May | 01 | 35.6 | - | 750 |
| June | 24 | 31.5 | 33.7 | 710 |
| July | 161 | 30.2 | - | 730 |
| Composition: CC – 012 (Applied volume = 6106 $m^3$) | | | | |
| May | 78 | 33.9 | 37.3 | 159 |
| June | 152 | 32.4 | 32.7 | 160 |
| July | 235 | 31.4 | 31.6 | 158 |
| Composition: CC – 019 (Applied volume = 2526 $m^3$) | | | | |
| May | 04 | 34.9 | - | 158 |
| June | 95 | 32.0 | 32.2 | 158 |
| July | 153 | 30.8 | 31.2 | 157 |

**Table 3**

Results of compressive strength for seven (7) and 28 days

| Month (2012) | No. Samples | Strength (MPa) 07 days | Average (±) Standard deviation | Strength (MPa) 28 days | Average (±) Standard deviation |
|---|---|---|---|---|---|
| Composition: SCC – 009 (Applied volume = 2763 $m^3$) | | | | | |
| May | 27 | 44.1±4.57 | 39.99±5.07 | 48.5±3.49 | 49.96±4.69 |
| June | 90 | 38.1±5.14 | | 49.5±4.98 | |
| July | 81 | 40.7±4.13 | | 51.0±4.53 | |
| Composition: SCC – 017 (Applied volume = 1084 $m^3$) | | | | | |
| May | 22 | 45.4±4.17 | 39.40±6.12 | 50.1±3.05 | 49.80±4.60 |
| June | 30 | 36.6±5.22 | | 49.1±5.89 | |
| July | 34 | 37.8±5.28 | | 50.3±4.15 | |
| Composition: SCC – 024 (Applied volume = 2198 $m^3$) | | | | | |
| May | 01 | 37.3±3.82 | 41.60±4.36 | 42.2±4.32 | 50.50±4.56 |
| June | 24 | 40.1±3.73 | | 49.7±3.84 | |
| July | 161 | 41.9±4.41 | | 50.7±4.63 | |
| Composition: CC – 012 (Applied volume = 6106 $m^3$) | | | | | |
| May | 78 | 43.1±3.70 | 38.70±4.97 | 49.0±3.34 | 48.60±4.01 |
| June | 152 | 36.5±4.60 | | 47.5±4.14 | |
| July | 235 | 38.8±4.60 | | 49.2±4.00 | |
| Composition: CC – 019 (Applied volume = 2526 $m^3$) | | | | | |
| May | 04 | 40.5±5.49 | 34.20±4.89 | 52.4±2.58 | 47.50±4.01 |
| June | 95 | 32.1±5.21 | | 46.1±2.95 | |
| July | 153 | 35.3±4.11 | | 48.2±4.31 | |

Figure 6 shows the graph of the results of compressive strength at seven (7) and 28 days of SCC-009, 017 and 024 and for CC-012 and 019 compositions, shown in Table 3.

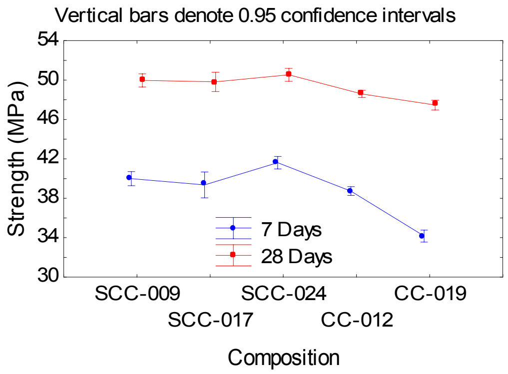

Fig. 6 – Results of strengths for seven (7) and 28 days. Compositions presented in Table 1.

Table 4 provides the results of the set of specific tests in the study performed on the jobsite with test samples (see Figure 1) SCC-009 (CP), CC-012 (CP) and test cores (see Figure 2) SCC-009 (TE) and CC-012 (TE). The results refer to the following tests: compressive strength; elasticity modulus; water absorption by capillarity and void ratio. The results for compressive strength and elasticity modulus refer to the average values of five (5) specimens for each test performed. The samples (CP) and (TE) were tested at an age of 33 days; the chloride ion diffusion tests were performed on specimens with 60 days of age; the water absorption by capillarity and void ratio tests were performed on specimens with 35 days old. The water absorption results give readings for 72 hours of testing.

Figure 7 shows the compressive strength results at 33 days of age for the SCC – 009 and CC-012 compositions presented in Table 4. Figure 8 shows the results of the elasticity modulus at the same age for the SCC-009 and CC-012 compositions presented in Table 4.

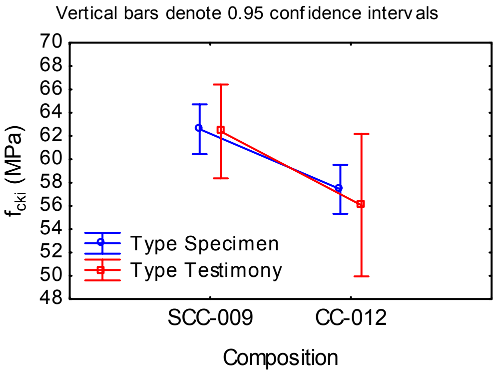

Fig. 7 – Results of compressive strength at 33 days old. Compositions presented in Table 1.

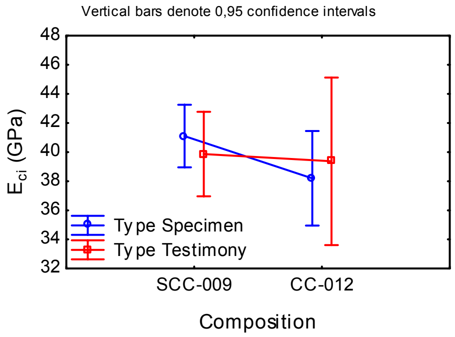

Fig. 8 – Results of the elasticity modulus at 33 days old. Compositions presented in Table 1.

**Table 4**

Results of the set of specific tests of the study on the jobsite

| Test | Composition | Type of sample | Result |
|---|---|---|---|
| Strength $f_{ckj}$ (MPa) | SCC-009 | CP<br>TE | 62,58 ± 1,72<br>63,14 ± 3,22 |
| | CC-012 | CP<br>TE | 57,42 ± 1,69<br>56,73 ± 3,65 |
| Elasticity modulus $E_{ci}$ (Gpa) | SCC-009 | CP<br>TE | 41,10 ± 0,87<br>39,90 ± 1,17 |
| | CC-012 | CP<br>TE | 38,20 ± 1,31<br>39,40 ± 2,32 |
| Chloride ion diffusion Average charge passed in Coulombs (C) | SCC-009 | CP<br>TE | 1665<br>2585 |
| | CC-012 | CP<br>TE | 2040<br>2940 |
| Water absorption by capillarity (g/cm$^2$) | SCC-009 | CP<br>TE | 0,424<br>0.446 |
| | CC-012 | CP<br>TE | 0.467<br>0.573 |
| Void ratio $I_v$ (%) | SCC-009 | CP<br>TE | 8.99<br>11.24 |
| | CC-012 | CP<br>TE | 10.59<br>12.22 |

The values of the results above refer to the average of the results for each specimen of tested samples: five (5) specimens for compressive strength and elasticity modulus tests; three (3) specimens for chloride ion diffusion, water absorption capillarity tests and calculation of the void ratio.

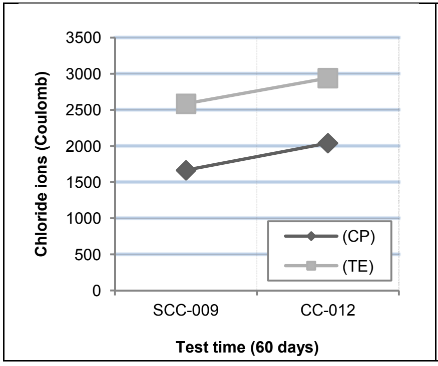

Fig. 9 – Chloride ion diffusion.

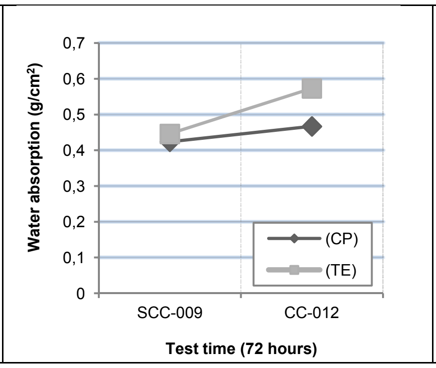

Fig. 10 – Water absorption.

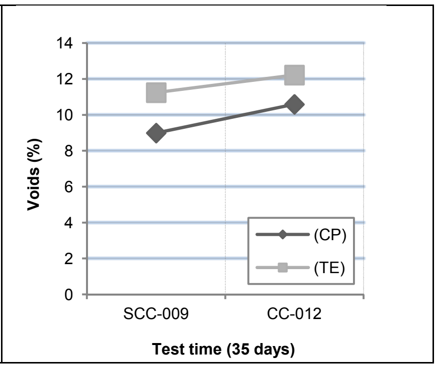

Fig. 11 - Void ratio.

Table 5

Comparative cost of compositions SCC-009 and CC-012.

| Materials (kg/m$^3$) | Compositions | | | |
|---|---|---|---|---|
| | CC-012 | | SCC-009 | |
| | Quantity | Cost 1 | Quantity | Cost 2 |
| Cement | 451 | 100 | 499 | 110.64 |
| Sand | 815 | 100 | 856 | 105.03 |
| Crushed stone 19 mm | 917 | 100 | 830 | 90.51 |
| Water | 180 | 100 | 199 | 110.56 |
| Plasticizer | 3.12 | 100 | 3.44 | 110.33 |
| Super-plasticizer | 1.98 | 100 | 4.94 | 248.89 |
| Total | | 100 | | 113.45 |

Figures 9, 10 and 11 show the results of the chloroide ion diffusion, water absorption by capillarity and void ratio tests, respectively. All the graphs were drawn based on the results presented in Table 4 for samples CP and TE of the compositions SCC-009 and CC-012.

Table 5 shows the comparative cost between compositions SCC-009 and CC-012 based on the quantitative of the materials deployed, applying a weight that took into account the variation of quantities and unit cost of the materials used in the two compositions analyzed.

An approximate increase was found of 13.45% in the unit cost of SCC in relation to CC, taking into consideration only the cost of the materials used.

The cost of the SCC may decrease by reducing the consumption of super-plasticizer in the SCC, for example.

## 4. Conclusions

The results were obtained by applying the adopted working methodology. Accordingly, after performing the study on the Arena Pernambuco jobsite, some conclusions can be offered as follows:

1) The self-compacting concrete was applied in the Arena Pernambuco due to two main reasons: to make easier, or even possible, the concreting of structural elements with high reinforcement density and to accelerate the time needed for stadium conclusion.

2) The workability of fresh SCC for at least 90 minutes was a big challenge for builders and was obtained by careful technological control of concrete. Thus, all the concrete placement operations were performed without problem. The average of slump-flow for SCC was 713 mm and the average of slump for CC was 158 mm.

3) Another major challenge was to use typical forms for CC and apply SCC with reinforcement adaptations. In fact it was verified that the pressure of SCC on the formwork was higher than to the CC.

4) The structural design did not have a supplementary analysis regarding the partial substitution of the CC for SCC. So the analysis was restricted to the systematic check of the compressive strength results and the asystematic check of the elasticity modulus.

5) For hardened concrete, SCC showed average compressive strengths 8.27% higher than those of the CC at 7 days and 3.83% at 28 days of age. SCC showed average elasticity modulus higher 4.38% than those of the CC at 33 days of age.

6) Durability indicators of hardened concrete showed that the SCC had performed better than the CC, both for CP and TE specimens. The average results were: chloride ion diffusion of CC was 18% higher than SCC; water absorption of CC was 19% higher than SCC and void ratio of CC was 13% higher than SCC.

7) The increased cost of SCC in relation to CC obtained was 13.45% taking into account only the materials cost. Considering that SCC allows a reduction on the execution time, workmanship and

enables the concreting of structural elements difficult to perform with CC, as it was detected at Arena Pernambuco, one can conclude that SCC usage complies economic feasibility.

Therefore, the results of the study have shown that there is a huge possibility for using self-compacting concrete as a feasible alternative to the use of vibrated conventional concrete even in warmer climates.

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