Self-Consolidating Concrete Produced With Fine CDW

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Abstract. Self-consolidating concrete is a concrete technology that seeks to simultaneously achieve fluidity, passing ability and segregation. In its manufacture there is the possibility of using alternative materials, such as ground ceramic, predominantly in construction and demolition waste. Therefore, this study aims to analyze the feasibility of this concrete regarding its properties in the fresh and hardened state when there is replacement of fine sand by ground ceramic aggregate. For this, the flowing tests, flow time, visual stability index, J ring, L box, V funnel and the molding of specimens in three different compositions were carried out, one being the reference compositions and the other two with replacements of 25% and 50% in the natural fine sand by the ceramic waste sand. The mixes in which the replacements were carried out presented good fluidity, without of segregation, however, the passing ability of the mix with 50% of replacement did not fit within the recommended range.

Keywords: Workability; D-flow; Superplasticizer; Segregation.

1 Introduction

Reinforced concrete is the most used structural construction technique in the world, it arose from the need to incorporate the high durability and compressive strength of concrete with the tensile strength of steel, being able to assume desired shapes easily and quickly [1]. Generally, the concrete used is the conventional, it has a dry consistency, characteristic compressive strength around 30 MPa and is used in most civil, industrial and precast factories [2]. However, the Conventional Concrete (CC) does not fit into projects with specific characteristics, such as the style of constructions adopted in Japan, where due to intense earthquakes, the structures have a high rate of steel and shapes complex, which makes it impossible to properly consolidate. Therefore, Hajime Okamura developed in 1983, at the University of Tokyo, the Self-consolidating Concrete (SCC) [3].

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SCC is a concrete technology that seeks to simultaneously achieve fluidity, passing ability and strength to segregation. Thus, it is able to cohesively occupy the empty spaces within the form, without obstruction or segregation, when in contact or not with obstacles, only through gravity, without external interference [4].

Regardless of the types of concrete, the biggest challenge currently faced is the need to prepare concrete that in the course of obtaining it generates the least possible impact [2]. As population development and urbanization led to an increase in demand for goods and services, which consequently led to more consumption and waste. Thus, this is the sector that most generates environmental degradation, as it has a vast generation of waste and poor final disposal, as Construction and Demolition Waste (CDW) are often discarded in irregular areas and dumps [5].

Solid civil construction waste, recycling areas with guidelines for design, implementation and operation is cited in Brazilian regulations [6]. It was based on Resolution 307 of the National Environmental Council (CONAMA), on July 5, 2002, which aimed to create a plan for an efficient management of this type of waste, promoting an adequate destination. The incorrect management of these wastes negatively interferes in environment, because it causes siltation of water bodies, in addition to visually polluting cities and affecting the health of the population, since their disposal on vacant land allows for the release of other types of waste, which contributes to the appearance of vectors responsible for the transmission of diseases [7]. The use of waste resulting from civil construction is identified as the best alternative to reduce these impacts caused by the constant consumption of raw materials and the large volume of CDW [8].

In order to minimize the volume of wastes in landfills or inappropriate places, studies were carried out, where is possible using of CDW's as aggregate for the manufacture of CC [9]. However, when it comes to the SCC, there are few studies on this replacement. It is possibility of using alternative materials in the production of SCC. Pozzolanic materials such as fly ash, rice husk ash, silica fume, metakaolin and blast furnace slag; and non-pozzolanic ones, for example, ground ceramic, limestone filler and fine sand, those being used in the replacement of the binder and these in the fine aggregate [4].

A non-pozzolanic material found predominantly in CDW's aggregates are ceramics, as the largest portion of waste generally comes from the masonry [10]. In studies carried out in a landfill in Itatiba-SP, ceramic waste represents 63% of total CDW [11].

Studies carried out over time, to characterize the use of fine aggregate from CDW, show a reduction in workability, due to greater water absorption, and a decrease in strength when applied to concrete. However, it is observed that even with these particularities, if the problem is well dealt with, concrete with fine recycled aggregates (FRA) can be used with high performance. The academic and scientific community is conservative regarding the application of this material, such as the Brazilian standard, for example, which only allows the use of FRA for non-structural purposes. The regulations of countries such as Portugal, United Kingdom, Spain, Germany, China and Hong Kong, for example, are even stricter, as they do not allow the replacement of natural aggregate by FRA in concrete [12].

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As previously mentioned in Refs. [9], [11], the positive impact that the use of CDWs has on the environment is indisputable. However, in addition to affecting workability due to water absorption by FRA, other factors can be discussed: the presence of new transition zones (ITZs) interferes with the mechanical properties and transport of new concrete [13]; the chemical attack caused by sulfates and chlorides influence the durability of concrete [14]; the variability of the aggregates, in a way that interferes with the physical and chemical properties and their quality control [15], which leads to many analyzes of concrete with agreggate CDW manufactured in the laboratory, however, with little practical application.

The application of different CDW materials to improve eco properties of SCC has being studied especially in the last decade. Among many others materials, research was carried out with ceramic waste [16], perlite [17], marble waste, fly ash and micro silica [18], glass powder [19], tire rubber [20]. Therefore, to propose an alternative for recycling ceramic CDW, due to the high percentage of this material that is generated during building demolitions, this study proposes the feasibility of partially replacing fine sand by crushed ceramic aggregate from CDW in SCC, evaluating its properties in the fresh and hardened state.

2 Materials and methods

Three SCC compositions aimed for 30 MPa were performed. A reference mixture (T1), a composition with 25% replacement of fine aggregate by ceramic aggregate CDW (T2) and the latter with 50% replacement (T3). According to NBR 15116 [21], recycled aggregates from civil construction waste can only be used for paving or in concrete without structural function (up to 15 MPa). Table 1 reports the aggregates properties.

Table 1. Aggregate characteristics.

Material	Specific gravity (kg/dm³)	Powder materials (%)	FM(1)	MCD(2) (mm)
Fine sand	2.60	1.60	2.07	1.2
CDW	2.17	28.20	2.54	1.2
Stone dust	2.66	19.4	4.34	4.8
Gravel 0	2.69	5.20	2.62	9.5
Gravel 1	-	-	0.66	19.0

(1) Fineness module. (2) Maximum characteristic dimension.

As expected, analyzing Table 1, one observed that ceramic CDW sand has specific gravity smaller than fine natural sand. Moreover, ceramic CDW has a higher fineness modulus than fine natural sand.

The reference mix (T1) had 346.07 kg/m^3 of the Brazilian Cement CPV according NBR 16697 [22], 673.33 kg/m^3 of natural fine sand, 286.67 kg/m^3 of stone dust, 666.67 kg/m^3 of Gravel 0, 166.67 kg/m^3 of Gravel 1, 185 liters of water and 3.13 liters of Additive MC-PowerFlow 1180. The natural fine sand in the mixes T2 and T3 was reduced for 504.80 and 336.40 kg/m^3, respectively. Additionally, the Ceramic CDW sand was of 140.40 kg/m^3 and 280.80 kg/m^3 in the mixes T2 and T3, respec-

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tively. It was defined that the concretes should obtain slump of 3 cm through the slump test, before the addition of the superplasticizer additive, as it needs a minimum of humidity to disperse, so it was necessary to increase the w/c of the T2 and T3 mixes. According to [23], the particle size of waste influences the w/c factor, as the amount of water applied increases with addition of fines. This was effectively observed in T2 and T3, since the ceramic CDW has a higher fineness modulus than the sand, thus, it increased the water needed for mixes until reaching minimum slump of 3 cm.

It was noted that there was a reduction in the w/c when there was also a reduction in the replacement of fine sand by waste aggregate [23]. The increase in water in mixes was also due to that ceramic is a porous material, which allows for greater water absorption.

Even after T1, T2 and T3 mixes reached the 3cm slump, it was necessary to add more additive, since the addition of initially intended 0.98%, as recommended, the mixes did not show a minimum spread of 550mm [4]. Thus, spreading and flow time tests were repeated at each addition of additive until they reached the minimum spreading. It can be seen from Table 4 that the greater the replacement proportion of fine sand by ceramic CDW, the greater the w/c, to reach minimum abatement; and higher additive consumption to achieve minimum spread. After the addition, it was observed whether the mixes visually presented a fluidity characteristic of SCC, and subsequently, the mixes were submitted to tests in a fresh state to verify the characteristics. The final corrections of the mix compositions are shown in Table 2.

Table 2. Consumption of materials.

Mix	**Consumption**							
	Cement CPV (kg/m³)	**Fine sand (kg/m³)**	**Ceramic CDW (kg/m³)**	**Stone dust (kg/m³)**	**Gravel 0 (kg/m³)**	**Gravel 1 (kg/m³)**	**Water (L)**	**Additive *MC-PowerFlow* 1180 (L)**
T1	346.07	673.33	0	286.67	666.67	166.67	185	3.42
T2	346.07	504.80	140.40	286.67	666.67	166.67	206	3.74
T3	346.07	336.40	280.80	286.67	666.67	166.67	248	4.44

2.1 Fresh State Tests

In the scattering test, the fluidity of SCC was determined by measuring two perpendicular measurements, of the diameter of circle formed by concrete, which was previously inside the Abrams cone (Fig. 1).

Fig. 1. (a) Abrams cone filled; (b) Scattering measurements.

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Concomitantly, the flow time was determined, as the result of this comes from the definition of the time it takes the SCC to reach the 500 mm mark, carried out on the base plate. For the IEV, the photographs obtained during the test were compared with Fig. 2.

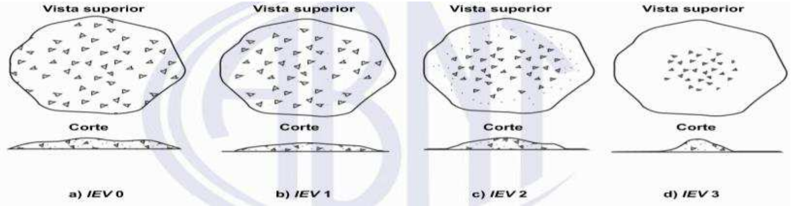

Fig. 2. Visual Stability Index Classes (IEV) according to NBR 15823-2 [24].

The J ring test was determined using the method proposed in NBR 15823-3 [25], so the Abrams cone and the J ring were positioned, both in the center of the base plate and the first of SCC; after removing the cone, the perpendicular diameters of the circle formed by the concrete were measured (Fig. 3).

The L box test follows the method proposed in NBR 15823-4 [26]. Therefore, the vertical compartment was filled by SCC and later the gate present at the end of this compartment was opened and allowed the passage of concrete, through steel bars, to the horizontal compartment. At the end of the flow, depth of SCC was measured at the end of the horizontal chamber next to the vertical chamber and at the opposite end of the horizontal compartment of the box (Fig. 4).

Fig. 3. (a) Positioning and filling the cone; (b) Suspension; (c) Measurement of diameters.

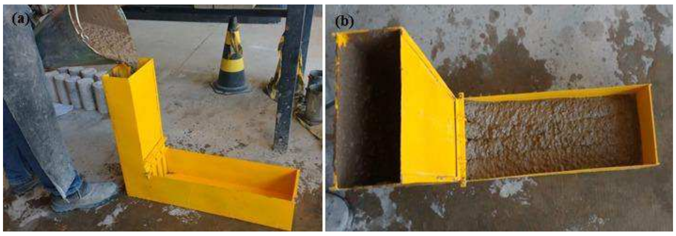

Fig. 4. (a) Filling the vertical chamber; (b) Opening the gate.

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In order to assess the quality of the SCC regarding its viscosity, the funnel V test was performed according to NBR 15823-5 [27]. This property, according to NBR 15823-1 [28], is related to the consistency of the mixture, which influences the concrete's strength to flow. In that test, the funnel was filled with concrete, and after its stabilization, the gate located at the bottom of the funnel was opened, allowing the passage of the concrete (Fig. 5). The time elapsed between the beginning and the end of the flow of all concrete through the funnel determines the viscosity of the SCC.

Fig. 5. (a) Filling the funnel; (b) Opening the gate.

2.2 Hardened state test

At the end of the fresh tests, the molding process of the specimens was started to carry out the compressive strength test, as proposed in NBR 5739 [29]. This test aims to analyze how the replacement of natural sand by CDW will change the mechanical strength of concrete. Twelve specimens were produced from each composition. Four specimens were tested at the age of 3 days, four at the age of 7 days and four at the age of 28 days.

The mold used was 100 mm in diameter and 200 mm in height and the specimens did not undergo densification. After 24 hours these were demolded and taken to the immersion tank and remained in the curing process, completely submerged, until testing.

3 Results and discussion

3.1 Tests in the fresh state

Results from the D-flow test, flow time, visual stability index and funnel V are shown in Table 3. None showed bleeding or segregation. However, results from the flow time and the V-funnel indicate lower viscosity for the mixes with ceramic CDW sand. This was probably due to the extra water and additive added to the mix composition.

Table 3. Scatter test results, flow time, visual stability index and funnel V.

Mix	Scattering (mm)	Flow time (s)	Visual Stability Index	Funnel V (s)	J Ring (mm)	L Box
T1	590.00	1.47	IEV 0	8.72	44.25	2.87
T2	602.50	1.23	IEV 0	4.68	49.25	1.08
T3	566.00	1.31	IEV 0	4.80	96.00	0.37

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The difficulty of mix with ceramic CDW in flowing is due to the waste aggregate used, which presents finer particles than sand, thus reducing the number of voids and making it more cohesive. Fig. 6 was used to classify the concrete in terms of visual stability index, as this demonstrates the appearance of the traces at the end of the flowing and flow time tests.

Fig. 6. (a) Mix T1; (b) Mix T2; (c) Mix T3.

In Fig. 6 none of the mixes showed bleeding or segregation, even with the increase in the w/c and of additive. The concretes presented a surface mortar halo in the center; however, this comes from a thin layer of grout contained in the walls of Abrams cone, below this the concrete presented uniformly. Regarding to the passing ability for the J ring and L box it is observed in Table that T1 and T2 were the only ones to obtain passing ability, determined by J ring, since these were less than 50 mm. Therefore, it fits in class PJ 2, this presents ability pass through in reinforcement spacing between 80 mm to 100 mm; and by L box, since both had a ratio greater than 0.80, thus, it integrates the PL 2 class, that is the ability to pass between reinforcements with spacings from 60 mm to 80 mm, as the box used had three steel bars.

By adding the ceramic waste, they reduced their passing ability, which placed T2 close to the established maximum limit, and the higher concentration of CDW in T3 made it unfeasible, as it made the mixture extremely cohesive, what made it impossible to go through the armors. Fig. 7 shows the characteristics of mixes at the end of the J ring. All mixtures did not show segregation at the end of the J ring test, including the T3 mix, which, despite not having the ability to flow through the steel bars, remained cohesive.

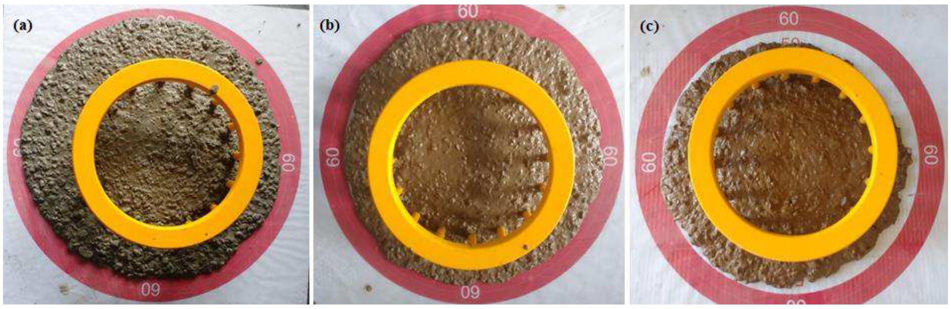

Fig. 7. (a) Mix T1; (b) Mix T2; (c) Mix T3.

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The results found diverge from the work carried out by Subaşi, Öztürk and Emiroğlu [16], who replace cement with ceramic waste in proportions of 5%, 10%, 15% and 20% (by mass), and found improvements in flow ability and viscosity of SCC. It is noteworthy that the residues used were similar in both works, however, one replaced fine aggregate and the other replaced the cementitious binder.

3.1 Hardened state test

The data obtained in compressive strength test of mixes analysis are shown in Fig. 8. Although the increase in the w/c and the proportion of ceramic waste, the strengths at three days did not show a significant difference. When comparing T3, where there was the highest percentage of replacement of recycled material, with the reference mix, the variation between resistances was less than 0.3 MPa. This is even smaller when comparing the two mixes in which there was replacing, even if the change in CDW between these mixes is 50%.

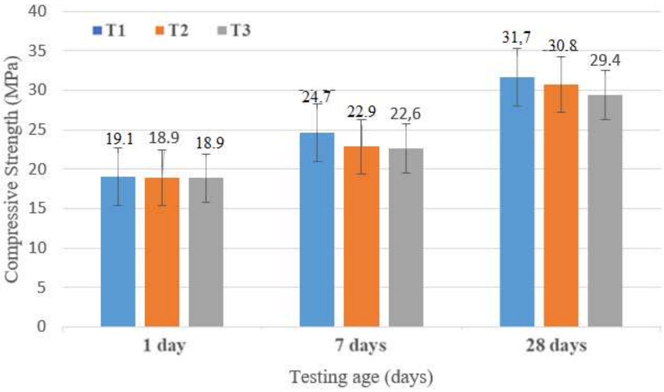

Fig. 8. Compressive strength.

At seven days, the reference mix had a greater strength gain compared to those that had been replaced, but this was still moderate, with a variation of approximately 2 MPa when compared to T3. The fact that the strengths in the early ages have remained close can be explained by the presence of fine materials in the mixtures, which increase the strengths in the early ages [4]. At 28 days, the strengths presented were still close, but T2 and T3 had their strengths lower than the reference. It is noticed that T1 and T2 surpassed the strength proposed, however, T3 did not reach this, however, its value was approximated. It is observed that the mixes did not oscillate their position in the graph, at all ages analyzed they maintained their strength so that T1 was higher, followed by T2 and, finally, by T3.

When comparing with the research carried out by Subaşi, Öztürk and Emiroğlu [16], the results are similar: both showed a slight decrease in compressive strength, however, little significant in relation to the estimated characteristic strength.

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4 Conclusions

This study presented results of the partial replacement of fine sand by ceramic CDW sand, regarding the properties in the fresh and hardened state of SCC. Although the present work lacks scientific rigor because water was added to the concrete compositions, from this exploratory work, the following remarks can be drawn:

- Mixes presented the similar classifications in regarding to fresh stage, since it did not impair the passing ability, and improved its characteristics in terms of fluidity and segregation resistance. In the hardened state, the mix wherein 25% of the natural sand was replaced by ceramic waste sand showed difference compared to the reference mix, even with the increase in the w/c.
- The mix wherein 50% of the natural sand was replaced by ceramic waste sand would be impractical even if it had strength close to the reference mix and to the one with 25% replacement, as it presented high cohesion due to the proportion of waste material used in it, and the greater this, the greater the difficulty presented by the concrete in passing through obstacles, that is, he has no passing ability, which is an essential feature of SCC.
- The content of fines interferes with fresh and hardened properties. The higher the proportion of fine sand replacement by ground ceramic CDW, the higher cohesion, resistance to segregation, less possibility of exudation and less compressive strength.
- Mixes with substitutions higher than 50% are unfeasible, as the concrete becomes an extremely cohesive mixture, with reduce fluidity and passing ability. On the other hand, mixtures with substitution proportions below 25% look viable, as they have the fresh characteristics necessary for a SCC and maintain acceptable strength when compared to the reference mix. However, the economic factor of these substitutions was not analyzed, which would be a suggestion for future work.

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