REVISTA MATÉRIA V.29 N.3
ISSN 1517-7076 artigos e20240317, 2024

Reaproveitamento de perdas de armazenamento: blocos intertravados utilizando concreto autoadensável com adição de finos cerâmicos

Reuse of storage loss: interlocked blocks using self-compacting concrete with addition of ceramic by-product fines

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RESUMO

Esta pesquisa avaliou as vantagens e desvantagens da substituição da areia por resíduo cerâmico no Concreto Autoadensável para produção de blocos intertravados. O subproduto foi obtido em armazém de uma loja comercial dedicada à construção civil na cidade de Maceió-Brasil e processado em moinhos de bolas em laboratório. O material foi caracterizado por Fluorescência de Raios X e Difração de Raios X e seu tamanho de partícula foi avaliado. O particulado foi incorporado em composições experimentais de 1:3 e 1:4 (cimento/agregado) e comparado com o traço de referência sem subproduto cerâmico. A avaliação do comportamento da mistura fresca foi realizada através dos testes Slump flow, L-box e V-funil. Posteriormente, a massa endurecida foi avaliada por ensaios de absorção de água e resistência à compressão. A superfície de fratura dos corpos de prova foi investigada por Microscopia Eletrônica de Varredura para compreensão do arranjo microestrutural. O estudo finalizou com a produção de blocos intertravados com três composições validadas, com substituições de 5%, 10% e 15% na mistura 1:3. Os resultados mostraram a viabilidade técnica de formulações com percentuais de substituição de até 15% na mistura 1:3 (cimento/agregado) e soma-se aos esforços que buscam uma produção mais limpa com foco no reaproveitamento de recursos que são desperdiçados.

Palavras-chave: Concreto sustentável; Resíduo cerâmico; Reuso.

ABSTRACT

This research evaluated the advantages and disadvantages of replacing sand with ceramic waste in self-compacting concrete for interlocking blocks production. The by-product was obtained in a warehouse of a commercial store dedicated to civil construction in the city of Maceió-Brazil and processed in ball mills in the laboratory. The material was characterized by X-Ray Fluorescence and X-ray Diffraction and its particle size was evaluated. The particulate was incorporated into experimental compositions of 1:3 and 1:4 (cement/aggregate) and compared with the reference mix without ceramic by-product. The evaluation of the behavior of fresh mix was carried out using the Slump flow, L-box and V funnel tests. Posteriorly, the hardened mass was evaluated by water absorption and compression resistance tests. The fracture surface of the specimens was investigated by Scanning Electron Microscopy for understanding the microstructural arrangement. The study ended with the production of interlocking blocks with three validated compositions, with substitutions of 5%, 10% and 15% in the 1:3 mix. The results showed the technical feasibility of formulations with replacement percentages of up to 15% in the 1:3 mix (cement/aggregate) and add to efforts that seek cleaner production with a focus on the reuse of resources that become waste.

Keywords: Sustainable concrete; Ceramics waste; Reuse.

Autor Responsável: Ronny Francisco Marques de Souza Data de envio 29/05/2024 Data de aceite 15/08/2024

DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0317

1. INTRODUCTION

Economic development is associated with the use of natural resources and consequently the generation of waste. This association is due to the current inefficiency of human production and consumption processes, which are unsustainable when compared to nature's recovery mechanisms. In this view, Civil Construction is seen as an activity with high environmental impact for consuming high amounts of natural resources and generating pollutants in its chain. However, the sector is essential for maintaining the modern way of life and has accompanied man for a long time in his migration from nomad to complex societies. The current challenge is developed methods, approaches and alternatives for reusing waste. In this quest, concrete is an excellent target towards this goal [1, 2].

It is widely accepted that human processes lack good yields. In general, from the energy production to food sector's, we observe waste related to manufacturing and distribution. In Civil Construction it's no different. Since the extraction of natural resources, distribution, production and end-product, large-scale waste is observed [3]. Finishing materials are generally those that require the greatest amount of water and energy in their production, therefore, they are those with the largest ecological footprint. In Brazil and in some regions of the world, many processes are not automated, which generates losses due to transportation, storage and distribution. A significant amount of damaged building materials is sent to landfills every year. Present-day estimated that one third of all solid waste produced in the world is Construction and Demolition Wastes (CDWs) [4].

The use of CDWs in the production of conventional concrete has been well explored in recent years, but its use increases the water/cement ratio in the composition, reducing compressive strength [5]. In this context, the reuse of this fine material in Self-Compacting Concrete (SCC) can be an interesting opportunity. Since its first application in the late 80s, this innovation has transformed engineering works around the world [6]. The SCC is characterized by its good fluidity that is useful for filling forms through the reinforcement without the occurrence of blockages, using its weight for this, dispensing with any consolidation methods. To reach this, it is necessary for concrete to have a greater quantity of fines for its composition, to obtain adequate workability without resulting in the segregation of its components [7].

Traditionally large-scale production of interlocking blocks is carried out using conventional concrete with assistance from a vibrating table or press [8]. This construction element has the advantage of forming an interconnected, versatile system shaped by the combination of parts easily repaired. Add to the project easy, cleanliness and low-cost labor providing system drainage of surface water, durability and resistance to abrasion. The aim is to achieve the characteristic compressive strength at 28 days of concrete in interlocking blocks with at least 35 MPa for pavements of commercial and 50 MPa for special traffic's [9].

The bottlenecks involved in obtaining natural inputs have been driving the search for alternative production routes, based on efficient and environmentally friendly methodologies that draw to incorporate waste into the cement matrix aiming to decrease the carbon footprint. This paradigm shift made some progress in incorporating unconventional by-products that include mollusk shells [10], plastics [11], paper [12], fibers [13], slag [14], ash [15] and other waste [16]. The incorporation of waste into SCC is a promising trend that can be seen in work with the addition of marble [17], eggshell [18], glass [19], copper [20]. Successful experiences of the addition of by-product ceramic to concrete have been reported and encourage new research [21–26].

The use of ceramic waste to SCC has been reported in compositions that replace fine aggregate or cement. Meena and collaborators studied the addition of ceramic residues to SCC in different approaches, in general, they observed that replacing the residue increases compression resistance while affecting the fresh state properties [21–24]. Achak and collaborators studied the effect of adding a combination of ceramic waste, microsilica and polypropylene fibers, observing the loss of fluidity and increased resistance to compression, was observed which the microsilica improves the microstructure, while polypropylene fibers increase the porosity and viscosity of the material [25]. In another approach, SCC were produced by replacing cement with ceramic waste as filler material; a decrease in compressive strength was observed accompanied by better fluidity in the fresh state at up to 15% addition of the by-product [26].

This study aimed to evaluate the potential use of ceramic waste generated by the commercial sector in its transportation, storage and distribution activities. Damaged products are almost always sent to landfills and inappropriate locations, mixing with other materials of a different chemical nature, making their use unfeasible. Here it is shown that this by-product can be used to produce SCC in percentages of up to 15% in replacement of fine aggregate (river sand), proposing an appropriate destination for the material while reducing the need of natural resources. The validated SCC were used to produce interlocking blocks that do not require conventional vibration and pressing methods, proposing the elimination of this step in the production chain.

2. MATERIALS AND METHODS

The experimental part was structured into four phases. The first was collection and processing of the ceramic material with evaluation of the specific mass and determination of pozzolanic activity. Laboratory analyzes of the residue used were also carried out using X-ray Fluorescence (XRF) and X-ray Diffraction (XRD). In the second part, dosage studies were carried out for the production of concrete, varying the percentage of replacement of fine aggregate by the ceramic by-product through tests such as V-funnel 5 min, Slump Flow, L-box and production of concrete test specimens. Subsequently, the specimens were subjected to technological tests of water absorption, dimensional and visual analysis and compression strength tests at 7, 14, 28 and 91 days, images were obtained by Scanning Electron Microscopy of the fracture surface. Finally, the fourth phase consisted of manufacturing the interlocking blocks using the SCC developed. The blocks were subjected to a detailed visual assessment, seeking to ensure quality and esthetic standards.

2.1. Raw material

In the production of the SCC, CP V ARI - RS cement from the Mizu brand and crushed stone with a maxi-mum size of 12.5 mm was used. The sand obtained in the Vale do São Francisco region, Juazeiro-BA, was used as fine aggregate. To preserve the necessary fluidity in the SCC mixture without changing the water/cement ratio, the additive MasterGlenium 51, from BASF, was used, based on carboxylates formulation, incorporated at up to 1% in relation to the cement mass. Was used from the public supply water network of Juazeiro-BA city, Brazil.

The ceramic by-product was collected in Maceió-AL, from a store specializing in construction materials. The pieces collected showed damage to their structure, resulting from handling, storage, pallet movement and transportation from the factory to the store. These defective products had their final destination in the city's landfill and were discarded weekly mixing with materials of another nature, as shown in the Figure 1.

After collection, the by-products were taken to the laboratory and were processed in a PAVITEST brand ball mill, model Los Angeles I-3021, equipped with a three-phase induction motor. The ceramic plates were introduced into the mill drum, and after 3 hours of processing, there was a reduction in the size of these pieces. Subsequently, through manual sieving, it was possible to obtain a standardized particle size, passing through a sieve with a 1.18 mm mesh opening.

2.2. Characterization of the ceramic by-product

The chemical analysis by X-ray Fluorescence (XRF) of the ceramic by-product powdered was carried out using the X-ray fluorescence spectrometer (EDX-700, Shimadzu) in a vacuum atmosphere, using the semiquantitative method to determine the elements present in the samples. The X-ray Diffraction (XRD) of the ceramic by-product powdered to generate the X-ray diffractogram, the Shimadzu XRD-6000 Diffractometer was used to identify the mineralogical phases present, using the following conditions: Cu-κα radiation ($\lambda = 1.54056$ Å, voltage 40 kV, current 30 mA, sweep angle (2θ) from 10 to 80°).

The determination of the specific mass of the powdered ceramic by-product was carried out following NBR 16605 [27]. In the procedure, the liquid used was kerosene.

2.2.1. Characterization of aggregates

The particle size was evaluated according to instructions from NBR NM 248 [28]. For the fine aggregate particle size test, the sand was placed in an oven (110 °C) until the mass was constant. After this process, the sample

Figure 1: Paths for ceramic by-product.

Table 1: Composition of SCC mixtures.

COMPOSITION	UNIT TRACE	CEMENT	STONE	SAND	BY-PRODUCT	WATER	**ADDITIVE
Compositions 1:3							
T1	1: 1.65 : 1.35 : 0.00	13.75	22.69	18.56	0.00	6.19	0.34
T2	1 : 1.65 : 1.28: 0.07	15.00	24.75	19.24	1.01	6.75	0.48
T3	1 : 1.65 : 1.22: 0.14	14.25	23.51	17.31	1.92	6.41	0.43
T4	1 : 1.65 : 1.15: 0.20	14.25	23.51	16.35	2.89	6.41	0.51
T5	1 : 1.65 : 1.08: 0.27	14.96	24.69	16.16	4.04	6.73	0.60
Compositions 1:4							
T1	1 : 2.20 : 1.80 : 0.00	11.00	24.20	19.80	0.00	4.95	0.88
T2	1 : 2.20 : 1.71 : 0.09	11.00	24.20	18.81	0.99	4.95	0.88
T3	1 : 2.20 : 1.62 : 0.18	12.10	26.62	19.60	2.18	5.45	0.91
T4	1 : 2.20 : 1.53 : 0.27	11.00	24.20	16.83	2.97	4.95	0.95
T5	1 : 2.20 : 1.44 : 0.36	11.00	24.20	15.84	3.96	4.95	1.10

*Cement, gravel, sand, by-product (kg). **Additive % in relation to the mass of the cement.

was cooled to room temperature and two samples weighing 500 grams each were separated and passed through sieves by vibrating for 15 minutes. The same procedure was carried out with the coarse aggregate. However, due to the larger maximum dimension (12.5 mm), 2.000 grams were used per sample, as recommended by NBR NM 248 [28]. The test to obtain the specific mass was carried out according to the recommendations of the standards NBR NM 52 [29] for fine aggregate and NBR NM 53 [30] for coarse aggregate.

2.3. Concrete compositions

The concrete dosage was followed according to the method for SCC [31]. The dosage began with the selection of the components: cement, sand, crushed stone, with the addition of the superplasticizer additive and the ceramic by-product. Tests were carried out with different proportions: 1:3 and 1:4 (cement:aggregate), maintaining the ratio between the aggregates at 55% coarse aggregate and 45% fine aggregate, and the water/cement ratio fixed at 0.45. The proportions of the compositions are shown in Table 1.

2.4. Rheological tests

The SCC produced were evaluated for their fluidity, passing ability and cohesion by the Slump flow, L-Box and V Funnel 5 min tests [32–34].

The Slump flow test was carried out in accordance with the recommendations of NBR 15823-2 using a rectangular metal sheet base measuring 900 mm × 1100 mm and 1.5 mm thick and a metal cone 1.5 mm thick, 300 mm high, and an upper internal diameter of 100 mm and a lower internal diameter of 200 mm. Based on NBR15823-4, the L-Box test was carried out using a box with a rectangular L-shaped section, consisting of a vertical and horizontal wooden compartment with an inert coating. The 5 min V-funnel test was carried out in accordance with NBR 15823-5 using a wooden funnel with an inert coating.

2.5. Production of test specimens

In the laboratory, 20 replicas of specimens were molded for each composition (4 for the compressive strength test at 7 days, 3 for the test at 14 days, 6 for the test at 28 days, 4 for the test at 91 days and 3 for the water absorption test).

2.5.1. Compressive strength tests

The compressive strength of the blocks produced was measured in accordance with the recommendations of NBR 9781 [33], at 7, 14, 28 and 91 days, to evaluate the progression of the increase in compressive strength in relation to time. The specimens were ground with a marble saw in their lower part to correct small ripples formed by the aggregates. After this process, they were broken with the help of a servo-controlled press, model WAW 1000C – Time Group Inc., at a loading speed of 0.55 MPa/s.

2.5.2. Water absorption tests

The test to evaluate water absorption in the blocks followed the guidelines of NBR 9781 [33]. The specimens were submerged in water for a period of 24 hours. After immersion, the specimens were weighed in a saturated dry surface condition. Drainage was done on a metal screen, followed by removing visible surface water with an absorbent cloth. Subsequently, the specimens were subjected to an oven with a temperature of 110°C, where they remained for 24 hours, in order to be dried in a controlled manner. Then, they were weighed again in the oven condition, being completely dry. This procedure was repeated at two-hour intervals until the discrepancy between two successive determinations was less than 0.5% in relation to the previous measurement.

2.5.3. Microscopy of the fracture surface

After rupture, small samples of the fracture surface were evaluated using Scanning Electron Microscopy (SEM). The samples were subjected to a metallization process with a thin layer of gold and magnified at 100, 2000 and 5000x for a better understanding of the microscopic arrangement.

2.5.4. Visual and dimensional assessment of interlocking blocks

Molds of rectangular blocks of interlocking pavement, measuring 20 cm × 10 cm × 6 cm, were used to carry out the study. The evaluation of the blocks followed the guidelines of NBR 9781 [9]

The visual inspection assessed the presence of defects in the parts that could harm the settlement, structural performance or appearance of the pavement. A batch is considered unacceptable if more than 5% of defective parts are identified in total. During the visual analysis, aspects such as uniformity, regularity of edges and right angles, defects such as burrs, delamination and peeling were considered.

The dimensional assessment was measured with a precision caliper. Each dimension was measured at two different points, and measurements were taken at the midpoint. Both tests were conducted using the same blocks used in the simple compressive strength test at 28 days of age.

3. RESULTS AND DISCUSSION

The analysis of the ceramic by-product using the XRF technique allowed the semi-quantitative identification of the oxides present in the sample, as shown in Table 2.

The predominant presence of SiO_2 and Al_2O_3 oxides (around 82.04%) is due to the clay used in the manufacture of ceramic pieces. The ceramic by-product rich in silicon dioxide and aluminum oxide can play an important role in the composition of SCC with substitution, promoting improvements in the density and performance of the material, as it can be involved in reactions with the cement matrix, showing pozzolanic activity [34]. The presence of Fe^{+3} ions can be interesting, because due to the size/charge relationship it can act like Al^{+3} ions during the crystallization process, modifying the nucleation bodies and diversifying the arrangement of microstructure [35]. Studies show that the addition of ceramic materials to cement compounds can present pozzolanic reactivity, generating better hydration products that contribute to locking the dry paste [36]. Furthermore, fine particles can act as nucleation and precipitation points for hydrates, resulting in superior macroscopic properties such as increased mechanical resistance [37].

The diffractogram of the ceramic by-product is shown in Figure 2.

The presence of crystalline phases of SiO_2 (quartz) and $CaAl_2Si_2O_8$ (anorthite) reinforces the profile found in the XRF, pointing to the potential for pozzolanic activity of the material. Natural clay combined with other mineral components undergoes a heating process to obtain the finished ceramic piece. In this process of evolution of the glass phase that occurs during sintering, anorthite is formed, being favored at temperatures above 900ºC [38]. The presence of these minerals can contribute to better SCC performance due to the microstructural diversification of the nucleation bodies in reactions with the cement in the matrix.

The use of porcelain tile residue to replace coarse aggregate in self-compacting concrete and calcium carbonate to replace cement led to improvements in workability, durability and mechanical properties [39]. In another example, the use of ceramic coating waste to replace natural river sand improved the compressive, flexural and tensile strength of SCC mixtures by up to 100% of the replacement level with a higher dosage of

Table 2: Chemical composition of the ceramic by-product.

OXIDES	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	TiO_2	SrO_2	ZnO	OTHERS
(%)	60.80	21.24	7.23	4.08	2.72	2.13	1.02	0.17	0.10	0.51

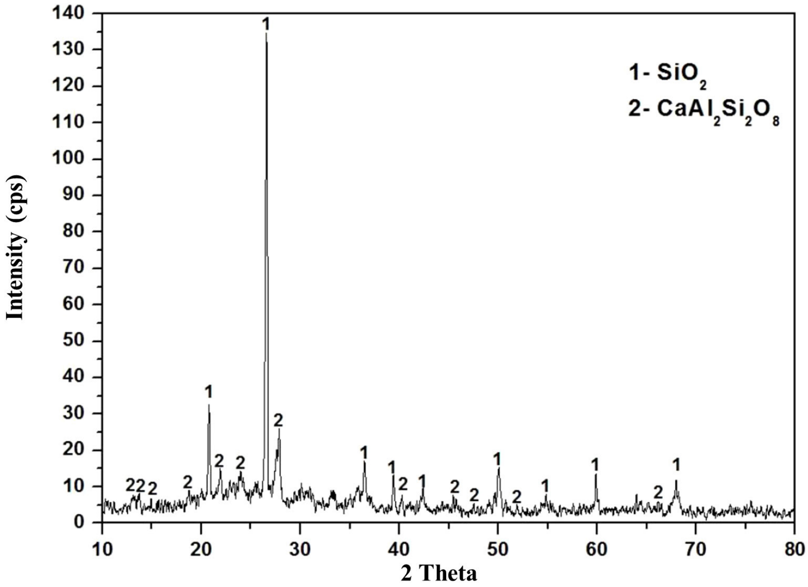

Figure 2: Diffractogram of the ceramic by-product.

superplasticizer [21]. In general, the use of ceramic waste has been well reported in conventional concrete [40], but there is little literature for the class of self-compacting concrete [21–26].

In order to verify the pozzolanic potential of the ceramic by-product, two mortar dosages were produced. Mortar A, containing CP II-F-32 cement, normal sand and water; Mortar B, containing 25% by mass of ceramic by-product, replacing an equal percentage of CP II-F-32 cement. Six specimens were molded. The compressive strength test on mortar A (22.7 MPa) and B (16.7 MPa) showed a pozzolanic activity performance index of 73.56%. Therefore, the byproduct used in this study does not present pozzolanic activity [34]. The by-product presents a specific mass of 2.69 g/cm^3 in the test [30].

The characterization of the fine aggregate showed particle size distribution with particle diameter between 0.15 mm to 2.40 mm. It was observed that on average 2.33% was retained in the coarse sand, 55.24% in the medium sand and 42.43% in the fine sand classification range. The coarse aggregate showed the maximum identified characteristic dimension of 12.5 mm and the fineness modulus of 5.80. The granulometric zone, in accordance with the limits of grain composition, was 4.75/12.5 mm, being classified as crushed stone 0 NBR 7211 [41].

Understanding the aggregates helped to define the composition of the traces without and with substitution of the ceramic by-product in proportions of 5, 10, 15, 20%. The Slump Flow, L-Box and V-funnel 5 min workability tests were carried out to evaluate the compositions. Table 3 shows the results for the Slump Flow test.

Table 3 shows that the addition of the ceramic by-product improved spreading in the concrete produced. In relation to the 1:3 ratio, the increase in the ceramic by-product caused the concretes to be classified as SF 3, as showed in Figure 3.

In general, all SCCs produced were within the satisfactory limit, between 550 and 850 mm. The addition of the ceramic by-product caused the concrete to change its class, which were SF 1 to SF2 or SF3. The SCC SF1 is the class used for applications in unreinforced structures or with a low reinforcement ratio and which require a short horizontal spreading distance. The SCCs SF 2 is suitable for most current applications and SF 3 is a class applied to structures with high reinforcement density of complex architectural form [41]. Similar values, between 663 and 721 mm, are described in the literature on SCC with replacement of ceramic waste by sand. The increase in the addition of ceramic material is accompanied by a decrease in the spreading diameter with more addition of the superplasticizer to the mixture [21]. Aiming to better understand the rheological properties of SCC, Passing Ability in the L-box tests were carried out, described in Table 4.

The value considered satisfactory for passing ability in L-box is at least 0.80. According to Table 4, all SCCs produced is within the application limit [41]. Studies have observed that the addition of ceramic material to replace sand led to an increase in the passage values with an increase in the replacement level by up to 100%. This was attributed to the rough and irregular shape of the particles, which increased friction between the aggregate and the binder, resulting in a reduction in the SCC's ability to pass through [21]. In general, the passing

Table 3: Results of Slump Flow tests (mm) for the SCC produced.

REPLACEMENT	COMPOSITION 1:3	CLASS	COMPOSITION 1:4	CLASS
T1 – 0%	600.00	SF1	695.00	SF2
T2 – 5%	795.00	SF3	725.00	SF2
T3 – 10%	820.00	SF3	735.00	SF2
T4 – 15%	685.00	SF2	740.00	SF2
T5 – 20%	770.00	SF3	715.00	SF2

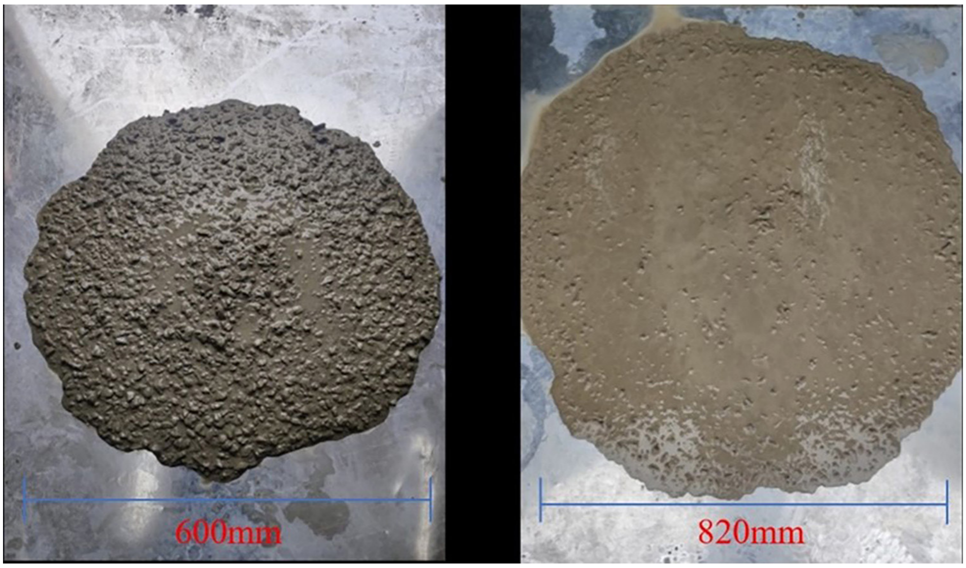

Figure 3: Slump Flow tests for SCC T1 and T3 of the compositions 1:3.

Table 4: Passing ability of SCC obtained in the L-Box test.

REPLACEMENT	PA OF COMPOSITIONS 1:3	PA OF COMPOSITIONS 1:4
T1 – 0%	0.84	0.89
T2 – 5%	0.94	0.84
T3 – 10%	0.94	0.80
T4 – 15%	0.89	0.87
T5 – 20%	0.94	0.84

ability in L-box test aims to establish a limit value to evaluate the fluidity of concrete by the action of its weight [41]. Another characteristic evaluated was plastic viscosity using the V-funnel test shown in Table 5.

The results in Table 5 show that all SCCs produced were within the normative limit considered for the appropriate apparent plastic viscosity, which varies from 0 to 25s [41, 42]. The replacement of sand with the ceramic by-product did not change the classes of concrete with a 1:3 ratio, all of which are considered VF 1, which is suitable for structural elements with high reinforcement density, but requires attention in controlling exudation and segregation. In relation to the 1:4 mixture, the replacement with the ceramic by-product caused the SCC to increase its test time, going from VF1 to VF2, which is relevant for most current applications, presenting better resistance to segregation, due to this, unwanted effects can occur on the finishing surface and filling the corners. After rheological tests in the fresh state, procedures were carried out to evaluate the performance in the hardened state for water absorption and compressive strength for the SCC produced. The compressive strength results are presented in Table 6.

The SCC with ceramic by-product showed high resistance at 7 days of age, which increased at 14 and 91 days. This behavior is probably due to the type of cement used in the study, CPV-ARI, which promotes high initial resistance. The 1:3 compositions, T3 and T4, reached compressive strengths very close to the results found for the reference concrete (T1) at all ages, surpassing it at 91 days of age. In relation to the 1:4 mix, there is a

Table 5: Plastic viscosity of SCC obtained in the V-funnel test.

REPLACEMENT	CLASS OF COMPOSITION 1:3	TIME	CLASS OF COMPOSITION 1:4	TIME
T1 – 0%	VF 1	6 s	VF 1	6 s
T2 – 5%	VF 1	6 s	VF 2	11 s
T3 – 10%	VF 1	5 s	VF 2	25 s
T4 – 15%	VF 1	6 s	VF 1	8 s
T5 – 20%	VF 1	6 s	VF 2	12 s

Table 6: Evolution compressive strength of 1:3 and 1:4 compositions in SCC.

REPLACEMENT	7 DAYS	14 DAYS	91 DAYS
Composition 1:3			
T1 – 0%	36.75	41.70	50.61
T2 – 5%	32.96	36.56	46.37
T3 – 10%	36.97	40.56	52.35
T4 – 15%	35.21	41.30	51.27
T5 – 20%	19.29	23.39	28.66
Composition 1:4			
T1 – 0%	36.74	40.41	44.07
T2 – 5%	24.04	27.26	36.38
T3 – 10%	24.00	29.67	40.36
T4 – 15%	19.43	22.48	28.26
T5 – 20%	15.14	17.60	22.60

pattern of decreasing resistance with the increase in the percentage of substitution of fine aggregate by ceramic by-product, with the exception of the T3 treatment at ages 14 and 91 days, which obtained greater resistance to compression than other replacement treatments. Figure 4 highlights the compressive strength values achieved after 28 days.

For human and vehicle traffic, the characteristic compressive strength required at 28 days of age must be greater than or equal to 35 MPa. Examining Figure 4, it is possible to see that for the 1:3 mixture, the formulations T1 (0%), T2 (5%), T3 (10%) and T4 (15%) exceeded the minimum value established by the normative standard. For the 1:4 trait, the only treatment that achieved this normative parameter was the reference (T1). These results are similar to those reported in the literature for the incorporation of ceramic waste in SCC [21]. Searching to better understand the effect of ceramic particles on SCC compositions, water absorption tests were carried out in the specimens as show in Table 7.

All SCCs showed water absorption with an average value less than or equal to 6%, certifying that all blocks produced are in accordance with this normative parameter [9]. This result shows the feasibility of incorporating by-products from damaged ceramic slabs into SCC for block production. The blocks are very versatile pieces and provide a great final finish to the work. They are generally applied in external locations subject to weathering and stress. In general, the minimum values for compression resistance and water absorption were achieved. Visual and metric analysis attest to the quality of the blocks produced, as shown in Figure 5.

The blocks produced with SCC showed no defects. Homogeneous pieces were obtained with regular edges and right angles; no burrs, delamination and peeling. The dimensional assessment showed uniformity in length, height and width measurements. The behavior of SCC in the hardened state is directly related to the microstructural arrangement. With the aim of understanding the cement matrix with and without ceramic by-product adding, images of SEM were obtained of the fracture surface of the specimens as shown in Figure 6.

Figure 6 shows that the compositions without replacing the aggregate with the ceramic by-product (A and B) have a greater number of empty spaces compared to the compositions with ceramic powder (C and D). This microstructural arrangement of the material can explain the mechanical behavior of the material in the hardened state. The ceramic by-product due to its smaller size compared to sand fill spaces more efficiently during

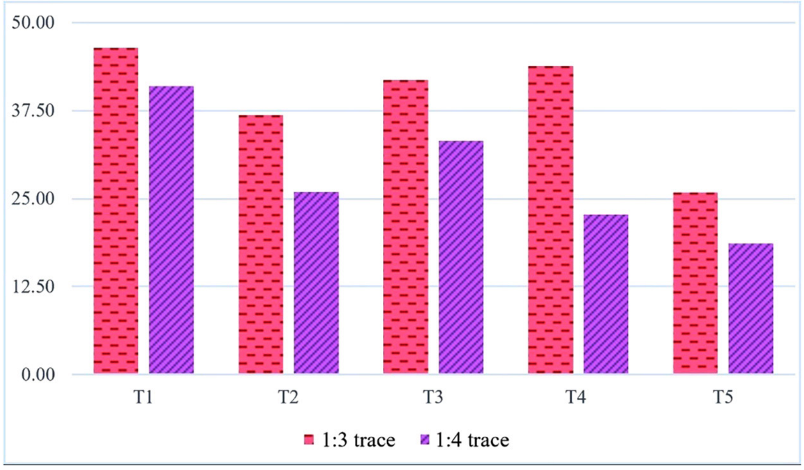

Figure 4: Compressive strength at 28 days.

Table 7: Water absorption of the compositions SCC.

COMPOSITIONS	REPLACEMENT	WATER ABSORPTION
1:3	T1 – 0%	4.89%
1:3	T2 – 5%	5.11%
1:3	T3 – 10%	5.32%
1:3	T4 – 15%	5.39%
1:3	T5 – 20%	5.83%
1:4	T1 – 0%	4.88%
1:4	T2 – 5%	5.21%
1:4	T3 – 10%	4.37%
1:4	T4 – 15%	5.49%
1:4	T5 – 20%	5.03%

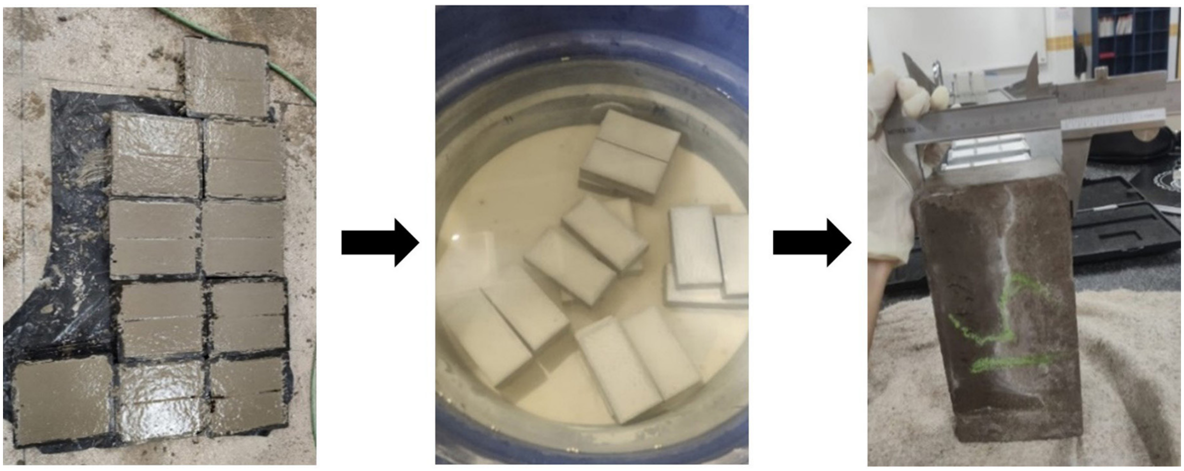

Figure 5: Molding, demolding and analysis of blocks.

the curing process in the cement reactions, and this can provide better structural locking which is reflected in better compressive strength in this composition. The filling caused by the material can reduce microcracks and promote less water absorption. Reported studies describe similar mechanical behaviors and microstructure arrangement by the addition of ceramic powder, in agreement with these observations [21, 43]. A summary of the proposal to transform damaged parts into interlocking blocks is shown in Figure 7.

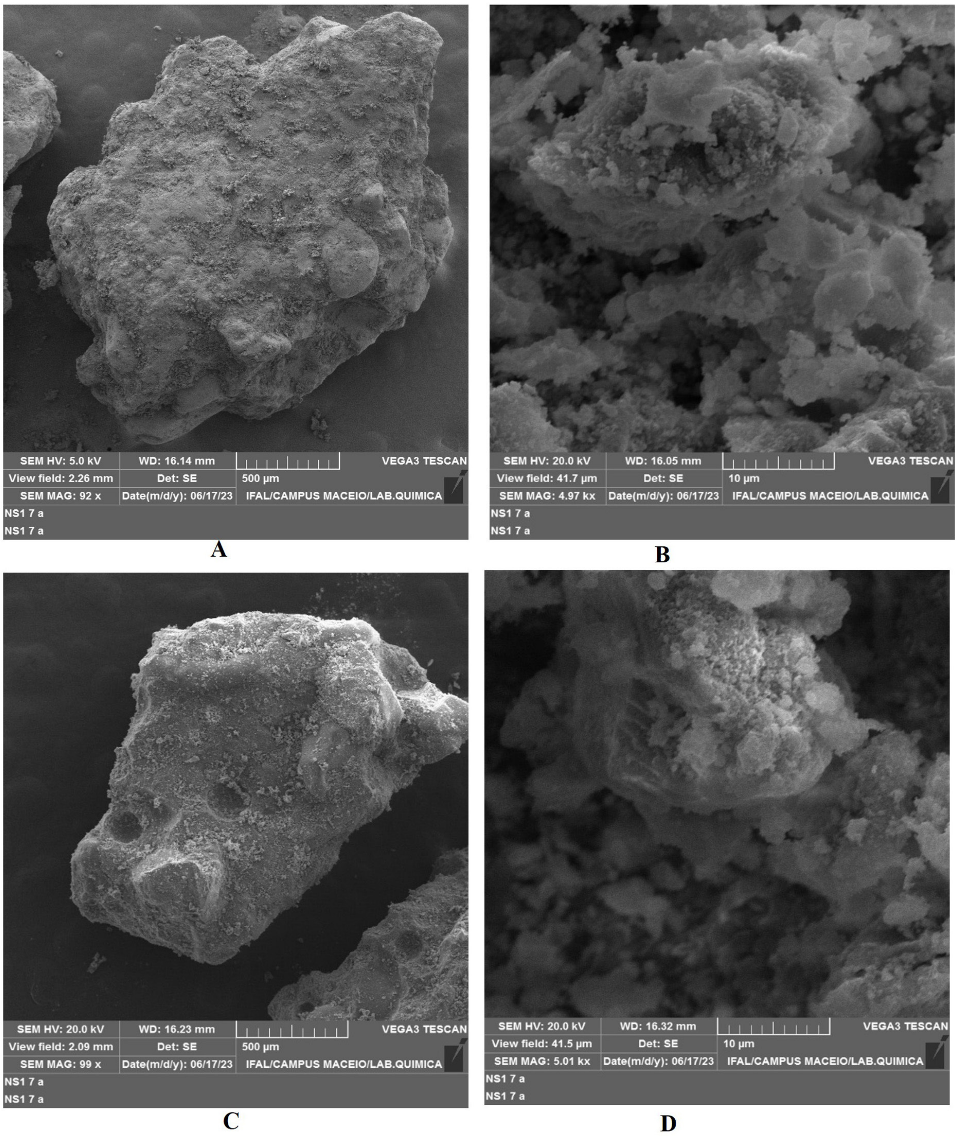

Figure 6: SEM of compositions T1 (A and B) and T3 (C and D) in a 1:3 ratio.

Figure 7: Production of interlocking blocks with SCC.

The development of materials and processes sustainable is a major current challenge. Humanity for a long time has been consuming natural resources without paying attention to environmental degradation, more recently in history, in our industrialization process we adopted a linear economy. This model is unviable any longer. Population growth and the complexity of events related to our lifestyle impose bottlenecks that drive our intrinsic characteristic: The innovation. Anchored in this movement, this work was carried out and the production of SCC blocks was achieved. The work presents a methodology that has the advantage of properly disposing of ceramic waste, reducing the need of sand and eliminating the traditional compaction step in making blocks (pressing or vibration). But it also has disadvantages: the logistics chain involved in transporting damaged parts to production of SCC exposes our productive inefficiency; The energy used in milling the ceramic pieces adds an energy expenditure stage that has a high carbon footprint. The production of SCC completely green and inserted into the circular economy model is a challenge. This work showed small advances in this direction.

4. CONCLUSION

The SCC with ceramic by-product fines met all requirements regarding fluidity, ability to pass through obstacles and resistance to aggregate segregation. The addition of the ceramic by-product improved the rheological aspects of the concrete produced. In general, the use of recycled ceramic fines resulted in improvements in the self-compacting properties of the concrete.

Compressive strength at 28 days of age in SCC with replacement was higher than in reference SCC. These required a lower water/cement ratio used in the production of SCC, which was possible through the use of the plasticizing additive. The reference treatments and replacements of 5%, 10% and 15% of the 1:3 mix showed values higher than the standard for pedestrian traffic, light vehicles and commercial vehicles (35 MPa). The water absorption by the blocks met the normative parameter with an average value less than or equal to 6%.

This study showed the feasibility of producing blocks interlocked with SCC with fine ceramics in pieces with excellent finishing. All blocks produced met visual and dimensional normative criteria.

In summary, the study demonstrated the technical feasibility of incorporating the ceramic by-product in the production of interlocking paving blocks from SCC in formulations with percentages of up to 15% and a 1:3 ratio.

The use of recycled ceramic aggregates in the manufacture of parts for interlocking flooring is an alternative for the reuse of by-products generated in the Civil Construction sector, enabling lower consumption of natural aggregates and reducing the environmental impact caused by the inadequate disposal of these materials.

5. ACKNOWLEDGMENTS

The authors would like to thank the Federal Institute of Alagoas, the Construction Materials Laboratory at UNIVASF and professor Johnnatan Duarte Freitas for the SEM images.

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