Physical mechanic properties of self-compacting concrete produced with concrete waste powder

Propiedades físico-mecánicas de concretos autocompactantes producidos con polvo de residuo de concreto

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Resumen

La gran demanda de Cemento Portland Ordinario (CPO) debido al incremento de nuevas obras civiles y la generación de Residuos de Construcción y Demolición (RCD) causan un impacto ambiental negativo, por lo que una solución a esta problemática es el reciclaje de estos materiales para la producción de nuevos concretos. El reemplazo parcial de CPO por polvo de residuo de concreto (Concrete Waste Powder, WCP), proveniente del proceso de reciclaje de concreto, ha sido un enfoque sostenible. En esta investigación ser realizó la caracterización química y puzolánica del WCP mediante Fluorescencia de Rayos X (FRX), la prueba Frattini e índice de actividad de resistencia. Además, se evaluó la factibilidad de producir Concretos Autocompactantes (CAC) elaborados con WCP. El comportamiento de los CAC preparado con varias relaciones de reemplazo de WCP por CPO (en 0, 10, 20 y 30 %) proveniente de RCD, se evaluaron experimentalmente. Las propiedades de trabajabilidad se determinaron mediante las pruebas de flujo de asentamiento, embudo en V y caja en L. Las propiedades en estado endurecido de los CAC estudiadas incluyeron la resistencia a la compresión, la resistencia a la tracción indirecta, la resistencia a la flexión, la porosidad y la succión capilar. Los resultados experimentales de este trabajo mostraron que el WCP puede ser empleado con éxito como relleno en concretos autocompactantes, a pesar de disminuir la trabajabilidad y la resistencia mecánica.

Palabras clave: concreto autocompactante; residuos de demolición y construcción; polvo de residuo de concreto; cemento Portland; trabajabilidad; propiedades mecánicas.

Abstract

The high demand of Ordinary Portland Cement (OPC) due to the increase in new civil works, in addition to the generation of Construction and Demolition Waste (CDW), cause a negative environmental impact, so a solution to this problem is the recycling of these materials to produce new concrete. The partial replacement of

Portland cement by Waste Concrete Powder (WCP) from the concrete recycling process has been highlighted as a sustainable approach. This paper presents the chemical and pozzolanic characterization of WCP through X-ray fluorescence (FRX) and the Frattini and resistance activity index test respectively. Also, the feasibility of producing self-prepared concretes (SCC) prepared with WCP was evaluated. The performance of SCC prepared with various replacement ratios of WCP to OPC (i.e., 0 %, 10 %, 20 %, and 30 %) from CDW, has been evaluated experimentally. The workability properties were performed regarding the slump flow test, V-funnel, and L-box. The hardened properties of SCCs including compressive strength, splitting tensile strength and flexural strength, porosity, and Capillary suction were studied. The experimental results of this work are showed that the WCP can be used successfully as a filler in self-compacting concrete, although decreasing workability and mechanical resistance.

Keywords: Self-compacting concrete; construction and demolition waste; concrete waste powder; Portland cement; workability; mechanical properties.

Introduction

Self-Compacting Concrete (SCC) is a special concrete that flows under its weight, takes the form of the formwork and fills all the empty spaces, maintaining its homogeneity, even in the presence of reinforcements (Señas; Priano; Marfil, 2016; Matos; Prudêncio-Jr .; Oliveira; Pelisser; Gleize, 2018), this makes the SCC particularly useful where casting is difficult, such as occurs in highly reinforced concrete structures or with complicated formwork (Silva; Robayo; Mattey; Delvasto, 2016). The appearance of self-compacting concrete has positively impacted the construction sector due to the innovation it entails. It was originally designed to compensate for an increasing shortage of specialized personnel in vibrating concrete, but it has proven to be advantageous in reducing construction time, labor, noise and vibration levels, and improving the quality of finishes (surface) and durability, have lower costs and energy consumption, among others. (Silva *et al*., 2016; Aydin; Nasl; Kotan, 2018). Another reason for the use of self-compacting concrete is the fact that it is a technology aimed at generating a positive environmental impact. SCCs incorporate industrial, agro-industrial, filler, demolition, and construction waste by-products (Mohammed; Dawson; Thom, 2013; Omrane; Kenai; Kadri; Aït-Mokhtar, 2017) that contribute to the sustainable development of concrete technology, making it greener (Cremades, 2011).

Regarding concrete, this is a composite material that due to its characteristics such as versatility and low cost, is the most commonly used in construction worldwide, so that as the population grows on earth, its use also increases (Aslani; Ma; Yim-Wan; Muselin, 2018). On the other hand, its current demand and the end of the useful life of old buildings produce large amounts of Construction and Demolition Waste (CDW) (Eguchi *et al*., 2007; Xiao; Ling; Kou; Wang; Poon, 2011).

CDWs consist of concrete, waste bricks, mortar, ceramics, metal, plastic, wood, and others. Bricks, concrete, ceramics, and mortar constitute 80 % of construction and demolition waste (Özalp; Yılmaz; Kara; Kaya; Şahin, 2016). The waste of these wastes generates a negative impact on the environment, since they are deposited in landfills without control (Arenas *et al*., 2017) and, in some cases, in unsuitable places that could generate contamination of water, the atmosphere and the ground (Xiao; Ma; Sui; Akbarnezhad; Duan, 2018). Every year around 1.3 billion tons of waste is generated in Europe, of which 40% or 510 million tons are CDW. The United States produces about 325 million tons of CDW and Japan about 77 million tons (World Business Council for Sustainable Development [WBCSD], 2009). In Colombia, more than 22 million tons of construction waste is produced (Ministry of Environment and Sustainable Development, 2017); and in the capital Bogotá alone, about 12 million tons of rubble are produced per year (Caicedo, 2016). In the city of Cali, around 2,480 m3 of daily rubble are produced, of which 23.4 % is contributed by home renovations, which are deposited in authorized dumps that are not sufficient for the large quantity of CDW, therefore, a large part of this waste is left in parks, green areas or lots, causing air, water, soil and landscape contamination (Ortiz; Silva, 2013).

The recycling and reuse of CDWs have become a topic of global interest and there is a high need for alternative applications for the different materials that make up CDWs. The recovery of CDWs not only reduces the impacts generated by their final disposal but also contributes to reducing the impact produced in the extraction of natural resources (Xiao *et al*., 2018). Various studies have been carried out with acceptable results on the use of CDW in concrete, as a recycled aggregate for road base and sub-base applications (Leite; Motta; Vasconcelos; Bernucci, 2011; Rahman; Imtiaz; Arulrajah; Piratheepan; Disfani, 2015; Xuan; Molenaar; Houben, 2015), as a coarse aggregate for the production of new concrete (Shi-cong; Bao-jian; Chi-sun, 2012; Xuan; Zhan; Chi-sun, 2016; Silva; Gordillo; Delvasto, 2017) and as a coarse aggregate for the manufacture of self-compacting concrete (Kou; Poon, 2009).

Also, the recycling of this residue (concrete) generates a fine by-product that is produced in crushing or grinding, which can be used in self-compacting concrete mixtures as partial replacement or addition of Portland cement, generating a comprehensive approach to recycling specifically, since the two materials produced in the recycling of this composite material can be used (aggregates and fines) simultaneously or individually, and thus alleviate the sustainability challenges facing the construction industry. The use of this concrete powder in SCCs has shown a substantial improvement in fluidity, resistance to segregation, and some cases in resistance to compression (Pajares; Sánchez de Rojas; Frías; Bárbara, 2008). Many researchers have studied different CDW and solid waste fillers that can replace the mineral filler in the concrete mix, (Chen; Lin; Wu, 2011; Elyamany; Elmoaty; Mohamed, 2014; Gómez-Meijide, 2015) discovering that these fillers may not have a negative influence on concrete mixes, as well as improvements in some properties.

In this context, this research aims to present a contribution to the study of the use of dust generated in the concrete grinding or recycling process as a partial replacement of Portland cement in self-compacting concrete, by evaluating the properties in the fresh state, mechanical properties (resistance compression, indirect traction, and flexion) and permeability indicators (capillary absorption and suction).

Methodology

For the development of this investigation, the methodological procedure shown in the scheme of Figure 1 was used. In the first instance, a sampling of the demolition and construction waste was carried out at a transfer station located in the city of Cali, Colombia. Construction and demolition waste sampled was only concrete.

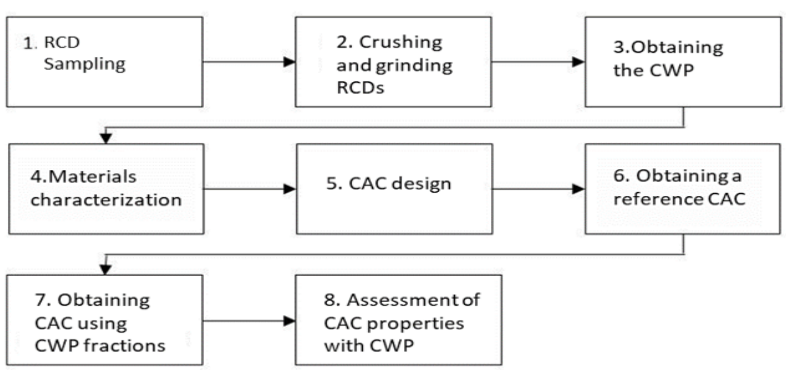

Figure 1. The methodology developed during the investigation.
Source: self-made.

In the recycling of the CDWs to obtain recycled coarse aggregate (see Figure 2), using a jaw crusher, dust is generated. Subsequently, this powder was subjected to a comminution process in a ball mill to bring it to the appropriate conditions for this study (impalpable), since it had been left with large particles (a few millimeters). The particle size distribution of the concrete powder or concrete residue powder (WCP) was obtained by laser granulometry (mastersizer 2000, Malvern brand, using water as dispersing medium) after two hours of grinding (see Figure 3). The average particle size obtained was 24.5 µm as observed in Table 1.

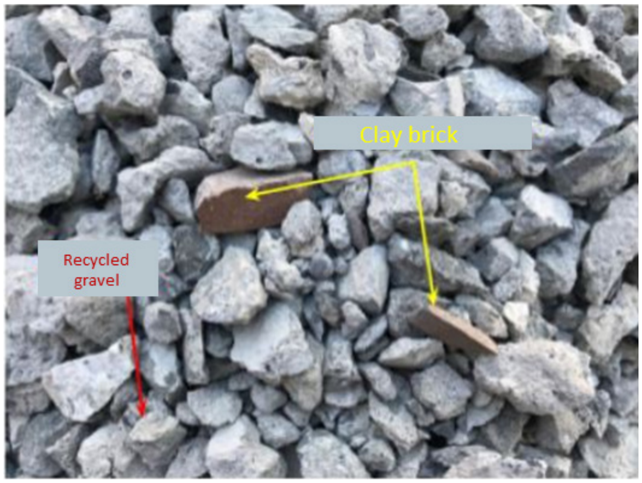

Figure 2. Recycled concrete.
Source: Self-made.

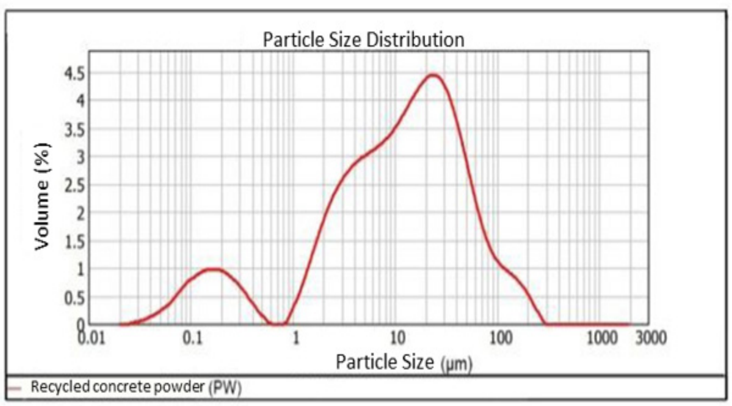

Figure 3 Concrete powder granulometry curve (CWP).
Source: Self-made.

Table 1.

CDW Concrete Dust Grading Distribution Values (WCP)

Shows	Average diameter (µm)	Diameter d (0.1) (µm)	Diameter d(0,5) (µm)	Diameter d(0,9) (µm)
WCP	24,53	0,41	12,27	59,42

Source: self-made.

Materials

Ordinary Portland Cement (OPC)

In this experimental study, ordinary or general use Portland cement was used following NTC 121 (INCOTEC, 1982). The OPC was obtained from Argos cement and contains a limestone mineral addition. The chemical composition is shown in Table 2 by FRX.

Concrete powder (WCP)

The recycled concrete powder used in this study was taken from concrete crushing waste material from the CDWs. The chemical composition was obtained using X-Ray Fluorescence (FRX), where it was identified that it mainly consists of SiO_2, CaO, Al_2O_3, and Fe_2O_3, (see Chart 2), also, it presented a higher percentage of Loss on Ignition (LOI) than the OPC. As it is a recycled material, all components were combined by grinding, including Portland cement mortar and coarse aggregate, which decreased the percentage of CaO, which is greater in Portland cement, and also increased the SiO_2 content due to the presence of sand. Regarding the morphology of the concrete powder, it was observed through Scanning Electron Microscopy (SEM), as shown in Figure 4, the WCP presented particles with irregular morphology of different sizes.

Table 2.

Chemical Composition of Ordinary Portland Cement (OPC) and Concrete Powder (WCP)

	Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	PI
OPC	% in weigh	19,39	4,13	4,7	55,68	1,7	0,31	0,28	3,9	9,21
WCP	% in weigh	39,95	8,55	5,85	26,53	1,66	0,65	0,84	1,11	14,01

Source: self-made.

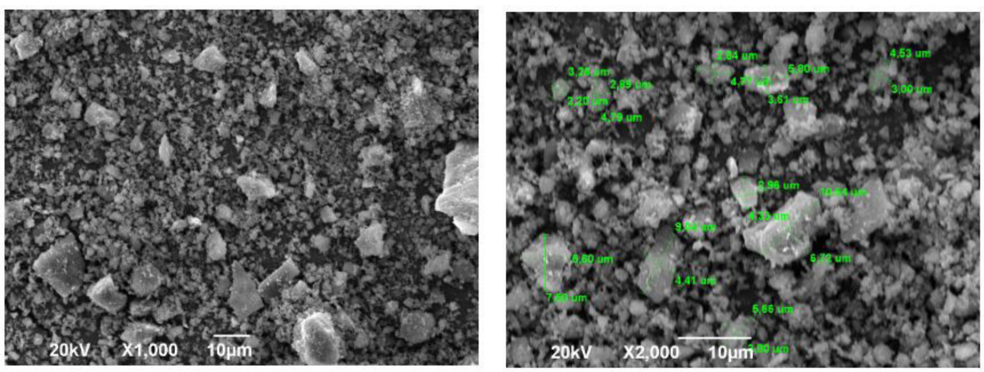

Figure 4. Micrograph of concrete powder (x1000 and x2000).
Source: self-made.

Natural aggregates

In this study, natural aggregates from the region were used. Coarse aggregate (gravel) with a maximum size of 12.5 mm (½ ") and river sand as fine aggregate. The characterization of this aggregate was carried out, under the Colombian Technical Standards (NTC) (see Table 3). The particle size tests (NTC 77), unit mass (NTC 92), density-absorption of coarse aggregate (NTC 176), density-absorption of fine aggregate (NTC 237), and resistance to wear using the Angeles abrasion machine (ASTM C131).

Table 3.

Physical and mechanical characteristics of natural aggregates (sand and gravel)

Characteristics	Rule	Sand	Gravel
Bulk density (kg/m3)	NTC 176 (ICONTEC, 1995)	2610	2740
Absorption (%)	NTC 176 (ICONTEC, 1995)	1,75	1,01
Loose unit mass (kg/m3)	NTC 92 (ICONTEC, 2019)	1511,80	1458,18
Compact unit mass (kg/m3)	NTC 92(ICONTEC, 2019)	1644,33	1610,90
Fineness module	NTC 77 (ICONTEC, 2018a)	2,88	-
Maximum size (mm)	NTC 77 (ICONTEC, 2018a)	12,7	12,7
Angels coefficient	ASTM C131 (ASTM International, 2014)	-	12,8 %

Source: self-made.

Superplasticizer Additive (SP)

The superplasticizer used in self-compacting concrete mixtures was Sikaplast 328®, composed of state-of-the-art polycarboxylate-based polymers and synthetic resins, meeting the requirements of ASTM C494 (ASTM International, 2017a) and classified as type F.

Methods of evaluation of the pozzolanic activity of CDW

The evaluation of the pozzolanic activity of the concrete powder (WCP) was determined by two methods:

Resistance Activity Index (RAI) (ASTM C618)

ASTM C618 (ASTM International, 2017b) presents the resistance activity index criterion previously known as the pozzolanic activity index, with which it was established as the ratio of the compressive strength of the mortar with 20 % mass replacement of OPC for the pozzolana to be evaluated and the compressive strength of the control mortar (with 100 % OPC). Also, some chemical and physical requirements for pozzolans as a replacement for Portland cement.

Chemical method (Frattini)

The Frattini test was used to determine the pozzolanic activity of WCP, according to the procedure described in NTC 1512 at 7 and 28 days (ICONTEC, 2018b). In this test, the CaO and OH contained in an aqueous solution that covers the hydrated sample at 40 °C for a certain time were compared with the solubility curve (solubility isotherm) for CH in an alkaline solution at the same temperature.

Dosage and production of concrete

In the first stage of the experimental work, the effect of the WCP was evaluated, where a total of 4 mixtures were made; a reference mixture with a total cement content of 490 kg/m^3 (15.8 % of the total volume of the SCC), the water content of 205 kg/m^3, natural aggregate (gravel and sand) and superplasticizer with a dosage between 4 and 4.4 kg/m^3. To study the potential of WCP in the SCC, cement at different levels was replaced by WCP (10, 20, and 30 % by volume) (see Table 4).

Table 4.
Dosing of SCC mixes with CDW WCP

Mixture	OPC (kg/m3)	WCP (kg/m3)	Water (kg/m3)	SP (kg/m3)	Gravel (kg/m3)	Sand (kg/m3)
Pattern	490	0	205	4,4	710,1	980,6
F-10 %	441	42,4	205	4,0	710,1	980,6
F-20 %	392	84,8	205	4,0	710,1	980,6
F-30 %	343	127,2	205	4,4	710,1	980,6

Source: self-made.

SCC fresh tests

The basic properties of the SCCs were evaluated through the specified tests and criteria defined by Experts for Specialized Construction and Concrete Systems (EFNARC, 2005). With these experimental tests fluency capacity, the flow capacity and the viscosity (flow rate) were evaluated. The following tests were performed:

Settling flow: final diameter reached by the concrete, and the T500 (the time it takes for the concrete to reach a diameter of 500 mm.

V-funnel test: the time required to drain the entire volume of concrete from the V-funnel.

L Box: a ratio of concrete heights of the horizontal section of the box in the final part and the part before the bars (3 bars).

Table 5.

EFNARC specifications for SCC fresh tests

Property	Test	Parameters	Class	Admissible values
Fluency	Settlement flow	Final diameter (mm)	SF1	550-650 mm
			SF2	660-750 mm
			SF3	760-850 mm
Viscosity (flow rate)	V-Funnel	Flow time in the funnel (s)	VF1	≤8 s
			VF2	9 – 25 s
Flow capacity	L box	Blocking coefficient (H2/H1)	PA1	≥0,80 con 2 bars
			PA2	≥0,80 con 3 bars

Source: EFNARC (2005).

SCC hardened state tests

To determine the properties of the SCC in the hardened state, cylindrical specimens of 76.2 mm diameter x 152.4 mm high were used, where the tests for compressive strength were carried out, according to ASTM C39 / C39M (ASTM International, 2018), for this, an axial compression load was applied to the cylinders until a failure occurred. Subsequently, the indirect tensile strength test was performed under ASTM C496 / C496M (ASTM International, 2017c), while the modulus of rupture was determined, according to ASTM C293 (loaded at the midpoint) in beams 75 mm high x 75 mm wide and 310 mm long (ASTM International, 2016). These properties were evaluated at 7, 28, and 56 days of curing, to monitor the effect of WCP addition and determine its ideal percentage. In each test, three samples were evaluated and the average of each test was reported.

Physical tests

The density, the absorption percentage, and the volume of permeable pores were evaluated, according to ASTM C642 (ASTM International, 2013a) and capillary suction using the procedure described in ASTM C1585 (ASTM International, 2013b). An average of 3 samples was used to calculate these properties. The procedure described in ASTM C642 standard consists of drying the specimens at a temperature of 110 ± 5 °C for no less than 24 hours until obtaining a constant mass (A). The concretes are then immersed in water for no less than 48 hours and the saturated mass (B) is recorded. Subsequently, the specimens are immersed in water in a suitable container and boiled for 5 hours, then allowed to cool for no less than 14 hours, the surface moisture is removed with a towel and the boiled mass is recorded (C). Finally, the specimen is suspended with a wire and the apparent mass in the water is determined (D). Absorption, density, and porosity were determined with equations 1,2, and 3, respectively.

$$\text{Absorption after immersion (\%)} = [(B-A)/A] \times 100 \quad (1)$$

$$\text{Bulk density} = [A / (A - D)] \times 1\ g / cm^3 = g_2 \quad (2)$$

$$\text{Permeable pore volume (\%)} = [[g_2 - [A / (C-D)] \times 1g / cm^3] / g_2] \times 100 \quad (3)$$

The capillary suction test allows determining the rate of water absorption by capillary action. The curing time of the samples for the execution of the tests was 28 days of curing.

Results and discussions

WCP pozzolanic activity

Resistance Activity Index (RAI)

Chart 6 presents the resistance activity index (RAI) of the WCP after 28 days of curing. According to ASTM C618, the RAI must exceed 75 %. The resistance activity index after 28 days was 94 %. Regarding its chemical composition, a good pozzolanic material requires at least 70% silica, alumina, and iron oxides. The sum of these WCP components is 54.35 %, so the WCP could not be classified as a natural pozzolan (class N), according to its chemical composition despite exceeding the RAI limit value.

Table 6.
Chemical and physical properties of pozzolans, according to ASTM C618

Requirements	Pozzolan Class N, ASTM C618	WCP
Chemical requirements		
$SiO_2 + Al_2O_3 + Fe_2O_3$, %	Min, 70,0	54,35
Sulfur trioxide (SO_3),%	Max, 4,0	3,9
Moisture content,%	Max, 3,0	3,15
Ignition loss,%	Max, 10,0	14,01
Physical requirements		
28-day resistance activity index, percent control	Min, 75	94

Source: self-made.

Chemical method (Frattini)

The pozzolanic activity of WCP was also evaluated by the Frattini test. Figure 5 shows the location of the WCP, which was located above the solubility isotherm, which indicated that the Ca^{2+} and OH- released in the hydration of Portland cement were not effectively consumed, as is normal in a pozzolanic reaction (Liu *et al.*, 2018), so it was evident that the WCP tested cannot generate pozzolanic reactions at any of the 2 times evaluated (7 and 28 days).

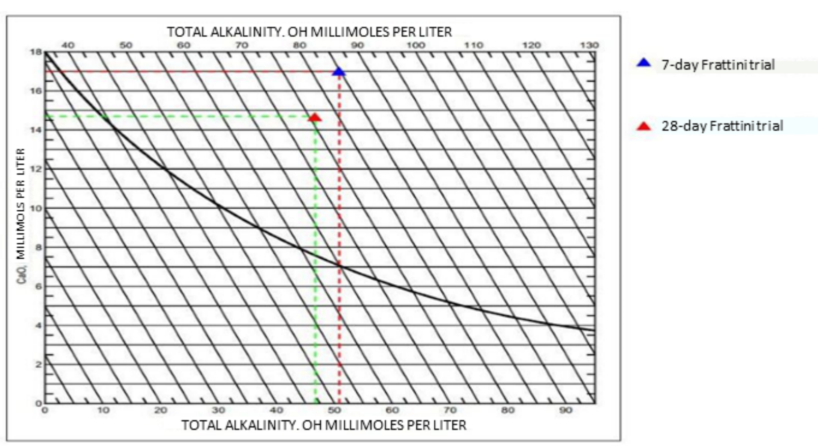

Figure 5. Saturation curve of the Frattini method at 7 and 28 days for the CWP.
Source: self-made.

Despite not being a pozzolanic material, it could be used as a replacement for the fine material, to generate a granulometric complement of the fine material in the concrete and to conceive greater compactness in the material. In the specific case of self-compacting concrete, it could produce positive effects on the fluidity and resistance to the segregation of the mixture.

Fresh properties of SCC with WCP

Regarding the results of the properties in the fresh state of the concrete with WCP (see Chart 7), the settlement flow test showed that the use of WCP generated a flow loss of 10.7 % for self-compacting concrete with 30 % (F-30 %). Despite the decrease in the settlement flow of the SCCs with WCP, all the concretes complied with the parameters established in the EFNARC (2005), for the filling capacity, since they were within the range of 550 mm and 850 mm established by this guideline (see Figure 6). The results of the V-funnel test showed that the time it took for all the mixtures to pass through the equipment was in a range of 7.12 s to 17.20 s, indicating a moderate viscosity, which avoided the segregation of its components. This range complies with the acceptance criteria for SCCs prescribed by EFNARC. In the L-box test, which was carried out to determine the flow capacity, none of the mixtures met the requirements of this test, since the minimum value of the blocking ratio is 0.8. This may be because the use of WCP partially reduces the deformability, and is more evident in the F-30 % mix since the concrete in the fresh state did not reach the final part of the horizontal section of the box in L, reason why the H2 height does not present value. A possible solution to the low deformability would be a higher dose of SP (Kaish; Breesem; Abood, 2018),

Chart 7.
Fresh behavior of self-compacting concrete with WCP addition

Test	Pattern	F-10 %	F-20 %	F-30 %
Settling flow (mm)	695	675	650	620
L-box (H2/H1)	0,69	0,63	0,51	-
V-funnel (s)	7,12	11,62	16,05	17,20

Source: self-made.

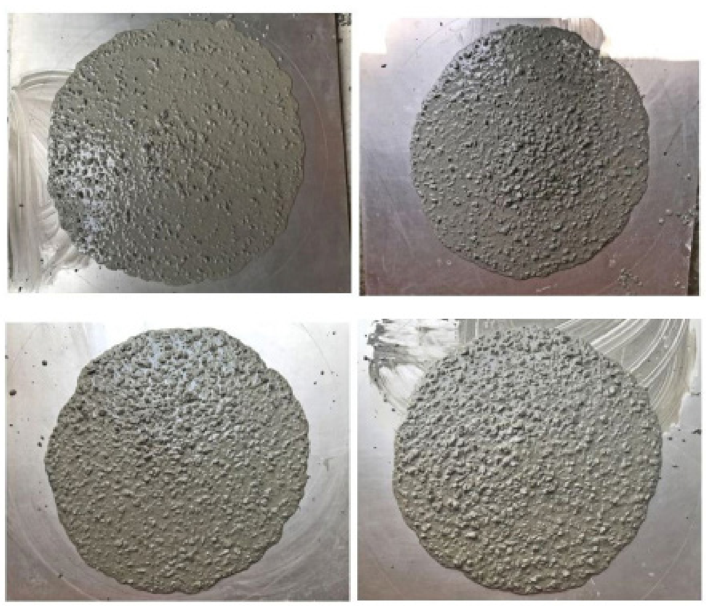

Figure 6. Settling flow test using Abrams cone, (from left to right, standard mix, F-10%, F-20 %, F-30 %.
Source: self-made.

Properties in the hardened state

The results of the compression and indirect tensile strength of the standard mix and the mix with WCP are presented in Figures 7 and 8. The compression strength of SCC decreased with the use of WCP, which is directly related to the percentage used. The replacement of 10, 20, and 30 % of OPC by WCP resulted in a decrease in resistance of 1.40 %, 16.49 %, and 19.78 %, respectively, at 28 days of cure. This decrease is attributed to the fact that this residue is nonreactive (Kim, 2017).

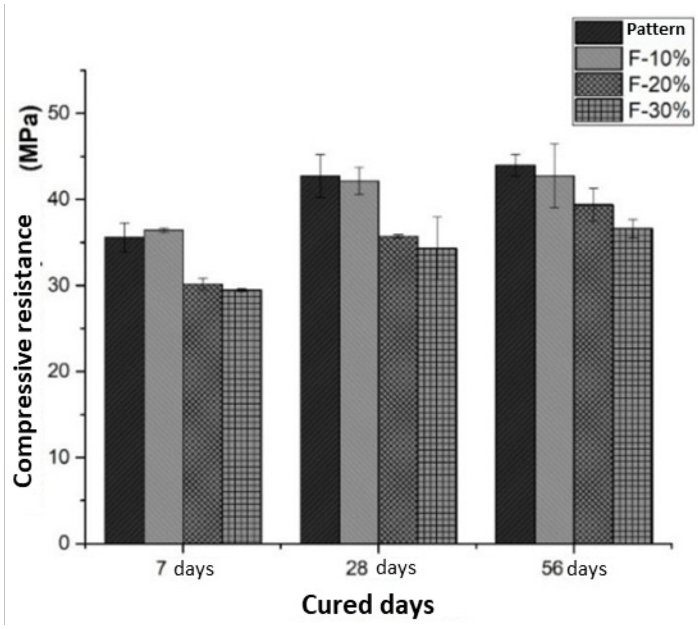

Figure 7. Compressive strength vs Curing days of SCCs with CWP.
Source: self-made.

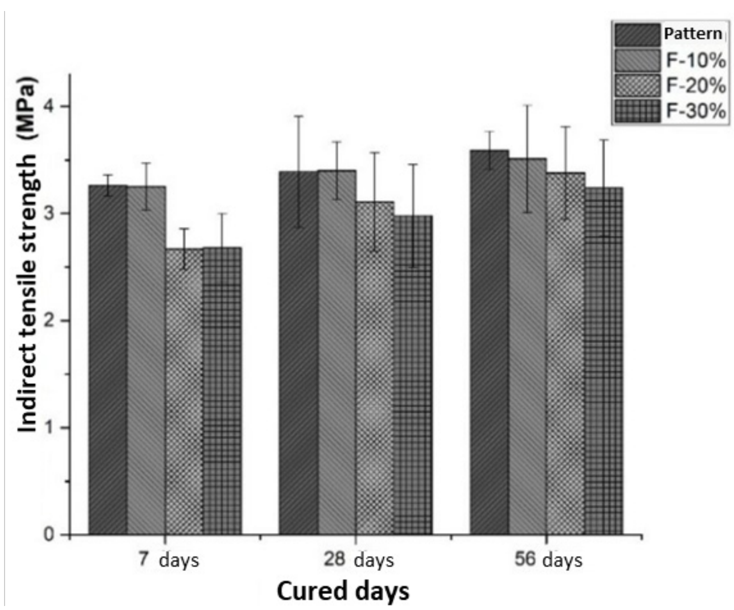

Figure 8. Indirect tensile strength vs Days of cure, of SCCs with WCP.
Source: self-made.

In other words, with a 10 % cement replacement by volume WCP, there was no significant decrease in compressive strength compared to the standard mix, even after 7 days of curing, the resistance was greater than 2, 36 % (see Figure 7).

Regarding the indirect tensile strength of the different SCCs with different WCP contents, a similar trend was evident in the compressive strength, where the presence of WCP did not present significant or potentially positive effects on indirect tensile strength (see Figure 8). However, the mixture with 10 % WCP (F10 %) presented a 2.2 % decrease in this property compared to the standard mixture, while the F-20 % and F-30 % mixtures decreased their resistance by 5 %, 8 % and 9.7 % at 56 days. This behavior is similar to that obtained by Yong and Yun (2012), who recommend replacing up to 15 % of cement with concrete powder.

The flexural strength results of SCCs with WCP at 28 and 56 days are presented in Figure 9. As with compressive strength, flexural strength decreases due to the presence of WCP, however, in the case of the F-20% mixture at 56 days, the resistance did not decrease significantly concerning the standard SCC.

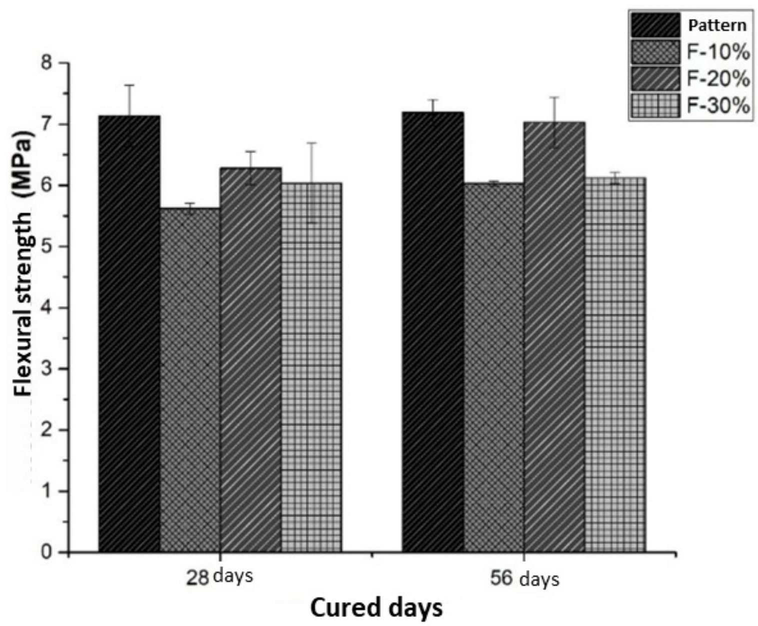

Figure 9. SCC flexural strength with CWP.
Source: self-made.

In general, the mechanical properties decline, which can be attributed to the fact that a greater amount of WCP in the SCC produces a greater amount of cracks and pores, which is greater with the increase in the amount of this residue. Furthermore, the use of WCP reduces the number of hydration products in concrete (Ma; Li; Wu; Cao, 2019).

Physical properties

Density, porosity, and absorption

The results of porosity, water absorption, and bulk density (specific gravity) of the SCC were determined, according to the ASTM C642 standard. It was observed that the mixtures showed greater absorption and porosity in the concretes containing WCP after 28 days of curing. This is attributed to the dilution effect since by replacing Portland cement with an inert material, the hydration products that can form over time are decreased, which increases the absorption in the mixture. On the other hand, Celik; Meral; Mancio; Mehta; Monteiro (2014) relate the increase in pores to the dilution effect due to the impact produced by an inert material in the hydration process of Portland cement. When substituting WCP for cement, the water/cement ratio increases and increases as the WCP content is higher in concrete.

In Table 8 it can be seen that the F-20 % mixture is the one that presented the lowest percentage of absorption and permeable pores compared to the other SCCs added with WCP. These results are, agree with those obtained in the mechanical properties, which decrease with the presence of WCP in the mixture due to the higher porosity.

Table 8.
Density, absorption, and porosity of the SCC with WCP after 28 days of curing

Mixture	Absorption after immersion (%)	Apparent density kg/m³	Permeable pore volume (%)
Pattern	3,83	2582	9,29
F-10%	4,40	2569	10,13
F-20%	4,34	2565	9,99
F-30%	4,43	2559	10,32

Source: self-made.

Capillary suction

Figure 10 shows the curves corresponding to the results obtained from the capillary suction test, according to ASTM C1585. The ordinate shows the amount of water absorbed per unit area of the sample, and the square root of the elapsed time in the abscissa. In the graph, it can be seen that as the percentage of substitution of OPC by WCP increases, the capillary absorption increases. Likewise, it is observed that the standard curve differs from the curves of the SCCs with WCP and is attributed to a greater tortuosity in the capillary pores generated by hydration products such as C-S-H. It is also highlighted that, even though the mixture with 20 % WCP has a greater dilution effect compared to the mixture with 10% WCP, there is less capillary absorption. This behavior can be attributed to the fact that 20 % of WCP in the mixture would generate a paste that would have an adequate weight so as not to open spaces that could generate capillary action in the concrete, which does occur in conventional concrete, which with a higher a/c ratio will present greater capillary absorption (Taus, 2003).

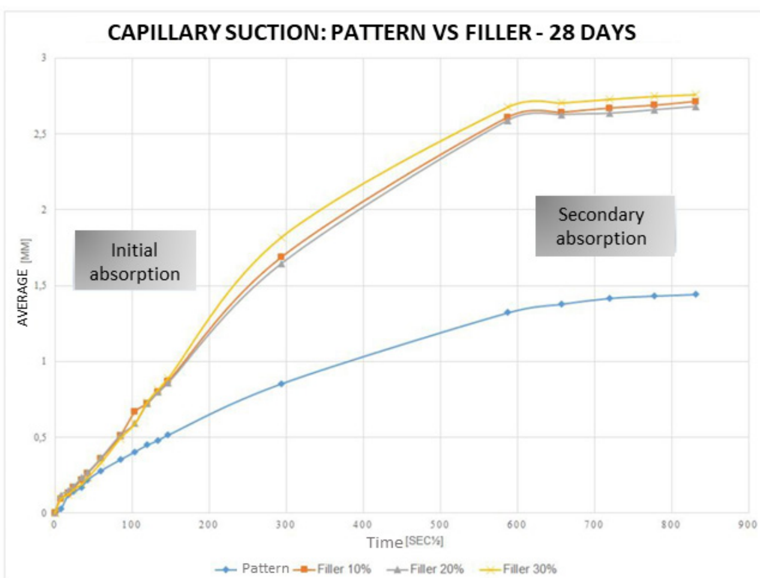

Figure 10. Capillary suction curves of SCCs with CWP at 28 days of curing.
Source: self-made.

Conclusions

The results of this experimental study highlight the use of WCP as a partial replacement for OPC in the production of self-compacting concrete. Based on the results obtained, it is concluded:

The characterization of the WCP, according to its chemical and physical behavior, revealed that this material cannot be considered as matter, although the RAI was higher than that specified by the standard (> 75 %) and that it did not present the chemical composition required. Furthermore, in the Frattini test, the representative points of the calcium oxide content as a function of total alkalinity were above the solubility isotherm, indicating that it did not present a pozzolanic character at the 2 times evaluated (7 and 28 days).

SCC's workability decreases with increasing WCP percentage. The property in which it had the greatest influence was in the passing capacity evaluated using the L-box since they were not even close to the lower limit suggested by the European guidelines of the EFNARC. However, settlement and V-funnel flow tests were satisfactory for all replacement rates.

The mechanical strengths of the mixtures decrease with increasing WCP replacement. This is attributed to the low or no reactivity of this residue, which leads to the dilution effect occurring in the mixtures because the amount of water remained constant in all SCCs, which was 205 kg / m^3, which generates a higher a / c ratio as the replacement of Portland cement by WCP was greater.

Absorption, porosity and capillary suction are characteristics that are related to the durability of a concrete structure or element, which increased with the presence of WCP in SCCs, so it is recommended to use 20 % WCP since with this quantity shows less absorption and capillary suction of the SCCs with WCP.

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