Development of self-compacting concretes using rice husk or fly ashes and different cement types

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Abstract

Self-compacting concretes (SCCs) are considered promising materials in the civil engineering field. Their main characteristic is the ability to compact only through gravitational force. Mineral additions such as rice husk ash (RHA) and fly ash (FA) are recommended to be used in SCCs during their mix designing, in order to increase fluidity and mechanical strength. These materials are also considered wastes from industry, without a certain destination, which contributes to environmental pollution. In this study, four mixtures of SCC were tested using RHA and FA with two different types of Portland cement, CEM CP IV and white CEM. For the fresh state tests, all of the SCCs mixtures showed satisfactory results. The SCCs with white CEM showed higher mechanical strength at 7 days than CEM CP IV. Analyzing the mineral additions, their use improved the mechanical strength of SCCs at 28 days, there is also observed a higher pozzolanic effect to RHA.

Keywords: Self-Compacting Concrete; Rice Husk Ash; Fly Ash; CP IV Cement; White Cement.

1. Introduction

The self-compacting concretes (SCC) comprehend a class of concretes that, in the fresh state, can be compacted only through gravitational force (Omran *et al*., 2017; Pelisser *et al*., 2018). They normally have more cement paste than the traditional concrete, to obtain the desirable flowability (Memon *et al*., 2011; Kannan e Ganesan, 2014; Sainz-Aja *et al*., 2019). To achieve the ideal proportion, with ideal packing density, high fluidity, and viscosity, it is necessary to use chemical admixtures, such as superplasticizers and a high rate of fine particles. It implies a material with great properties in the fresh and hardened state (Juradin *et al*., 2014; Barluenga *et al*., 2015).

The use of fillers and admixtures can represent a high cost for the industry. The non-use of vibration indicates a great economy, reduction in noise pollution, and good surface appearance. The exclusion of the use of dipping vibrators and workers to operate the equipment represents an economy for the civil engineering industry. Also, for projects that require a structure with a high density of reinforcement, it implies a great advantage (Tutikian and Pacheco, 2012).

The reuse of industrial by-products as supplementary material in the products of civil engineering is a way that facilitates access to SCC technologies (Santos *et al*., 2019). Materials, such as rice husk ash (RHA) and fly ash (FA), are mineral admixtures considered environmental wastes. The RHA is a by-product formed during the calcination of the rice husk. The FA, in turn, is obtained directly from thermal power plants (Mahalingam *et al*., 2016).

Nowadays recycled materials have been studied as replacement of course aggregate in SCC (Silva *et al*., 2014), replacement of the cement using byproducts of the manufacture of white cement production (Ashteyat *et al*., 2018), and even the use of fly ash (Matos *et al*., 2019). A good option is to use these residues in concretes as a replacement for Portland cement. It implies not only improvement of the properties of the concrete, but also, decreases the clinker factor used. Thus, it is possible to dispose of this industrial waste, usually discarded in landfills, as precursor material for civil construction that enhances mechanical properties, but also to reduce CO_2 emissions by reducing the clink factor of the cements (Mahalingam *et al*., 2016).

Silva and Brito (2015) observed that FA and limestone fillers have a potential as an addition in SCC due to their synergetic interactions, improving fresh and hardened properties in SCC.

Matos *et al*. (2019) verified that higher replacement of Portland cement with fly ash in SCC results in an increase of fluidity due to the spherical and smooth particles of the mineral admixture. The authors replaced up to 60% of the Portland cement with a gain in the binder index of the samples over 90 days of hydration. Bacarji et al. (2016) evaluated the influence of by-products from crushed coarse aggregate for SCC production. The authors observed that granite and silica fume improved the mechanical and sustainable properties of SCC.

When used in SCC, mineral admixtures provide changes in the cement paste, as in the fresh and hardened state. The changes in the fresh state are related to the viscosity that the mineral additions provide, which increases the self-compacting potential. In the hardened state, the most important effect is related to the higher durability, because of the smaller capillary absorption. This fact explains that the SCCs tend to have a lower porous rate and permeability than conventional concretes (Oliveira *et al*., 2006; Mir and Nehme, 2015).

Another parameter that influences the fresh and hardened properties of SCC is the type of cement used. In the fresh state, the most important parameters to quote are related to the physical and chemical characteristics of the cement, such as granulometric distribution, surface area, morphology, the content of C_3A, loss of ignition, type of calcium sulfate added to the clinker and the alkali content. In the hardened state, it is necessary to know the contents of C_3S, C_3A, and C_2S that each cement must have to improve the strength and durability development due to the kinetic reaction of this phase. Since the cements have specific compositions and characteristics, the final SCC will present different results in the tests performed (Castro *et al*., 2011; Okamura *et al*., 2008; Jansen *et al*., 2012).

The objective of this study is to investigate the viability of the production of SCC produced with two cement types (CEM CP IV and white cement) using different mineral additions (rice husk ash and fly ash). Investigations of the fresh properties (fluidity, workability, segregation resistance) and hardened properties (compressive and tension strength) of the SCCs formulated were carried out.

2. Materials and methods

2.1 Materials

In this research, the materials used were: White Cement Weber Saint-Gobain® (White CEM) and CEM CP IV Votoran® Portland cements, crushed stone as coarse aggregate (particle size under 9.5 mm) from the Pedra Rosada® crusher, fine sand from the Ibicuí river bed, superplasticizer, and viscosity modifier additives from the company Grace Construction Products®, rice husk ash of controlled combustion in fluidized bed from the company Pilecco Nobre® and fly ash from the Jorge Lacerda® thermoelectric plant.

The chemical composition of the Portland cements (CEM CP IV and white CEM), the rice husk ash, and the fly ash are shown in Table 1. Energy Dispersive X-Ray Spectrometer 700 (EDX 700, Shimadzu®) was used to identify the oxide content of each material. The Bogue method was applied to obtain the mineralogy composition of the cements, to CEM CP IV the pozzolanic content was excluded from the calculation. White cement presented low C_4AF content due to the influence of this phase on the color of the cement. Higher C_2S and C_3A content is observed in the cement with additions.

The specific gravity values of 2.84 g/cm³ and 3.04 g/cm³ were obtained to CEM CP IV and White Cement (WC), respectively. The rice husk ash and fly ash presented a specific gravity of 2.03 g/cm³ and 2.00 g/cm³, respectively.

Table 1 - Chemical and physical properties of materials (by weight).

Component	CEM CP IV	White CEM	RHA	FA
SiO_2	12.31	20.28	92.74	60.93
Al_2O_3	3.91	3.06	-	24.54
Fe_2O_3	2.14	0.18	-	5.12
CaO	74.65	65.47	0.55	1.51
MgO	1.04	1.03	-	-
SO_3	2.00	2.57	-	0.29
C_3S	52.02	67.05	-	-
C_2S	19.10	11.43	-	-
C_3A	11.64	9.65	-	-
C_4AF	10.79	0.42	-	-
LoI	3.24	10.54	4.45	4.62
Specific gravity (g/cm³)	2.84	3.04	2.03	2.00
Blaine fineness (m²/kg)	326.7	512.5	1174.0	300.2

LoI: Loss on ignition

The CEM CP IV, White CEM, RHA, and FA had Blaine fineness values of 326.7 m²/kg, 512.5 m²/kg, 1174.0 m²/kg, and 300.2 m²/kg, respectively. Superplasticizer additive based on polycarboxylate ether with a solid content of 0.23 and specific gravity equals 1.06g/cm³ was also used. In summary, between the cements, CEM CP IV presented a larger particle size and less C_3S content, probably affecting its reaction at first ages. Regarding the additions analyzed, it is observed that RHA presented a greater particle fineness and FA showed a fineness similar to CEM CP IV.

Pozzolanic activity of the RHA and FA was determined according to NBR 5752 (2014), where a strength activity index was obtained at 28 days of hydration through compressive strength tests. The pozzolanic activity is calculated by the ratio of control sample (100% CEM II) and 25% ash substitution strengths. The results show 122% and 76% of pozzolanic activity of RHA and FA, respectively. An improvement in mechanical strength is seen when using RHA, likely due to an acceleration of hydration reactions. RHA have pozzolanic activity because the mechanical strength is higher than 90% of the control sample, however, FA showed lower reactivity, not considered pozzolanic material in this test.

2.2 Mix proportion

Towards the preparation of the self-compacting concrete (SCC) specimens, two different cements were used. The dosage of the superplasticizer and the mineral addition content was done through mini-slump tests, where a paste with a final diameter of 180 mm ± 10 mm was obtained and a time to reach 115 mm in the range of 2 s to 3.5 s.

To achieve this mini-slump parameter, a small content of rice husk ash (RHA) was used (3.57%) for the CEM CP IV composition and the greater fly ash (FA) content was used as an addition (30%), for white CEM composition. The paste dimensions for mini-slump test are presented in Figure 1.

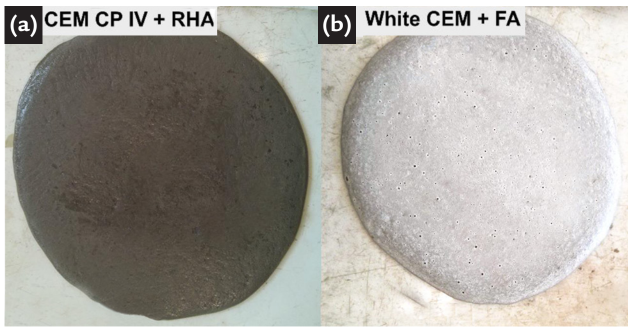

Figure 1 - Mini-slump results for (a) CEM CP IV + RHA and (b) White CEM + FA.

2.3 Design method to obtain self-compacting concrete

The SCC were designed according to the Gomes, Gettu, and Agulló method of mix design (Gomes *et al*., 2001). In this method, the mixture occurs in 3 steps, which comprises the definition of:

Initially, the **granular aggregate packing** through the ideal percentage of sand and gravel that optimize the SCC mixture is defined. This proportion corresponds to the combination of both aggregates with a smaller rate of air void ratio. Obtaining this parameter represents a lower percentage of voids in the aggregates and results in lower cement paste consumption. Therewith the shrinkage and porosity of the hardened concrete will be reduced.

To determine the granular skeleton of this study, sand and gravel were tested in 7 different mixtures, with percentages that varied in a range of 35/65 to 65/35 sand/gravel, with changes of 5%. The aggregates were homogenized with a total mass of 15 kg in a concrete mixer for 1 minute, being after submitted to the test of apparent specific gravity, according to the Brazilian technical standard NBR 16972 (2021).

With the results obtained after the mixtures, it was possible to determine the void volume through Equations 1, 2, and 3. Where **Vv** = Void volume; ρ**dm** = Specific gravity of the dry mixture; **Bd** = bulk density of the mixture; ρ**ds** = Specific gravity of the dry aggregate; **s/a** = Sand/aggregate ratio; ρ**dg** = Specific gravity of the dry gravel; **g/a** = Gravel/aggregate ratio; **Twm** = Total weight of the mixture; **Tvm** = Total volume of the mixture.

$$Vv\,(\%) = \frac{\rho dm - Bd}{\rho dm} * 100 \quad (1)$$

$$\rho dm = \frac{\left(\rho ds * \frac{s}{a}(\%) + \rho dg * \frac{g}{a}(\%) \right)}{100} \quad (2)$$

$$Uwm = \frac{Twm}{Tvm} * 100 \quad (3)$$

Then, the **initial cement content and volume of cement paste** were calculated, whereby the initial cement content was selected arbitrarily to achieve the initial paste volume. In this process, the parameters were determined according to the superplasticizer, filler, pozzolans and water of the SCC, through the Equations 4, 5, 6, 7, 8, 9, 10 and 11. Where **Ipv** = Initial paste volume; **C** = Initial cement consumption (adopted according to desired mechanical strength); **Wm** = Water mass; **Fm** = Filler mass; **Pm** = Pozzolan mass; **LSm** = Liquid superplasticizer mass; **WLSm** = Water contained in the liquid superplasticizer mass; ρ**c** = Cement specific gravity; ρ**w** = Water specific gravity; ρ**f** = Filler specific gravity; ρ**p** = Pozolan specific gravity; ρ**s** = Superplasticizer specific gravity; **Sc** = Superplasticizer solid content; **w/c** = Water/cement ratio; **f/c** = Filler/cement ratio; **p/c** = Pozolan/cement ratio; **s/c** = Superplasticizer/cement ratio; **WCm** = Adjusteed water mass.

$$Ipv = \frac{C}{\rho c} + \frac{Wm}{\rho w} + \frac{Fm}{\rho f} + \frac{Pm}{\rho p} + \frac{LSm}{\rho s} + \frac{WLSm}{\rho w} \tag{4}$$

$$Wm = w/c * C \tag{5}$$

$$Fm = f/c * C \tag{6}$$

$$Wm = w/c * C \tag{7}$$

$$Pm = p/c * C \tag{8}$$

$$LSm = \frac{\left(\frac{s}{c} * C\right)}{\frac{Sc}{100}} \tag{9}$$

$$WLSm = ((s/c) * C) * \left(\frac{100}{Sc} - 1\right) \tag{10}$$

$$WCm = Wm - WLSm \tag{11}$$

The last step was the SCC composition obtained after the definition of the initial volume of cement paste and granular skeleton. Whereupon the corrected cement consumption is calculated. This parameter is determined according to Equation 12. When this parameter is defined, it is possible to stipulate the content of aggregates, in function of the paste volume. Where **Cpc** = Cement paste composition; **Ipv** = Initial paste volume; **w/c** = Water/cement ratio; ρ**w** = Water density; **f/c** = Filler/cement ratio; ρ**f** = Filler specific gravity; **p/c** = Pozolan/cement ratio; ρ**p** = Pozolan specific gravity; **s/c** = Superplasticizer/cement ratio; **Sc** = Superplasticizer solid content; ρ**s** = Superplasticizer density; ρ**w** = Water density.

$$Cpc = \frac{Ipv}{\frac{1}{\rho c} + \frac{\frac{w}{c}}{\rho w} + \frac{\frac{f}{c}}{\rho f} + \frac{\frac{p}{c}}{\rho p} + \frac{\frac{s}{c} * \frac{100}{Sc}}{\rho s} - \frac{\frac{s}{c} * \left(\frac{100}{Sc} - 1\right)}{\rho w}} \tag{12}$$

By this method, it is possible to vary the cement consumption of the SCC as well as the content of superplasticizer, filler, pozzolan, and water in order to obtain the ideal proportion of materials for an SCC composition until the satisfactory parameters of fluidity and viscosity are reached.

2.4 Mixing process

The mixing process occurs as follows: Initially, sand and coarse aggregate were homogenized for 30 s in a concrete mixer, 2/3 of water was added and mixed during 60 s. Binder was added and mixed for 120 s. Thereafter superplasticizer with the remaining water was introduced, and the concrete was mixed for 300 s. The mixing process was stopped, and the slump was measured before the casting.

2.5 Fresh properties

To evaluate the properties of the SCC in the fresh state (fluidity, passing ability, and segregation resistance), the different proportions were submitted to fresh tests according to EFNARC (2002) and Brazilian standards NBR 15823-1 (2017). Slump flow and a slum flow T50 test were measured according to NBR 15823-2 (2017), where the ability of the SCC to flow freely through a board was measured, observing the aspects of segregation and exudation of the concretes. L-Box test NBR 15823-4 (2017) was used to evaluate the passing ability of the SCC through an L-shaped apparatus. A V-Funnel 5-minute test NBR 15823-5 (2017) was performed to measure the time that SCC takes to flow inside of a funnel, waiting 5 minutes for concrete accommodation and measuring the time that it takes to completely flow through the funnel. A sieve test was used to determinate the segregation resistance according to NBR 15823-6 (2017).

2.6 Hardened properties

After the determination of the SCC properties in the fresh state, the mixtures were inserted into cylindric molds (10x20 cm) and were cured underwater at a temperature of 20 + 3 °C. To evaluate the mechanical strength, a procedure was used to evaluate the compressive strength and tension by diametral compression according to Brazilian standards NBR 5739 (2018) and NBR 7222 (2011) at 7 d and 28 d of hydration. The equipment used was an Emic PC 150 testing machine, with a load cell of 1500 kN. Six specimens were tested for each analysis.

3. Results and discussion

3.1 Granular skeleton

The granulometry of the aggregates used in the mixtures is presented in Figure 2. The determination of the specific gravity and particle size distribution of aggregates followed the Brazilian technical standards NBR 16916 (2021), NBR NM 16917 (2021) and NBR NM 248 (2003). The specific gravity of the aggregates was of 2.63 g/cm³ for the sand and of 2.85 g/cm³ for the gravel. In order to obtain the correct water/binder ratio, the aggregates were previously washed and dried in an oven at 105 °C for 24 hours. This procedure ensures that the impurities from the aggregates were removed, avoiding contaminations and absorption of the water from the concrete.

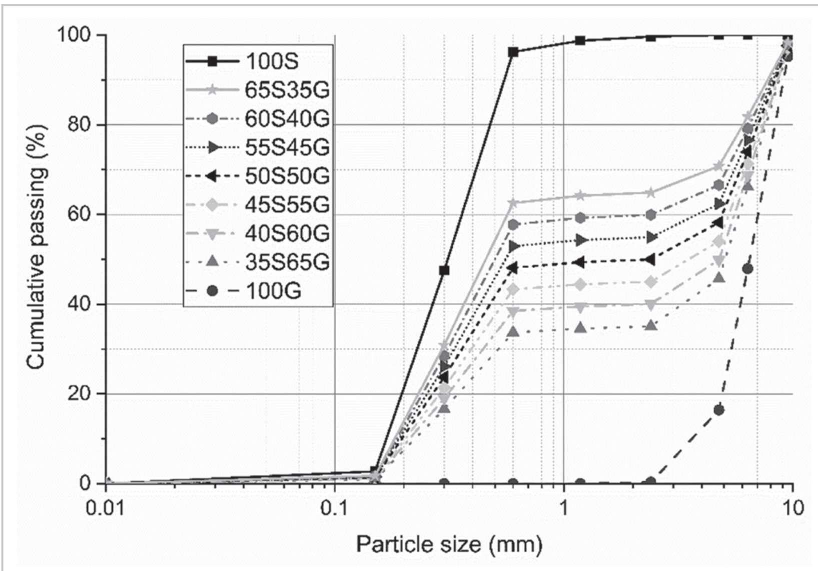

Figure 2 - Aggregate grading curves for granular aggregate packing.

Table 2 shows the physics properties of fresh mixtures to determine the granular skeleton, which was possible to determine according to the Equations 1, 2 and 3.

Table 2 - Results obtained for the granular skeleton.

Variable	Unit	Mix. 1	Mix. 2	Mix. 3	Mix. 4	Mix. 5	Mix. 6	Mix. 7
ρds	kg/dm³	2.631	2.631	2.631	2.631	2.631	2.631	2.631
ρdg	kg/dm³	2.85	2.85	2.85	2.85	2.85	2.85	2.85
s/a	%	35	40	45	50	55	60	65
g/a	%	65	60	55	50	45	40	35
Twm	kg	13.16	13.58	14.04	13.75	13.43	13.24	13.03
Tvm	dm³	7.56	7.56	7.56	7.56	7.56	7.56	7.56
Uwm	kg/dm³	1.74	1.79	1.86	1.82	1.78	1.75	1.72
ρdm	-	2.77	2.76	2.75	2.74	2.73	2.71	2.7
Vi (%)	%	37.18	35.14	**32.36**	33.58	34.08	35.42	36.29

In Figure 3, the void percentage for the different mixtures tested is presented. It can be seen that after homogenizing the aggregates, sand and gravel, the ideal proportion obtained corresponds to mixture 3, with the proportion of 45% of sand and 55% of gravel. This mixture results in a maximum void of 32.36 %. Also, it is observed from results in Table 2, that there is a tendency for the mixtures to decrease their void volume until they find the ideal proportion, and from this point on, start to rise again.

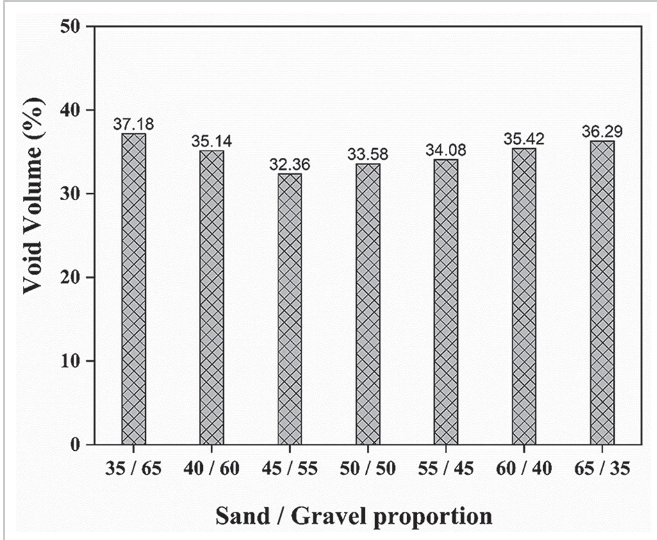

Figure 3 - Void volume for the skeleton granular.

3.2 Determination of the SCCs: initial cement composition and volume of cement paste

To define the SCCs composition, the paste content by volume was used To obtain this parameter, tests were performed on concrete by varying the volume of paste in order to determine the necessary properties that satisfy the requirements of self-compacting concrete. The paste volume is theoretically calculated according to Eq. 4 and corrected to achieve the SCC parameters.

To determine the composition of the SCCs with CEM CP IV and White CEM, a cement consumption of 450 kg/m³ was initially arbitrated. The superplasticizer rate of 1 % was stipulated following the Gomes *et al.* (2001) method, obtained through paste study (mini-slump), seen in Figure 1. The calculations were performed based on Equations 4 to 12, for a volume of 1 m³. The method's compositions were obtained varying the different parameters of cement paste, cement consumption, water-cement rate, and superplasticizer/cement rate. However, only the final composition is presented in this study.

In total, 4 preliminary corrections were made to determine the ideal self-compacting properties. The main feature evaluated in these preliminary tests were the concrete slump test and its verification of exudation and segregation after the test. Initially, 400 kg/m³ for cement consumption, 0.4 for water/cement ratio, 1 % for superplasticizer admixture, and 3.57 % for pozzolan/cement ratio were used, achieving a paste volume of 0.312 m³ and corrected cement consumption of 445.51 kg/m³. For all the dosages, this composition resulted in a concrete with exudation and segregation. Therefore, the additive content was adjusted by increasing the paste volume of the concretes. For compositions with lower segregation and exudation, corrections of 2.5% of the paste volume were initially performed during preliminary tests. For the compositions with higher exudation (White CEM), paste volume corrections were performed initially by 5%, with corrections of 2.5%, when closer to the slump and low exudation limits. The final composition of the SCCs obtained can be seen in Table 3.

Table 3 - Composition of the SCCs obtained.

Material content	CEM CP IV	CEM CP IV+RHA	White CEM	White CEM+FA
Paste volume (m³)	0.342	0.353	0.348	0.397
Corrected cement consumption (kg/m³)	453.58 (18.5%)	453.15 (18.4%)	474.11 (18.5%)	440.43 (17.8%)
Sand (kg/m³)	816.44 (33.3%)	815.67 (33.1%)	853.40 (33.3%)	792.77 (32.1%)
Gravel (kg/m³)	997.87 (40.7%)	996.93 (40.4%)	1043.04 (40.7%)	968.95 (39.3%)
Mineral admixture (kg/m³)	-	16.19 (0.7%)	-	86.93 (3.5%)
Superplasticizer (m³)	2.49 (0.1%)	2.49 (0.1%)	2.60 (0.1%)	2.42 (0.1%)
Water (m³)	181.30 (7.4%)	181.30 (7.4%)	189.60 (7.4%)	176.20 (7.1%)

3.3 Fresh properties

In Figure 4, the self-compacting concrete after the slump flow test is shown. It is observed in Figure 4a and Figure 4b that the reference mixture produced only with CEM CP IV and mixture with CEM CP VI with RHA, obtained great spreadability, as well as for the SCC produced with only white CEM (Figure 4c) and the mixture of white CEM and fly ash (Figure 4d). It can be seen for all the compositions, that the SCCs presented a homogeneous gravel distribution, all over the cement paste. Also, it is not possible to see clear visual changes between the 4 compositions.

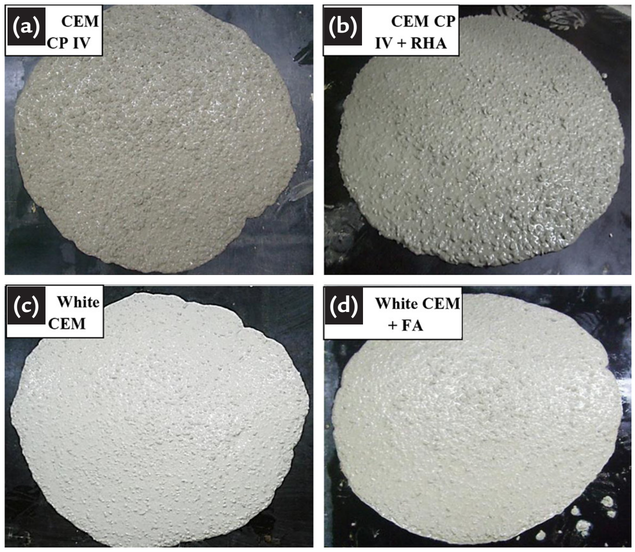

Figure 4 - Self-compacting concretes after Slump test (a) CEM CP IV (b) CEM CP IV + RHA (c) White CEM (d) White CEM + FA.

The SCCs produced can be seen more clearly in Figure 5. It is observed for all of the compositions that the SCC did not present exudation or segregation. The cement paste shows high cohesion, which maintains the SCC integrated, even after hardening.

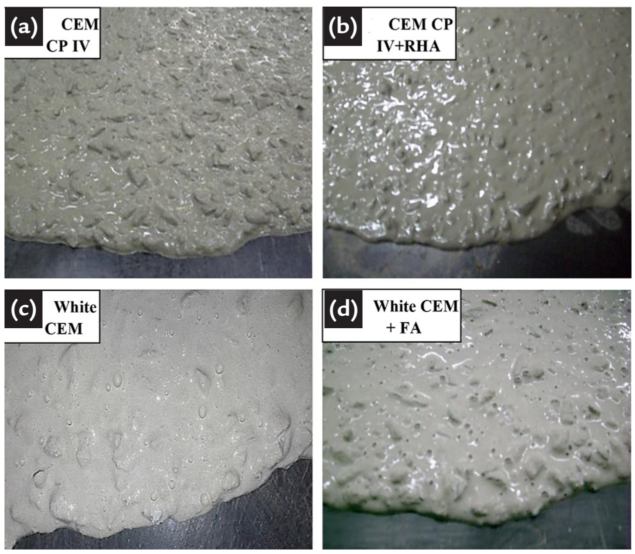

Figure 5 - Self-compacting concretes after Slump test, evidencing the lack of exudation of the cement paste (a) CEM CP IV (b) CEM CP IV + RHA (c) White CEM (d) White CEM + FA.

Table 4 shows the results obtained for the tests of slump flow, slump flow T50, L-box, and V-Funnel 5 minutes. It is observed that all of the SCCs produced reached the values stipulated in the Brazilian technical standard NBR 15823–1 (2010). The high quality obtained is due to the controlled parameters with the Gomes *et al.* (2001) method, where it is possible to affirm that these compositions are appropriate for use in structural applications.

Table 4 - Results obtained for the tests of slump flow, slump flow t 50, L-box, and V-funnel 5 minutes.

Test	Mixtures				NBR 15823-1				EFNARC			
	P-REF	P-RHA	W-REF	W-FA	P-REF	P-RHA	W-REF	W-FA	P-REF	P-RHA	W-REF	W-FA
Slump flow (mm)	715	680	714	735	SF2	SF2	SF2	SF2	OK	OK	OK	OK
T50 (s)	3	4	2	3	VS2	VS2	VS1	VS2				
L-Box	0.84	0.82	0.82	0.80	PL2	PL2	PL2	PL2				
V-Funnel												
5 minutes (s)	20	21	14	20	VS2	VS2	VS2	VS2				
Sieve test	15	15	18	14	SR2	SR2	SR1	SR2				

By analysis of the individual parameters, a few differences are noted. In terms of fluidity, the compositions presented similar spreading values and times, with exception of the CEM CP IV+RHA. This mixture presented the least fluidity among all, considering that it showed the highest time and the smallest value of spreading (4.90% less spreading than the reference CEM CP IV). It can be attributed to the addition of the CEM CP IV cement for RHA, which makes the mixture drier and, consequently, less fluid. Considering the passing ability, all the compositions demonstrated similar behavior. For the segregation resistance, the results obtained were also similar, except for the reference with white CEM. It demonstrated less time for the V–funnel 5 minutes test, which indicates lower viscosity. Angelin *et al.* (2018) affirm that the lower viscosity for SCC is related to lesser segregation resistance. This characteristic can be observed with the sieve test that shows a segregation resistance of SR2 to all the mixtures, except to White CEM that presented SR1. SR2 is a stricter limit value, with applications in prefabricated elements or deep foundations, while SR1 is indicated for structures with low complexity.

Figure 6 shows the slump flow results and superplasticizer content of the SCC elaborated. The superplasticizer represents the volume of SP/volume of binder ratio due to the differences in specific gravity, as recommended by Matos *et al.* (2019). All the SCC was classified as SF2 according to EFNARC (2002) and NBR 15823-1 (2017). It is observed that the addition of ~3% of RHA reduced by around 5% the fluidity of self-compacting concretes fabricated only with CEM CP IV; however, less superplasticizer content was needed to obtain an SCC. On the other hand, white CEM presented an increase of fluidity when added by 30% for fly ash with a decrease in superplasticizer content (~16% less than white CEM). This divergent behavior is due to the different shapes between RHA and FA particles. The RHA presents a rough and shapeless surface of particle Tambara Júnior *et al.* (2018) which increases the friction between the particles. Fly ashes have a spherical shape and smooth texture in which promotes a bearing effect and reduces the friction between the particles (Ahari *et al.*, 2015).

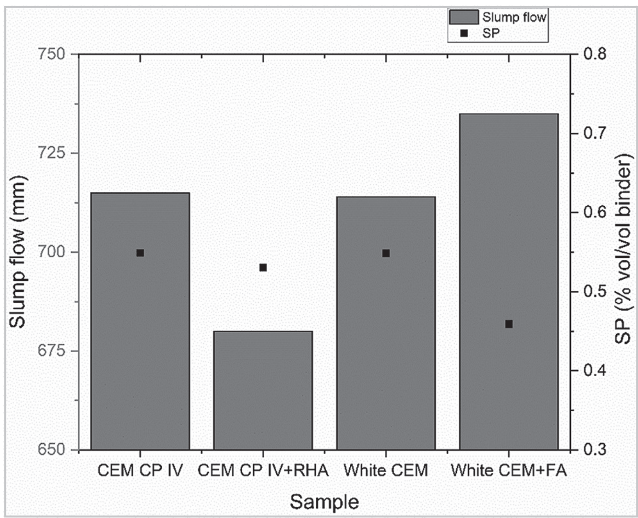

Figure 6 - Slump flow and superplasticizer content on SCC.

3.4 Mechanical properties

The results obtained for the compositions in the mechanical tests can be seen in Figure 7. To the references, there was observed higher mechanical strength for White CEM than CEM CP IV. This occurs because, in the cement CP IV, up to 50% of the clinker can be replaced by pozzolanic material, which would imply a lower development of mechanical strength at early ages, as observed in the study.

As observed, for both compression and tension tests, the mixtures had their strength increase from 7 days to 28 days. In general, it is verified that the compositions with rice husk ash and fly ash presented the worst values of compression and tension at the age of 7 days. Although the pozzolanic activity did not show reactivity for FA, at 28 days of hydration, a higher mechanical strength when compared with respective references is observed. This may be associated with the pozzolanic effect of the ashes. For white CEM+FA, a reduction of cement consumption compared to the reference is observed, which also contributed to low mechanical development.

The mixture with CEM CP IV presented a 20.67% gain in the compression strength and 18.5% in the tension strength from 7 to 28 days. CEM CP IV+RHA presented a 45.81% gain in the compression strength and 51.35% in tension. White CEM presented a 10.98% gain in the compression resistance and 6.48% in the traction strength. At last, WHITE CEM+FA presented a 39% gain in the compressive strength and 36.94 % in the tension strength.

It is possible to attest that the use of the mineral additions RHA and FA in the SCCs produced with different cement types decrease their mechanical strength at the initial ages, but at 28 days, the strength increases when compared with SCCs produced without additions. It is confirmed by Kannan and Ganesan (2014), which explain that the use of RHA and FA improve the mechanical properties of the SCC. Also, the authors elucidate that the replacement of 30% of the cement for FA implies better results in the fresh state, whereby it eliminates the need to use chemical additives to change the viscosity of the cement.

According to the mineralogical composition, a higher content of C3S to White CEM is noted. This results in a higher compressive strength at the first age analyzed due to the greater reactivity of the alite. The fineness of the white cement also contributes to the higher gain of strength.

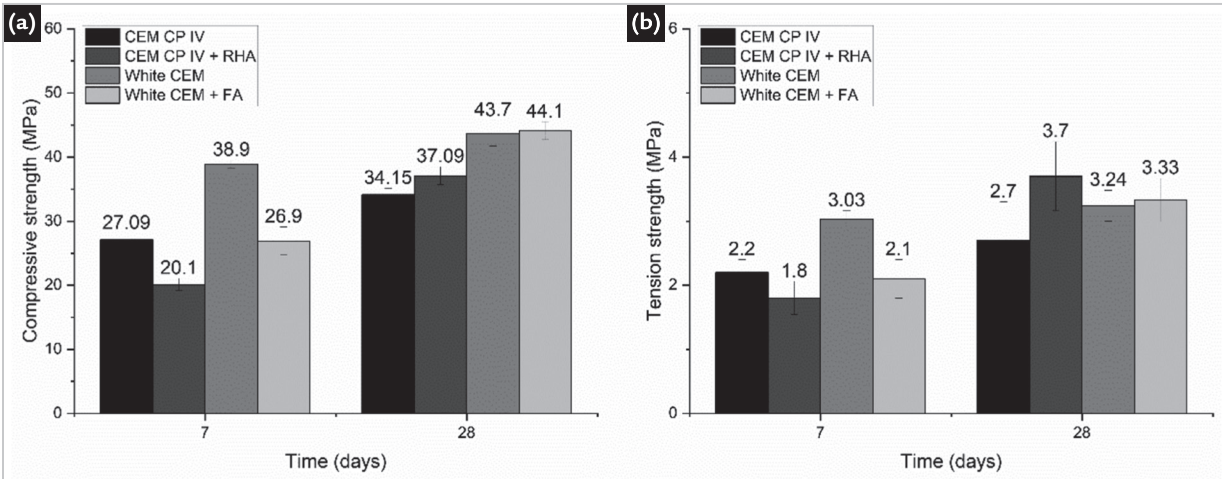

Figure 7 - Compressive and tension strength to the samples.

3.5 Binder index

Figure 8 shows the Binder index of the SCC studied at 7 d and 28 d, given in kg/m³/MPa of compressive strength. At 7 d the reference samples showed a lower binder index (16.24% to CEM CP IV and 12.19% to White CEM) when compared with the samples with mineral admixture. This occurs due to the higher development of compressive strength at early ages, compared to the references. At 7 days, CEM CP IV+RHA presented the higher binder index, i.e., indicates a less efficient SCC at early ages. White cement presented the lower binder index due to the rapid reaction of C3S presented in the clinker. However, at 28 d, it is observed that the samples containing mineral admixture presented a great reduction in the binder index, reaching values close to the references at this same age. This shows that the contribution of the mineral admixture at the latter ages of the SCC obtains the same efficiency for concrete performance. It is necessary to consider that the curing condition of the specimens was performed at low temperature (20 ±3 °C) due to weather conditions. This resulted in slow mechanical strength development, increasing the binder index for all the mixtures.

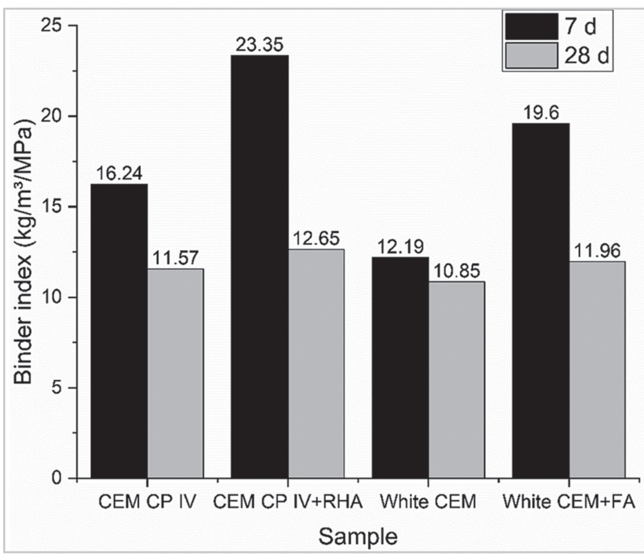

Figure 8 - Binder index of the SCC at 7 d and 28 d.

4. Conclusions

From the results herein achieved, it is possible to conclude that:

- It was possible to develop SCC with RHA and FA. White cement presented higher C_3S content and fineness, due to this higher hydration reaction occurring at 7 days, developing higher mechanical strength when compared with CEM CP IV.

- The physical aspect of the mineral admixture has influenced the fluidity of the SCC. RHA particles have a rough, indefinite shape, increasing the friction of the particles. FA presented spherical and smooth particles, which reduce the friction in the particles, increasing the viscosity.

- It was observed that the RHA content influences more than FA for the fresh properties; only 3% of replacement changed the fluidity and increased the segregation resistance. On the other hand, it was necessary for a 30% of FA replacement to achieve similar behavior with white cement. This is associated with the higher pozzolanic activity and fineness of RHA.

- The use of RHA and FA improved the reactivity of the cement, reaching higher mechanical strength at 28 days, when compared with the reference. Also, lower cement consumption with similar properties at 7 days and better mechanical strength at 28 days were obtained.

- The Binder Index shows that

at 28 days all the mixtures presented similar efficiency in mechanical performance. Therefore, cement replacement by fly ash or rice husk ash results in an economic system that increases the performance of the SCC.

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