Investigation of the Pozzolanic Activity Index of Glass Residue in Ultra-High Performance Concrete

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Abstract

The exponential advance of leading edge technologies in the field of civil construction seeks to confer to the materials the eco-efficient potential linked to the mechanical performance that allows diverse applications. This work aims to evaluate the glass residue, used in ultra-high performance concrete in the sustainability bias, regarding the pozzolanic potential and if it interferes in the process of hydration of Portland cement in the mixture, through NBR 5752:2014. The residue of the glass submitted to the test of pozzolanic activity was crushed in a ball mill at 47rpm, and sieved in a 75µm aperture mesh (ABNT nº 200). It was used CP II F-40 class cement, normal sand, water from the public supply network, and superplasticizer additive for the trace with 25% of the residue in substitution to the cement. The residue of the evaluated glass did not reach the minimum index of 75% established by the norm, obtaining only 45,72%, being classified as non-pozzolanic.

Keywords: Glass residue, special concrete, UHPC, pozzolanic potential

INTRODUCTION

At present, the design of studies that seek to incorporate conventional materials into the eco-efficient potential is increasingly present due to the considerable increase in consumption of non-renewable raw material. Studies with solid waste, for effective use in the civil construction sector, are favorably configured by industry as one of the most consuming inputs of non-renewable origin, such as natural aggregates for mortars and concretes, as well as high load environment, such as Portland cement.

Regarding solid waste, it should be emphasized that the management of industrial byproducts needs to consider a work perspective that is based on a direct emission mitigation program at source, as well as through the recycling mechanism itself [1]. Associated with the search for this reduction, the cement industry seeks through the use of mineral additions to reduce costs with the production of cement, mainly of energy order, and that in accordance with this, it was possible to obtain benefits in the quality of the final product [2].

Testing the pozzolanicity of the industrial by-products enables additional cementitious materials to be obtained, since the pozzolanic potential of a material is configured to detonate cementitious properties when it reacts in the presence of calcium hydroxide (CH), which originates from the hydrated phases of Portland cement, producing low-density calcium silicate hydrates (C-S-H) compared to that produced by C_3S and C_2S (tricalcium and dicalcium silicates), however increasing the durability of the paste in the hardened state.

The production of the glass residue has a record of generating at least 48 thousand tons of dust per year in Brazil [3], and the adoption of the powdered residue to improve the microstructure properties of matrix materials Cement is one of the most developed study lines in the world due to its interesting characteristics: amorphous structure and large amount of silicon present [4].

Several studies indicate that the glass residue, when finely ground (in particle size ranges below 75μm), has a pozzolanic potential and can be used in cement substitution ranges from 10% to 25%, with satisfactory results [5]. In addition to providing better long-term performance, the addition positively reduces the permeability of the concrete, resulting in increased durability resulting from the densification of the microstructure of the material through the effect of micro filler [6]. The application of this residue occurs in several ways in the mixtures of concretes and mortars, involving the sphere of the aggregates, composing the class of the aggregates and acting as filling material by the larger size of the grains in the mixture, and the sphere of the non inert, which due to its high fineness and reactivity make up the group of mineral additions [6].

Considering that ultra-high performance concretes (UHPC) use high percentages of mineral additions to increase their performance for axial compression and pore refinement on a microstructural scale, the residue of the glass incorporated into the mixture has the effect of filler by the reduced granulometry, which recommends its use for granulometric bands of the fine aggregates, by the similar density and lower absorption [7].

The objective of this study was to evaluate the Pozzolan Activity Index (PAI) of glass residue, collected at different locations in the city of Campina Grande-PB, through ABNT NBR 5752:2014 [8]. it also interferes with the Portland cement hydration process in the UHPC mixture by incorporating it as a fine aggregate, ascertaining the compressive strength at 7 days of age, with percentages of 20%, 40%, 60%, 80% and 100% of the natural aggregate, in the same granulometric distribution.

EXPERIMENTAL PROGRAM

The research was carried out at the Building Materials Laboratory of the Instituto Federal da Paraíba – Campus Campina Grande (-7° 14' 24.845"-35° 54' 54.651", 498m). Based on the standard that evaluates the pozzolanic potential of materials in the form of powder in the presence of Portland cement, for this study was used the residue of the glass, classified as common because it comes from the disposal of bottles of alcoholic beverages, bottles of perfume etc., previously passed by crushing in a jaw crusher (Figure 1).

Figure 1. Jaw crusher used (left), and crushed residue (right).

It was used the cement class CP II F-40 of the manufacturer Elizabeth Cimentos, normal sand based on ABNT NBR 7214:1982 [9], water from the public supply network of the city of Campina Grande-PB, and superplasticizer additive type MasterGlenium® 51 from the manufacturer BASF for the trace with 25% of the residue instead of the cement. The residue of the glass submitted to the test of pozzolanic activity, after crushing, was crushed in a bench ball mill at 47rpm (Figure 2), and 75μm aperture sieve (ABNT n° 200 sieve) (Figure 3).

Figure 2. Ball mill used (left), and ground residue (right).

Figure 3. ABNT mesh sieve No. 200 (left), and final visual appearance of the residue (right).

In order to quantify the amount of material for the production of the specimens, the quantitative values suggested by the NBR [8] were taken as parameters, however with the water/cement factor adaptation suggested by the NBR from 0.48 to 0.60, once that the amount of water to be used should recommend a reduction of 225mm [10]. The cylindrical molds of 5x10cm, of 1:3 trait, were composed of two mortars: control (A), and cement substitution for 25% of residue (B), with rupture performed at 28 days of age following to NBR [8]. Table 1 shows the quantitative values for the two manufactured mortars, and in Table 2 the grain size composition of normal sand according to NBR [9].

Table 1. Quantitative inputs for mortars A and B according to NBR [8].

Mortar A – Control (g)	Mortar B – Glass #200 mesh (g)
624 – Cement	468 – Cement
1872 – Sand	156 – Glass
374 – Water	1872 – Sand
–	374 – Water
–	5 – Additive

Table 2. Values of the retained in each granulometric range corresponding to NBR [9].

Retained Values	Opening Screens
50 grams	#10 *mesh* (2,0 mm)
200 grams	#16 *mesh* (1,2 mm)
250 grams	#30 *mesh* (600 µm)
250 grams	#50 *mesh* (300 µm)
250 grams	#100 *mesh* (150 µm)
1 Kg	–

Following the PAI test, UHPC prototypes were made, adopting composition, laboratory preparation methodology and specific cure according to a previously performed study [11], using granulometric composition where the aggregate had an Aggregate Fineness Module of 1.468 (fine/very fine sand). In the same granulometry, the glass residue was replaced in 0% (control), 20%, 40%, 60%, 80% and 100% bands, following the trace determined by Table 3, for the 7 days of age the axial compressive strength test was performed by ABTN NBR 5739:2007 [12].

Table 3. Composition of UHPC, by mass, used based on literature [11].

Cement	Aggregate	Silica Fume	Metakaolin	Additive	Water (w/c)
1	1,050	0,110	0,060	0,075	0,197

RESULTS AND DISCUSSION

In order to interpret the result obtained from the pozzolanic potential of the glass residue to produce C-S-H in the presence of Portlandite, with particle size less than 75μm, Table 4 shows the arithmetic mean for 4 specimens tested for each composition (mortars A and B).

Table 4. Pozzolanic activity index for common glass residue.

Specimens	Compression Resistance – 28 days (MPa)	Pozzolanicity (%)
Control	31,58	–
Glass #200 mesh	14,44	45,72

It is clear that for these study conditions, from the treatment of the residue for use as binder to the manufacture of the mortars, it does not show any potential to act as supplementary cementitious material, reaching only 45.72%, while the minimum established by norm [8] is 75%, showing that it does not consume the CH present in the paste after the start of the hydration reactions of the cement.

For the composition of UHPC applied to this study, which used a laboratory manufacturing method [11], tested at 7 days of age for the 5 percentages of natural replacement by recycled, the results can be observed in Table 5.

Table 5. Compressive strength results, at 7 days, of UHPC blends made.

Values per Percent of Replacement (MPa)					
0%	20%	40%	60%	80%	100%
160,621	171,781	121,178	117,147	117,380	104,504

The behavior of UHPC mixtures in the hardened state at 7 days of age shows improvement only to 20% of substitution, something already expected in the literature to state that the recycled glass aggregate increases the resistive capacity of the material. The amount of the passant in the 75μm mesh, which corresponds to the particle size distribution used for the UHPC, corresponds to only 1-2% of the whole recycled aggregate mass, confirming once again that the probability of the residue, as material passing through the ABNT sieve n° 200, of interfering in the hydration reactions of the cement with the mineral additions used in the dosage is minimal.

On the other hand, even characterized as amorphous, the residue did not act as a reactive material in the mixture even with reduced granulometry, but as a filler, refining the pores of the microstructure of the UHPC by its natural morphology as a fine aggregate, so the resistance to 20% of incorporation becomes superior to the control tract with 0% residue.

The percentages of 40% to 100% use of the recycled aggregate are in accordance with what the state of the art explains about the limits of using glass as an aggregate, since the less rugged surface of the recycled aggregate has no adhesion similar to the natural aggregate, more porous and rough, then compromise the resistance due to the fragility caused in the interfacial transition zone between the recycled aggregate and hardened cement paste. Factors such as the alkali-aggregate reaction should be measured for greater technological control of composite life, since structural performance is compromised by creating expansive gel in the environment of the recycled aggregate when in the presence of excess moisture.

CONCLUSIONS

The residue of the glass evaluated did not reach the minimum index of 75% established by the norm, obtaining only 45.72%, being classified as non-pozzolanic, that is, it remains inert during the hydration process of the mixture of ultra-high performance concrete when used as an aggregate, and the synergistic reactions of the cement with the mineral additions act freely without interference.

For the compressive strengths, the trait with 20% of residue was the only one that positively surpassed the control trait, reaching 171.781MPa resistance at 7 days. The other values obtained for the substitutions up to 100% were not successful because the phallus of the recycled aggregate was inadequately configured as grain morphology, since the benefit is only evidenced when its use is moderate.

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