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STRUCTURAL GROUTS WITH PARTIAL REPLACEMENT OF NATURAL AGGREGATE BY CERAMIC RESIDUES (CR)

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Abstract
This paper aims at investigating the behavior of structural grouts with partial replacement of the natural coarse aggregate by 50% of ceramic waste (CW). Five mixtures were dosed, varying in the addition of CW replacement, hydrated lime and superplasticizer. The fresh and hardened properties of each composite were analyzed through the slump test, compressive strength, capillary and total water absorption. Concerning the hardened state, grouts with CW addition and superplasticizer had the best results. Ceramic aggregates provided a 8% increase in compressive strength compared to the reference mixture, reaching almost 30 MPa for the matrices with CW and superplasticizer. Besides that, total and capillary water absorption were reduced by 2.5 times comparing to the references. However, the highest slump loss was obtained for grouts with CW and superplasticizer, despite their satisfactory consistency during the first 30 minutes, once that the chemical admixture loses its effect after this period. On the other hand, grouts with CW replacement and without superplasticizer maintained consistency for a 120 min and, even with a higher w/c ratio, their compressive strength reached 20 MPa, still above the 14 MPa required for structural grouts, according to ASTM C476. The addition of hydrated lime, in its turn, did not provide such an enhanced mechanical behavior to justify its use. Therefore, CW replacement of natural coarse aggregate is suitable to produce structural grouts.

Keywords: chemical conditioning, dewatering, geotextile fabric, experimental design, ETA residue.

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Introduction

Although the relevance to Brazilian financial stability (IBGE, 2016), civil construction lacks innovations and technology, as observed in the usual way that some activities are handled manually, originating vast amounts of residues (Šipoš *et al*., 2017; Rodrigues *et al*., 2018). In general, this industry is subjected to intense generation of wastes in its whole production cycle. As main factors of waste, massive losses during the transportation of materials can be highlighted (Pellegrini *et al*., 2018), as well as other losses due to errors in manufacturing and execution, and even inappropriate destination of residues from renovations and demolitions (Abreu *et al*., 2018). Thus, it is inevitable to analyze critical points and suggest improvements, such as reutilizing materials to create more sustainable buildings and preserve natural resources (Rashid *et al*., 2017).

Organizations, academic institutions, companies and other entities, along with society, seek to progressively develop more sustainable construction processes with the optimization of construction and demolition waste (CDW) (Šipoš *et al*., 2017; Bosque *et al*., 2017; Guo *et al*., 2018; Dimitriou *et al*., 2018). Researchers as Medina *et al*. (2012), Schackow *et al*. (2015) and Wu *et al*. (2019) have been approaching higher rates of materials reuse, such as aggregates and cement, as they are responsible for most of CO_2 emission to atmosphere. Regarding that ceramic products are one of the main inputs of buildings, their reuse in the system would be expressively relevant (Murmu and Patel, 2018). An alternative is adopting ceramic residue (CR) as recycled aggregates in mortars, concretes or structural grouts (Souza *et al*., 2014).

The use of red ceramic grogs as coarse aggregates in grouts shows interesting results, representing the inherent potential of this material in cementitious matrices (Giseler and Tutikian, 2013; González *et al*., 2017). Some studies, as Uddin *et al*. (2017), Bui *et al*. (2017) and Xua *et al*. (2018), evaluate the mechanical behavior of cementitious matrices with partial substitution of CR. They show that replacing basaltic aggregate by recycled aggregate causes losses to compressive strength, which can be from 10 to 35% for coarse aggregates and from 30 to 40% for fine aggregates. On the other hand, Adamson *et al*. (2015) defend an increase in strength and durability with the addition of ceramic aggregates in structural concretes. It should be noted that studies on the durability of structures are essential for each content of residues addition.

According to Gayarre *et al*. (2017), recycled aggregates can have higher water absorption than natural basaltic aggregates. For grouts, as fluidity is an important parameter, water consumption from cement paste by aggregates can cause serious casting problems. To avoid the problem of workability loss for grouts with CR, Anagnostopoulos (2014) recommends increasing the consumption of water or use superplasticizer. The choice, however, must be taken carefully. Low quantities of water do not provide the fluidity required by structural grouts, easily obtained with superplasticizers, and adding higher quantities of water can bring mechanical strength issues.

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These admixtures are used to increase concrete fluidity, but maintain the water/cement ratio (w/c), according to NBR 11768 (ABNT, 2011). Another option by employing hydrated lime, which improves curing conditions by retaining water inside the mixture, granting more efficient hydration reactions (Rodrigues *et al*., 2014; Shamsuddoha *et al*., 2018; Silva *et al*., 2018).

Therefore, this study aimed to investigate civil construction residues applied to structural grouts for structural masonry, through the replacement of the natural coarse aggregate by ceramic residue CR in 50% in mass, with volume compensation, and its association with superplasticizer, based on polycarboxylate, and hydrated lime. The compressive strength of the specimens was evaluated at 1, 7 and 28 days; additional tests intended to determine slump loss within the first 2 hours, total and capillary water absorption at 28 days, void ratio and bulk specific gravity, along with a microscopic analysis of post-stress ceramic aggregates after mixing.

Materials and methods

Five mixtures were dosed according to Table 1, varying in the use or not of CR replacement, hydrated lime and superplasticizer. For each composition, 12 cylindrical specimens were tested with dimensions of 100 mm (diameter) and 200 mm (height). From these, three replications specimens had their compressive strength determined at 1, 7 and 28 days. Also, total and capillary water absorptions were measured at 28 days for each mixture, with 3 specimens cut at dimensions of 100 mm in diameter and 50 mm thick. The fresh state properties of grouts were estimated through the consistency test, evaluating slump loss of grouts along time.

Table 1. Composition of the mixtures (kg/m³).

Grout	Ref w/o Lime	Ref w/ Lime	CR w/o Lime	CR w/o Lime + SP	CR w/ Lime + SP
CEMENT	400	400	400	400	400
LIME	0	16	0	0	16
SAND	880	880	880	880	880
GRAVEL	680	680	340	340	340
CR	0	0	340	340	340
WATER	240	240	328	240	240
SUPERP.	0	0	0	4.20	3.32
W/C	0.60	0.60	0.82	0.60	0.60

Subtitle: (Ref w/o Lime) reference without lime; (Ref w/ Lime) reference with lime; (CR w/o Lime) ceramic residue without lime; (CR w/o Lime + SP) ceramic residue without lime and superplasticizer; (CR w/ Lime + SP) residue with lime and superplasticizer.

Materials

In this study, Portland cement Type II-MH (moderate heat) was used, according to ASTM C150 (ASTM, 2018c). This choice is due to the frequent and suitable use of PC II-MH in construction sites, since the purpose of this research is making the structural grouts with CR actually viable.

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The hydrated lime is type CH-I, with a bulk specific gravity of 2.35 g/cm³ and the function of improving the consistency and fluidity of the mixture.

The granulometric composition of the natural and recycled aggregates was obtained following the parameters of ASTM C33 (ASTM, 2018d). The natural fine aggregate had quartz origin, with maximum size and fineness modulus of 1.20 mm and 1.17, respectively. Its bulk specific gravity was 2.54 g/cm³ and the unit weight was 1.40 g/cm³, both determined based on ASTM C136 (ASTM, 2014). The natural coarse aggregate was of basaltic origin, as it is the most common in the South region of Brazil. The gravel's bulk specific gravity was 2.69 g/cm³ and its unit weight was 1.35 g/cm³, in accordance with ASTM C136 (ASTM, 2014). The particle size distribution of the material followed ASTM C33 (ASTM, 2018d), with maximum size of the aggregate and fineness modulus of 12.5 mm and 6.83, respectively.

CR of red ceramic structural blocks was used as recycled aggregate after processing in a jaw crusher for 15 min. The structural blocks used had compressive strength of 7.0 MPa, resulting in aggregates with bulk specific gravity of 2.72 g/cm³ and unit weight of 1.01 g/cm³, determined through ASTM C136 (ASTM, 2014). The particle size distribution of the material followed ASTM C33 (ASTM, 2018d), with maximum size of the aggregate and fineness modulus of 12.5 mm and 6.37, respectively. The initial and total water absorption of CRs was determined based on ASTM C127 (ASTM, 2015b), resulting in 12% for the first minute and 18% at 120 min. Measurement times were determined based on the process of material homogenization and slump loss test.

Dosage method

The mix was chosen based on Giseler and Tutikian (2013), with a proportion of materials for grouts equal to 1: 0.04: 2.2: 1.7 (cement: lime: natural fine aggregate: natural coarse aggregate/CR), in mass. Concerning the coarse aggregate, the percentage of substitution of the natural aggregate by CR was 50% in mass, with compensation of volume (Bui *et al*., 2017; Gayarre *et al*., 2017; Nepomuceno *et al.*, 2018), and dispensing CR pre-wet. The mortar content of the mix was 65% and the slump of the structural grout was fixed in 230 mm, what led to an increase in the amount of water of the mixture (Ref w/o Lime, Ref w/ Lime and CR w/o Lime) or use of superplasticizer Powerflow 1180 (CR w/o Lime + SP and CR w/ Lime + SP).

Process of mixing, casting the grout and curing

The mixing procedure of materials was conducted in the same way for each case. The combination of materials began with the addition of the natural coarse aggregate, followed by 1/3 of the total water. Afterwards, cement, CR and fine aggregate were added. Finally, the remaining amount of water and the superplasticizer were added until the desired slump was achieved. When hydrated lime was used, it was included after the sand.

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For the compressive strength test, grouts were molded manually in cylindrical forms of 100 mm (diameter) and 200 mm (height) by ASTM C39 (ASTM, 2018a). The specimens were kept at ambient temperature for 24 h, protected by a glass plate to preserve their moisture. Then, the specimens were cured in a room with temperature of 21 ± 2 ºC and humidity of 95 ± 3%, and they remained under these conditions until the test day.

Slump loss
The slump loss test for grouts was performed as defined by ASTM C143 (ASTM, 2015a). All mixtures were evaluated using the frustum of cone method, with the same apparatus of the consistency test. Thus, the slump was measured every 15 min during a period of 2 h. Between evaluations, the grouts were remixed for 1 min and left to rest for 10 min. The climate conditions during the tests were temperature of 11°C and relative humidity of 62%.

Compressive strength test
The compressive strength test was performed following the procedures of ASTM C39 (ASTM, 2018a), with an applied load at a speed of 0.45 MPa/s. The tests were performed on samples at 24 h, 7 and 28 days, with three replications per age.

Capillary water absorption
The capillary water absorption was determined at 28 days through TC 116 (RILEM, 1999). After cutting the cylindrical specimens in slices with a thickness of 50 mm, their sides and the top surface were sealed, leaving only the bottom surface in direct contact with a layer of 3 mm of water. The results were expressed as the weight gained by the samples within periods of 30 s, 1, 2, 3, 4, 5, 10, 30 and 60 min, and 2, 4, 8 and 24 h. Before weighting, the excessive water was removed from the bottom surface of the slices.

Total water absorption, void ratio and bulk specific gravity
Water absorption, void ratio and bulk specific gravity of grouts were determined through the procedure of ASTM C642 (ASTM, 2013), and using the same specimens. They were stored in an oven with temperature of 105 °C for 72 h and then immersed in water with temperature of 23 °C for 3 days. After, they were submerged in boiling water for 5 h.

Microscopic analysis of post-stress ceramic aggregates
The equipment used for this test was the Anatomic Optical Microscope, located in the Petrography and Soils Mechanics Laboratory of Unisinos/BR. Due to ceramic aggregates' dimensions and image quality, a standard approximation of 100x was adopted. CRs were collected randomly from the vertical concrete mixer at chosen times for microscopic analysis. The procedures adopted were in order to preserve the properties of the aggregates after exposure to the conditions: post-stress with 60 s of mixing without superplasticizer (P-T60) and post-stress

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with 120 s of mixing with superplasticizer (P-T120). In addition, to analyze the aggregates post stresses in the homogenization, natural samples were collected before being added to the mixer. Thus, influence of mixing processes on CRs could be observed.

Results and discussion

In the following items, the fresh and hardened properties of the grouts are exposed, along with a microscopic analysis of the ceramic residue aggregate.

Slump loss

The slump loss results for the 5 mixtures are exposed in Fig.1, beginning with the same initial workability of 230 mm and decreasing with time.

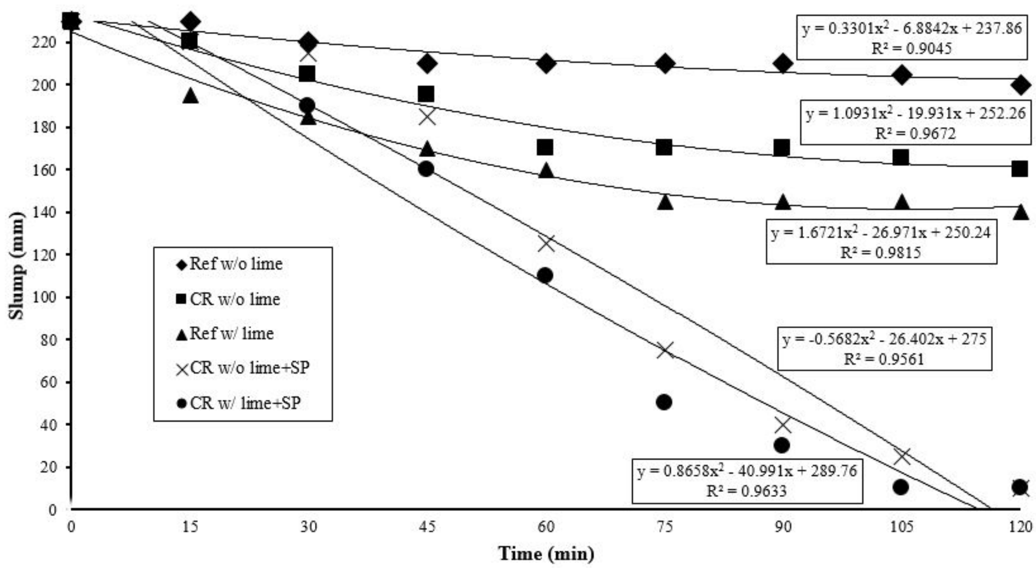

Figure 1. Slump loss over 2 h for the concrete mixtures.

These data show a more expressive slump loss of grouts with superplasticizer, up to 7 times higher when compared to those with no admixture, indicating the worst results. However, the workability of the mixtures with superplasticizer was affected mostly only after 45 min from the beginning of the test; at this moment, a significant slump loss of 50 mm over 15 min was observed for both mixtures with superplasticizer (CR w/o Lime + SP and CR w/ Lime + SP).

A similar behavior was also reported by Nepomuceno *et al.* (2018) and Siddique *et al.* (2019), where the slump loss was justified by the excessive water consumption of the recycled aggregate.

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This phenomenon can be explained by the superplasticizer's loss of efficiency over time, due to the product's maintenance period and the kneading water absorbed by the recycled aggregates, which disturb wet chemical reactions with cement grains. Even the mix CR w/o Lime had a higher slump loss compared to the reference, due to water absorption of the ceramic residue.

The workability variation of CR w/o Lime + SP and CR w/ Lime + SP was 220 mm after 2 h, reaching 10 mm of slump at the end of the experiment, that is, it has returned to its initial condition. Besides, the grouts Ref w/o Lime, CR w/o Lime and Ref w/ Lime presented workability variations of 30 mm, 70 mm and 90 mm, respectively. Concerning these samples without admixture, though, their loss of workability became more evident only in the first 45 min, being practically null after this period, mainly for grouts without residue.

The addition of lime in CR mixtures did not seem to have a considerable influence in the slump maintenance, comparing to the behavior of the blend without lime. This could be explained because adding a material with small size, as CH-I, increases the total superficial area of the mixture, and a higher quantity of water is absorbed by the surface, according to Pérez-Nicolás *et al.* (2016). The addition of lime to cement matrices is more efficient for mortars, in the fresh state.

As shown in Fig.1, CRs indeed affect the fresh state properties of the grouts, but when they are not combined with the hydrated lime and superplasticizer, the results are satisfactory, as in CR w/o Lime. It is pointed out that the CR w/o Lime had a w/c ratio of 0.82 to achieve the fixed slump of 230 mm, which is a w/c ratio higher than the standard recommended. In contrast, the mixtures with CR and superplasticizer had a high slump loss, making their use impossible after 45 min.

Compressive strength

The potential compressive strength results of the mixtures are illustrated in Fig.2, divided in the ages of 1, 7 and 28 days, respectively. Evaluating the effect of replacement of natural aggregates by recycled ones, the uniformity of compressive strength results stands out, particularly for older ages. Such findings are in agreement with other developed about mechanical properties of concrete with recycled ceramic aggregates (Valdés *et al*., 2010; González *et al.*, 2014 and Gayarre *et al*., 2019).

At the first day, compressive strength results for Ref w/ Lime are 2.5 times higher than for Ref w/o Lime, indicating a contribution of the hydrated lime in this case. However, these advantage of the mix with lime is minimized at older ages. A similar behavior is verified for CR w/ Lime + SP and CR w/o Lime + SP, once that the first mix had the highest compressive strength of all samples at ages of 7 and 28 days, reaching 29.8 MPa. It should be noted that in the first day, the blend CR w/ Lime + SP had the lower compressive strength comparing to the mix w/o Lime. Thus, the lime addition did not show such a significant effect in the compressive strength behavior of mixtures at older ages.

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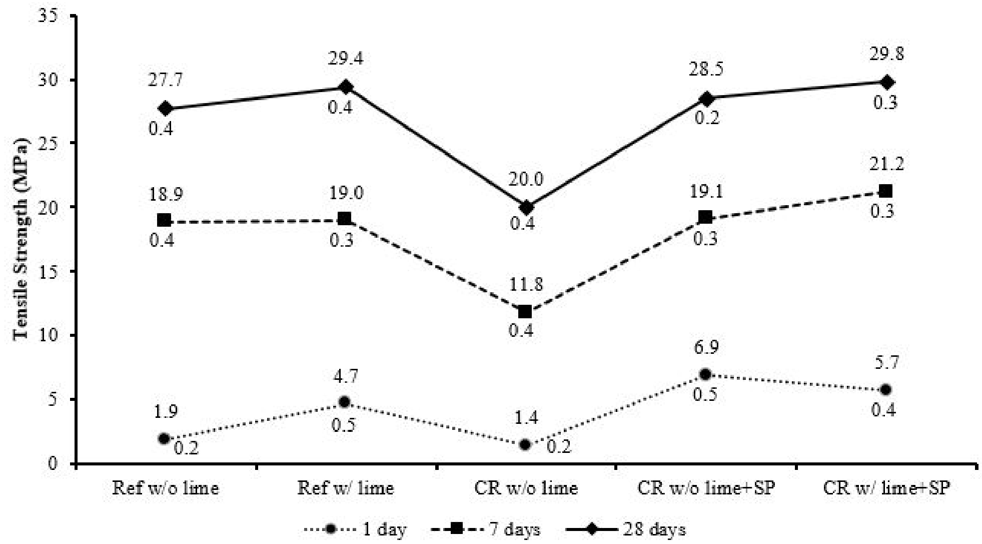

Figure 2. Compressive strength of matrices.

In a general way, the mixtures with CR replacement and superplasticizer had the best results compared with the reference ones. Analogous results were reported by Nepomuceno *et al.* (2018) in a study about concrete with recycled ceramic coarse aggregates, where the mixtures with replacement had a slightly higher performance than the reference matrix, close to 12%. Such conclusions can be related to a better cure provided by the lime, once that it preserves moisture inside the matrix, and mostly the refinement of coarse aggregates, because CR had a fineness modulus smaller than the natural aggregate's one. The fineness modulus of the CR decreased after the mixing process, because they were crushed due to their brittleness and vertical blender force (visual inspection). Therefore, the packing factor of grains is improved when particles are refined, positively influencing the mechanical properties of the composite (Silva *et al.,* 2018)

In contrast with the other mixtures, the mechanical properties of the samples CR w/o Lime were more affected by the addition of residue, because to meet predetermined slump requisites, the w/c ratio of this mixture was 0.82, while the same slump was obtained on a ratio of 0.60 for the other ones.

The influence that the water amount had upon the compressive strength of grouts is outstanding, comparing to the CR addition that did not influence the resistance of the grouts as much. Furthermore, the performance of matrices with different w/c ratios was analyzed by Gayarre *et al*. (2019), where mixtures with rates higher than 0.60 presented a higher reduction in compressive strength, as was the case of the CR w/o Lime blend. Comparing to REF w/o Lime, a reduction of 28% in compressive strength occurred when 50% of coarse aggregate was replaced

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with ceramic residue, what still is a good result. Anyway, all mixtures exceeded 14 MPa of compressive strength at 28 days, as requested by ASTM C476 (ASTM, 2018b), allowing their use in standard constructions.

The Figure 3 shows the ceramic aggregates present in the grouts. Based on the images, it is verified that the distribution of the ceramic materials inside the grouts is satisfactory, since there are not zones of intense concentration of CRs. A study of Senthamarai *et al.* (2005) concerning aggregate distribution supports this observation. In addition to these statements, the rupture plane is initiated at the ceramic aggregates, which have the lowest strength and, this way, represent the most significant factor influencing the properties of these composites.

Figure 3. CR aggregates present in grouts.

Capillary water absorption

The results from the capillary water absorption test are shown in Fig.4. Within the first 10 min of the test, the samples did not show expressive variations. However, after 1 h, the absorption increased expressively for mixtures with no admixtures, mainly CR w/o Lime, which had the highest water absorption, what can be related to its higher w/c ratio and lower compressive strength.

The grouts CR w/o Lime + SP and CR w/ Lime + SP exhibited smaller values of absorption in comparison with the other matrices, with an irrelevant difference between them. Such result can be explained by the reduction of the fineness modulus of coarse aggregates with CR, favoring the packing of grains of the matrix. This behavior is in accordance with the compressive strength test, in which these blends achieved the best results.

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It is noteworthy that water absorption results of grouts with chemical admixture were 2.5 times smaller than the results of matrices with no superplasticizer. Researchers such as Nepomuceno *et al.* (2018) and Seco *et al.* (2018) also identified a higher reduction in total water absorption and capillarity in cementitious matrices with the insertion of ceramic aggregates. From these test results, the durability of the matrix can be determined, as the smaller the water absorption through capillary pores, the higher the durability of the system, according to Senthamarai *et al.* (2011).

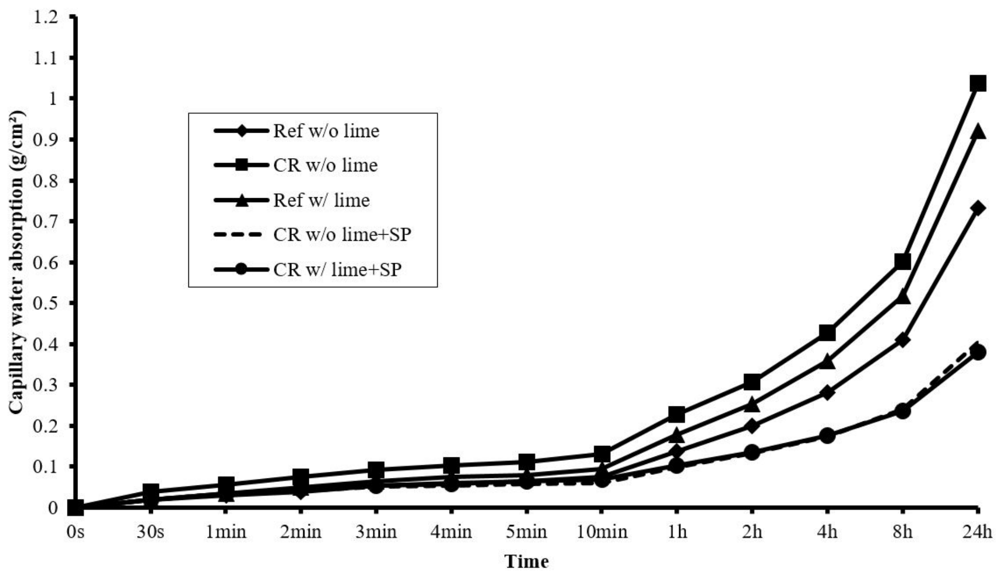

Figure 4. Capillary water absorption of grouts at 28 days.

<u>*Total water absorption, void ratio and bulk specific gravity*</u>

The results for water absorption and void ratio of grouts are shown in Fig.5. Strong differences can be point out between grout CR w/o Lime and the other mixtures, as this composite has w/c ratio of 0.82, in contrast of w/c of 0.60 for the other ones. As a reflex of the increase of total water absorption, the development of other pores in the matrix is proven by its void ratio, which reached 18.3%. In turn, grouts with CRs and superplasticizer (with and without hydrated lime) allowed the smallest values for water absorption and void ratio of this research, with the best behavior assigned once again to CR w/ Lime + SP. The values for the reference grouts remained similar with and without lime, having total water absorption and void ratio of 6.9% and 15.0%, respectively.

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It is already known that the void index is interconnected with the w/c ratio of the mixture and it is also a consequence of the absorption by capillarity and total water. An impressive result is that the ceramic aggregate had a water absorption 18 times higher than the natural aggregate, but inside the mixture, the grout with ceramic residue presented a lower void index than the reference one. As previously reported the results found in the previous items, the packing factor of CR grains was very important. This packing was possible due to the granulometric variation of CR aggregates before mixing and may be even after. In other terms, the refinement of aggregates continued to happen after mixing the materials because CRs fragmented more easily than the natural aggregates, due to their fragility.

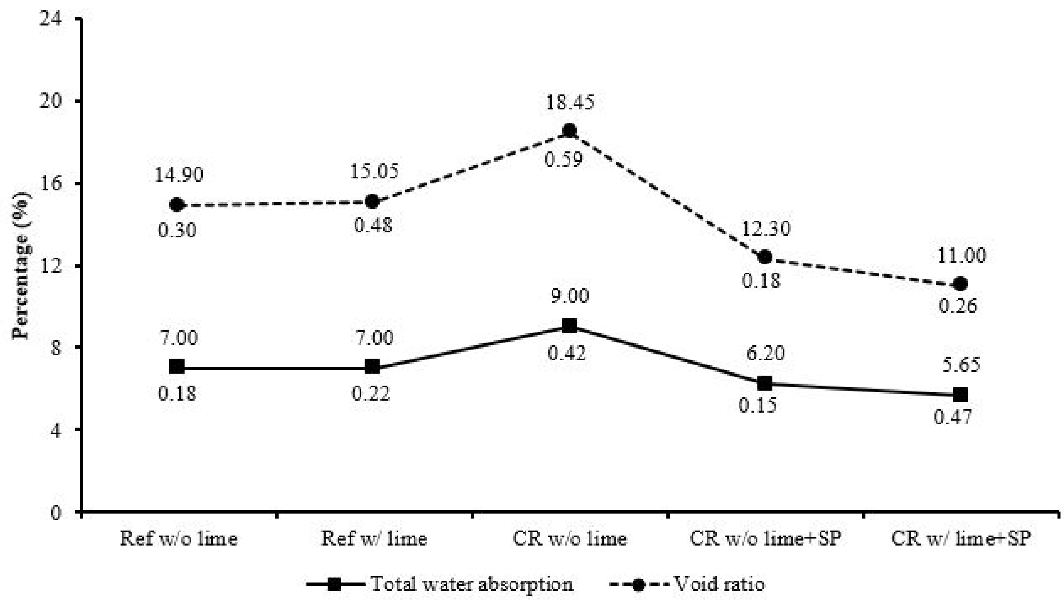

Figure 5. Water absorption and Void ratio (%).

Another research about incorporation of construction and demolition waste in concrete identified the same behavior for the total water absorption of mortars with ceramic aggregates, as well as the same mechanical behavior found in this study (Seco *et al.*, 2018). In summary, there is a dependency in the values of compressive strength, total water absorption and void ratio expressed in Fig. 2 and Fig. 5, supporting the reliability of the results.

Even though the grouts with superplasticizer obtained a higher slump loss after 45 min, their properties in the hardened state were the most satisfying. Thus, if the grouts are applied in field

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before the 45 min, preferentially before 30 min, they can produce a mixture with a compressive strength up to 30 MPa and probably better durability when compared to reference ones.

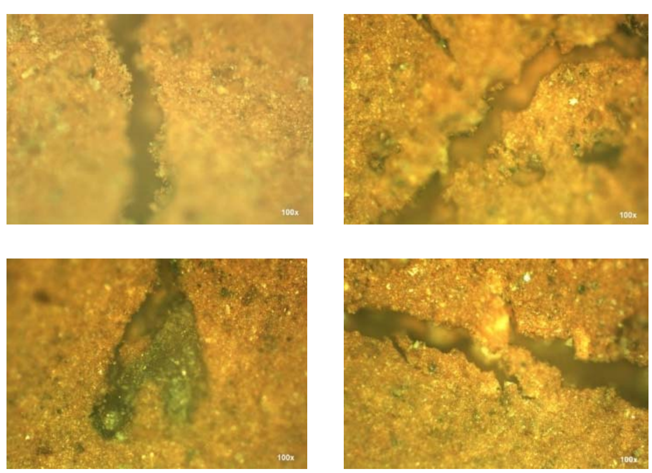
Table 2 expresses the results of bulk specific gravity (BSG) of the composites. The results show that the bulk specific gravity of hardened state mixtures was reduced when the natural aggregate is replaced by ceramic ones. These values are trustworthy, once that the BSG of the ceramic aggregate used for this research is smaller than the natural aggregates one. Identical observation was done by Nepomuceno *et al.* (2018), that reported the decrease of specific mass of the matrix as the incorporation of the ceramic residue occurs.

Table 2. Bulk specific gravity of grouts studied.

Grout	Additions	Bulk specific gravity (g/cm^3)
REF	w/o Lime	2.20
	w/ Lime	2.20
CR	w/o Lime	2.00
	w/o Lime + SP	2.00
	w/ Lime + SP	2.00

Microscopic analysis of pre and post-stress ceramic aggregates

Through the microscopic analysis of the recycled ceramic aggregates, it is possible to observe the modifications the impact caused by the mixing process. Fig. 6 shows the conditions of the aggregates after mixing when the blends were with and without superplasticizer.



CR P-T60 (w/o super.) CR P-T120 (w/ super.)

Figure 6. Conditions of ceramic aggregates in grouts production (100x).

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Based on the fragments of the ceramic aggregates showed in Fig.6, symmetry is observed among them. It should be emphasized that P-T60 samples were removed of the mixture without the presence of the superplasticizer, when the composite was extremely dry and the slump was 0 mm. Under these conditions, the shear stresses required for the good homogenization of the mixture tended to be higher. Thus, there was an increase of the wear, friction and stresses among the materials, what also induced CRs break due to their low strengths. However, P-T120 samples collected from the same mixture, but 120 s after the insertion of the superplasticizer, presented similar cracks to the P-T60 samples. This behavior can be related to the consistency gain of the matrix with the additive, which caused the reduction of the shear stresses on the composite and the homogenization of the materials, without breaking CR aggregates anymore. Thus, the degradation of the ceramic aggregates can be associated to the beginning of the process and, in its turn, the failure stabilization is associated to the change in the mixture consistency. In addition, if the superplasticizer was not used, the aggregate could be completely fragmented and further reduce its granulometry.

The good results for compressive strength and the improvements obtained in the durability of the mixtures with addition of CR are related to the mixing processes adopted in this research, since localized damages were identified in samples collected at different stages of homogenization. The suitability of the grouts consistency was improved with the use of the superplasticizer, what also avoided the complete degradation of the ceramic aggregates, since the natural procedures of mixing the materials exposed the CRs to the high shear stresses.

Conclusion

From the results obtained in this research work, it was concluded that:

- The slump loss of grouts with superplasticizer turned out to be more intense, mainly after the first 45 min, compared with grouts with natural aggregate.
- The partial substitution of natural aggregated by CRs, when linked to a superplasticizer, positively impacts the compressive strength of the mixtures.
- The hydrated lime showed minor improvements to the consistency of the grouts, however, not justifying the point to justify its addition.
- The grouts with CR and superplasticizer presented the lowest capillary water absorption values, compared with the reference grouts.
- Total water absorption and void ratio were less expressive for mixtures CR w/o Lime + SP and CR w/ Lime + SP.
- The bulk specific gravity of the mixtures with recycled aggregate was smaller than those of one with natural aggregate, assuming a lighter matrix.
- The mixing process impacts in the physical conditions of the ceramic aggregates, since the low consistency mixture caused higher shear stresses in the homogenization process, weakening the aggregate.

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Therefore, it was concluded that the partial natural aggregates replacement by ceramic residue in structural grouts is suitable, as the results were acceptable and do not hinder the mixture above normative limits for a given use. Conforming the criteria of the American standard, ASTM C476 (ASTM, 2018b), the typical compressive strength of hardened state structural grouts must be at least 14 MPa at 28 days, what is achieved for all grouts with ceramic residues replacement studied in this paper.

If the grouts with CR replacement and superplasticizer could be produced and used within the 45 min of good workability, ideally in the first 30 min, their choice would return in the best hardened state properties. However, if this is not possible, using grouts with CR replacement and increasing the amount of water to reach workability would also be viable, since they have a lower slump loss along time. Likewise, hydrated lime addition can be unconsidered without major issues to grouts properties, but simplifying their production process in field.

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