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Incorporation of glass beer bottles waste in concrete blocks

Changes in the population's consumption habits have contributed to the increase in the generation of glass waste (VR), especially "long neck" glass bottles. Due to the high cost of reusing these bottles in the manufacturing process, the incorporation of this waste in the most different materials has been studied. Thus, the replacement of natural aggregates in concrete mixes by VR can be a technically and ecologically viable alternative. With this, in order to offer an alternative destination for these "long neck" type bottles, this work incorporated the mixture of dry concrete for blocks in the proportions of 10, 20 and 30% of RV in place of sand and evaluated the compressive strength and water absorption in 7 and 28 days. With the results obtained, it can be stated that the incorporation of VR provided resistance gain with additions of up to 30% of VR. In addition, all concrete blocks with the addition of waste glass had lower water absorption values than the mix without addition.

Palavras-chave: Sand; Beverage bottles; Compressive strength; Reuse.

Incorporação de resíduos de vidro do tipo "garrafas long neck" em blocos de concreto

Mudança nos hábitos de consumo da população tem contribuído com o aumento da geração de resíduos de vidro (RV), principalmente as garrafas de vidro do tipo "long neck", os quais tem agravado o problema de superlotação de aterros sanitários e lixões. Devido ao alto custo de reutilização dessas garrafas no processo fabril, a incorporação deste resíduo nos mais diferentes materiais tem sido estudada de modo a minimizar o impacto causado pelo mesmo ao meio ambiente. Desse modo, a substituição dos agregados naturais nas misturas de concreto por RV pode ser uma alternativa técnica e ecologicamente viável. Com isto, visando oferecer uma alternativa de destinação para estas garrafas do tipo "long neck", este trabalho incorporou a mistura de concreto seco para blocos nas proporções de 10, 20 e 30% de RV em substituição da areia e avaliou a resistência à compressão e absorção de água em 7 e 28 dias. Com os resultados obtidos, pode-se afirmar que a incorporação de RV proporcionou ganho de resistência com adições de até 30% de RV. Além disso todos os blocos de concreto com adição de resíduo de vidro apresentaram valores de absorção de água menores que no traço sem adição.

Keywords: Areia; Garrafas de bebidas; Resistência à compressão; Reutilização.

Topic: **Construções e Arquitetura Sustentáveis**

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INTRODUCTION

With the rapid development of cities and improvements in the population's standard of living, there are also changes in consumer standards, who have increasingly opted for the consumption of products in glass packaging[1]. Linked to this consumption, there is the problem of the large generation of glass waste, a non-biodegradable material, which is mostly not recycled and does not return to the manufacturing process, having as final destination the landfills and municipal dumps (TURGUT et al., 2009; RAHIM et al., 2015; KILIÇOĞLU et al., 2017). Among these glass waste, there are the "long neck" type bottles, which end up not being reused due to the high cost of separation, cleaning and transport to the factories (AFSHINNIA et al., 2016; WARNPHEN et al., 2019; FLOOD et al., 2020).

According to recycling data around the world, the United States recycled about 25% of the glass generated in 2018 (EPA, 2020), while in Europe, recycling rates for glass packaging reached 76% in 2017[2]. The latest data on glass recycling in Brazil show that more than half of the glass consumed is not being recycled[3] (BRASIL, 2011) and, consequently, they are being improperly disposed of, filling landfills and occupying the space of biodegradable materials (OGUNDAIRO et al., 2019).

In order to offer an alternative to reuse glass and reduce the impact caused in landfills, studies have suggested its reuse in the production of various materials, such as soil-cement bricks (MACHADO et al., 2020), pavements (TURGUT et al., 2009; NISHIKANT et al., 2016) as well as in the manufacture of concrete (DU et al., 2014; BISHT et al., 2018; LU et al., 2019). The civil construction industry has increasingly consumed raw materials, such as natural aggregates, which are mostly non-returnable. The exploitation of these has generated the degradation of the environment and they end up becoming scarce due to the high demand of this sector (MALIK et al., 2013; OGUNDAIRO et al., 2019; WARNPHEN et al., 2019).

Therefore, glass has been a sustainable and technically efficient alternative to meet the various types of concrete used in civil construction. Due to its physical and chemical characteristics similar to fine aggregate, studies show that the replacement of sand in proportions of approximately 20% by glass residue (RV) has resulted in a gain in compressive strength and a decrease in absorption rates in concrete (ISMAIL et al., 2009; ABDALLAH et al., 2014; WARNPHEN et al., 2019). However, most studies cover the incorporation in plastic-type concrete (DU et al., 2014; BISHT et al., 2018)

[1] https://feve.org/glass-packaging-is-the-top-choice-for-environmentally-conscious-consumers-new-survey-reveals/
[2] https://feve.org/record-collection-of-glass-containers-for-recycling-hits-76-in-the-eu/#:~:text=Record%20collection%20of%20glass%20containers%20for%20recycling%20hits%2076%25%20in%20the%20EU,-Brussels%2C%2029%20October&text=Latest%20industry%20data%20%E2%80%93%20published%20today,%25%20in%202017%20(1).
[3] https://sidra.ibge.gov.br/tabela/1202

with slump between 5 to 10 cm, and in dry-type concrete, that is, with slump less than 5 cm, there are few literatures on the use of glass in concrete blocks (ABDALLAH et al., 2014; WARNPHEN et al., 2019), being more commonly found studies with incorporation of VR in paver type pavements (TURGUT et al., 2009; LU et al., 2019).

In this context, in order to offer an adequate destination to the "long neck" type glass bottles, in this study, sand was partially replaced by RV in concrete blocks, in the proportions of 10, 20 and 30%, in order to assess the resistance to compression and water absorption, in order to offer technically and environmentally viable concrete blocks.

METHODOLOGY

Material

For the manufacture of the blocks, aggregates from the northern region of Mato Grosso and Portland cement CPIIF-40 from the region of Nobres-MT were used, locally used in the various fields of civil construction in Sinop-MT and the same materials used by the Bloco Norte factory, where the molding of the blocks was carried out. As fine aggregate, natural quartz sand from the Teles Pires River was used, with a fineness modulus of 1.72, and a specific gravity of 2.64 g cm^{-3}. In addition to sand, stone dust from a crusher in the region of Nova Santa Helena-MT with characteristics of a granitic conglomerate was also used as fine aggregate, with a fineness modulus of 3.07 and a specific mass of 2.68 g cm^{-3}. As coarse aggregate, gravel was used (gravel 0) also from the Nova Santa Helena region, with a fineness modulus of 6.11 and a specific gravity of 2.69 g cm^{-3}.

The glass waste used in the tests was “long neck” type beverage bottles, in green and brown, which were collected in bars and restaurants in Sinop, and also in the PEV – Recyclable Waste Voluntary Delivery Point in Sinop. The bottles were washed to remove the labels and any impurities, and then crushed using a mechanical crusher with 4 helices (Figure 1a). To obtain the glass residue, 10 bottles at a time were crushed for 20 seconds, as this was the most efficient time to use this machine, since in longer times of crushing (25 and 30 s) there was no significant change in the granulometry obtained, as shows Figure. 1b. Thus, after crushing, an aggregate with a fineness modulus of 2.18 and a specific mass of 2.51 g cm^{-3} was obtained, for partial replacement of the fine aggregate. Approximately 640 bottles were used for this study.

Characterization of aggregates

All aggregates used were subjected to physical characterization tests, in compliance with current standards, to determine the specific mass, moisture content, powdery material index, clay lumps, absorption and swelling test and the particle size test.

Granulometry

The particle size test was carried out according to NBR NM 248 (ABNT, 2003), in which approximately

1 kg of each fine aggregate and 5 kg of the coarse aggregate (gravel 0) were separated by means of splitting for the test sieving. Sieves between 9.50 mm and 75 µm were used for testing fine aggregates, and sieves from 19 mm to 2.00 mm for coarse aggregate. The sieving was carried out using a mechanical stirrer for 5 min, and then the quantity retained in each of the sieves was weighed for the granulometric characterization of each material. The gravel used had a granulometry < 9.5 mm, the stone powder with a range between 2.4 and 0.075 mm, the sand with a granulometry < 4.75 mm and the waste glass comprising a range between 9.5 mm to 0.075 mm. The entire spectrum of the ground glass residue was used, in order to make its use and subsequent commercial application viable.

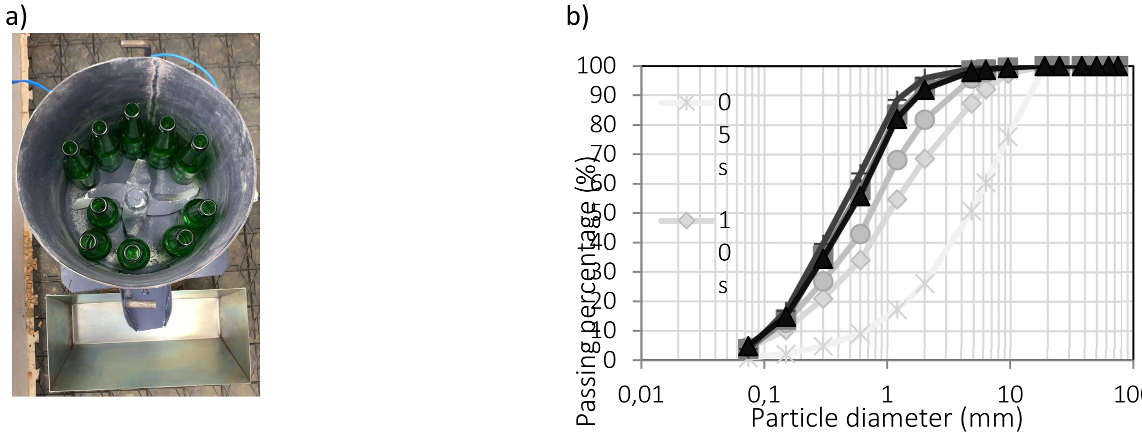

Figure 1: a) Mechanical crusher; b) Efficiency of mechanical crusher with crushing tim.

The granulometric curves of the sand and glass residue to be used in the mixtures are shown in Figure 2, where it can be seen that the granulometric distribution of the glass residue is better than that of the sand, since the granulometric range of the VR is fully understood within the usable limit of fine aggregates in concrete as specified by NBR 7211 (ABNT, 2009). The use of sand in this study, even with an irregular distribution between the range of 0.60 mm to 1.20 mm, can be justified, due to local availability and because it is the sand commercially used by the Bloco Norte plant in the line under analysis. Thus, observing the better distribution of the glass residue in this range in relation to sand, possibly the use of VR in the mixture will bring better results than the mix without addition.

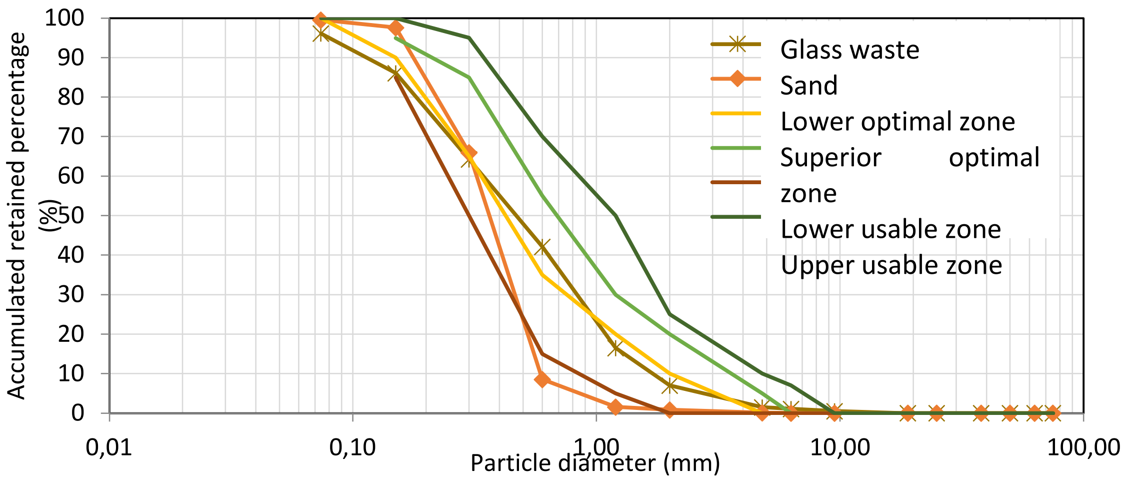

Figure 2: Particle size curves of glass residue and sand.

In Figure 3, it is possible to visualize the different particle sizes of the glass waste that was used in this study to replace sand, which has a continuous particle size distribution. In addition, the fineness modulus of all aggregates was determined by the sum of the retained percentages accumulated in mass of an aggregate in each sieve of the normal series, dividing by 100. The maximum characteristic diameter of each aggregate was determined by the opening of the sieve that has an accumulated retained percentage equal to 5% according to NBR NM 248 (ABNT, 2003).

Figure 3: Different particle sizes of glass residue.

Especific mass

The specific mass of the grains was determined according to NBR NM 52 (ABNT, 2009) and NBR NM 53 (ABNT, 2009) and the natural or apparent specific mass of the aggregates according to NBR NM 53 (ABNT, 2009). The first is the determination of the actual mass of the aggregates disregarding the voids, and the second is the mass or apparent density in the natural state of the aggregate.

Moisture content and water absorption

The moisture content of the aggregates was obtained using the NBR 9939 standard (ABNT, 2011), in which a sample of wet material was dried in an oven, in order to determine the amount of water present in the material in relation to the completely dry mass. However, the water absorption test for fine aggregates used the NBR NM 30 (ABNT, 2001) and for large aggregates the procedures present in NBR NM 53 (ABNT, 2009). The test comprises sample saturation and drying cycles to obtain the absorption capacity of each material.

Test of powdery material

This test was carried out in order to determine the number of fine aggregates, by washing the sample, in each material according to NBR NM 46 (ABNT, 2003). Quantities of fine aggregates smaller than 0.075 mm mesh, when in excess, can affect the adhesion of the cement paste and the gain in strength of concrete and mortar.

Clay lumps

This test was carried out in sand, according to NBR 7218 (ABNT, 2010) to determine the amount of poorly resistant grains in the aggregate that could impair the mixture's strength gain.

Swelling

This test was performed on fine aggregates, due to the volume change that occurs when the grains absorb water, and is expressed by a coefficient according to NBR 6467 (ABNT, 2009). According to the characterization tests, the results of each aggregate are presented in Table 1. Analyzing the results regarding the characterization of sand and glass residue, it can be observed that, by the fineness modulus, the sand is much finer than the VR. With a fineness modulus of 2.18, the VR can be classified as medium fine aggregate, and is closer to the optimal zone of use than the sand to be replaced. In addition, VR has a lower specific weight than sand, making it less dense. Another important feature is the practically zero water absorption rate when compared to the other materials in the mixture.

Table 1: Characterization of aggregates.

Tests	Glass residue	Sand	Stone dust	Gravel 0
Specific Mass of Grains (g/cm³)	2.51	2.64	2.68	2.69
Apparent Specific Mass (g/cm³)	1.49	1.54	1.46	1.35
Finesse Module	2.18	1.72	3.07	6.11
Maximum Diameter (mm)	4.80	1.20	2.40	9.50
Moisture content (%)	0.09	1.14	0.49	0.37
Water Absorption (%)	0.03	1.63	1.95	0.48
Powder Material (%)	14.22	0.54	9.18	0.89
Clay lumps (%)	-	2.84	-	-
Swelling (%)	1.15	1.35	1.24	-

Manufacture of the blocks

The manufacture and molding of the blocks took place at the Bloco Norte company located in Sinop-MT, which manufactures and sells concrete artifacts. In order to compare the commercial block of family 15 (14 x 19 x 39) produced by the factory, with the block that had the addition of glass residue, the same commercial trait was used for molding the base sample, and the quantity was changed. of sand by weight, with its partial replacement by the RV in 10%, 20% and 30%. The traces and quantities of aggregates used in the manufacture of blocks can be seen in Table 2.

Table 2: Traces of the concrete blocks.

Trace	Glass waste (kg)	Sand (kg)	Cement (kg)	Stone dust (kg)	Gravel 0 (kg)	Moisture content (%)
0	0	210	65	240	110	5.94
1	21	189	65	240	110	5.98
2	42	168	65	240	110	5.66
3	63	147	65	240	110	5.82
Total	126	714	260	960	440	-

As for the granulometric curve of the mixture of each mix, shown in Figure 4, it can be seen that mix 0 and 1 are slightly outside the recommended lower limit range (Fernandes, 2019). However, as the basic trait used is a commercial trait and the objective of this work is to evaluate the performance of the traits with the addition of glass, it is possible to see that the traits with a greater amount of VR (2 and 3), as they have a particle size distribution rather, they meet the limits of the usable particle size range for concrete blocks.

Thus, for the manufacture, the materials were weighed on the conveyor and taken to the planetary mixer, with subsequent addition of water and commercial additive "LIQUIPLAST-1400 Super", binding and mold release, which helps both in the cohesion of the dry concrete mixture and in the deformation of the concrete parts. The molding of the blocks for each line was performed using a hydraulic and automatic machine, with molds for making blocks of 14 x 19 x 39 cm. The molds were vibrated pressed for 8 seconds, and compacted in the molds with a compression force of 160 kN and later demolded (Figure 5a).

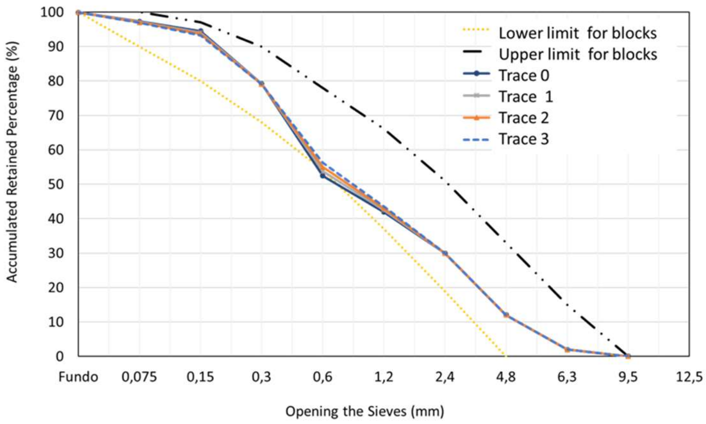

Figure 4: Particle size curves of the lines and limit ranges indicated for concrete blocks.

Then, the blocks were placed on pallets, wrapped in black canvas, and stored in a curing chamber at the factory for the dry curing process for 24 hours (Figure 5b). Subsequently, the blocks were sprayed with water for up to 72 hours and were kept wrapped in plastic canvas and stored in a shed for 7 and 28 days, for the performance of the compressive strength and water absorption test.

Figure 5: a) Manufacture of blocks; b) Cure using canvas.

Block absorption test

According to Fernandes (2019), the absorption test aims to assess the part's porosity and the block's ability to retain liquid, a factor that can affect its performance. The water absorption test was performed at 7 and 28 days, according to NBR 12118 (ABNT, 2013) in which the values were obtained through Eq. (1). NBR 6136 (ABNT, 2007) still specifies an absorption value of no. maximum 10% for blocks with normal aggregates and less than or equal to 13% for blocks with light aggregates, where a is the water absorption (%), m_2 is the saturated mass (of the block after it has been submerged in water for 24 hours (g); and m_1 is the dry mass of the block after drying in an oven for 24 hours (g).

$$\boldsymbol{a} = \frac{m_2 - m_1}{m_1}\ \boldsymbol{x}\ 100 \qquad (1)$$

Compressive strength test

To perform the compressive strength test, after curing, a sample (n) of 6 blocks of each mix was taken at 7 and 28 days, in which they were capped to regularize the surface so that the applied load could be evenly distributed in the entire area of the piece (ABNT NBR 12118, 2013). The test was performed using a hydraulic press, with application of a force of 0.05 MPa s^{-1}, until the block rupture (Figure 6).

Figure 6: Compressive strength test.

The individual strength of each sample was obtained by the ratio of the breaking load to the gross area of the block. To define the estimated characteristic strength of each analyzed batch, Equation 2 (ABNT NBR 12118, 2013) was used.

$$fbk, est = 2\left[\frac{fb1 + fb2 + \ldots + fbi-1}{i-1}\right] - fbi \qquad (2)$$

Where: i refers to half the number of specimens (n) to be submitted to the resistance test when even, and when n is odd, i+1 is used; fb1, fb2....fbi-1 are the compressive strength values in ascending order, with fb1 being the lowest value obtained.

However, when you have an even number of specimens, such as 6 samples, the equation can be simplified and considered the sum of the two smallest values of strength and subtraction of the third smallest value obtained in the batch, according to Equation 3 (FERNANDES, 2019).

$$fbk, est = fb1 + fb2 - fb3 \qquad (3)$$

Statistical analysis

The data related to water absorption and compressive strength of each sample and each mix at 7 and 28 days had a completely randomized statistical design (DIC), in a factorial arrangement (2x4), analyzing the two ages and the four traits through the Sisvar software. Data were subjected to analysis of variance (ANOVA), mean comparison test (Scott-Knott) and regression analysis, when necessary, to analyze the behavior of the values obtained.

RESULTS AND DISCUSSION

Water absorption

Figure 7 shows the results obtained in the water absorption test of the blocks at 7 and 28 days according to Equation 1 of NBR 12118 (ABNT, 2013), which requires the water absorption test with only 3 samples for each mix.

Comparing the results between mixes at 7 days, there was a 4.55% increase in water absorption in mix 1 compared to mix without addition of glass, a reduction in mix 2 of 12.07% when compared to mix 0 and mix. 15.90% compared to mix 1, and an increase in absorption of 6.34% in mix 3 when compared to mix 2, but a decrease of 6.49% compared to the base mix (Figure 7).

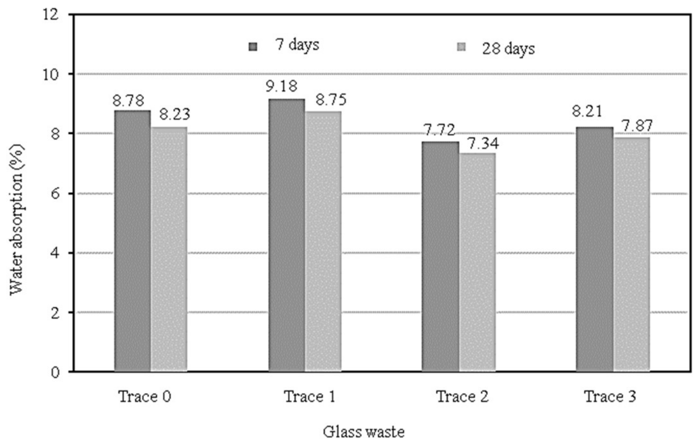

Figure 7: Water absorption in concrete blocks.

At 28 days, the behavior between traits was similar to that observed at 7 days, but when compared to the decrease in absorption of trait 2 in relation to trait 1, a value of 16.11% lower was obtained. Furthermore, the increase in absorption in Trace 3 compared to Trace 2 was approximately 7.22% (Figure 7). At both ages, the water absorption values in concrete blocks with larger glass replacements (traces 2 and 3) decreased in relation to the mix without the residue, reaching 10.81% (trace 2) and 4.37% (dash 3) at 28 days. With these results, it can be stated that there is a tendency for a decrease in absorption as the amount of glass residue between traces increases.

Analyzing the tendency of an increase in the absorption rate with 10% VR in relation to the 0 trait, at both ages, this behavior can be justified by the use of VR, which has a poor grain geometry, and because the added amount is small it has a smaller number of fines in the mixture, contributing to voids, giving porosity to the concrete with the glass and consequently greater water absorption (LEE et al., 2013; BISHT et al., 2018; WARNPHEN et al., 2019).

With the higher addition of VR (30%) there was also a tendency to increase the rate of water absorption when compared to the mix with 20% addition of VR. According to results obtained at 28 days by Warnphen et al. (2019), for the replacement of 20% of VR, the water absorption values were lower than the base mix, however with 30% glass residue the absorption value was a little higher than the concrete without addition and with 20% of RV. Even with a greater number of fines in the addition of 30%, there is also an amount of larger irregular grains present in the mixture, which can contribute to the increase in porosity, as the cement paste cannot enter the spaces between these grains, due to irregular and smooth geometry of the VR, facilitating the appearance of voids (BISHT et al., 2018; WARNPHEN et al., 2019).

Comparing the values of each trait between the ages of 7 and 28 days, there is a reduction of 4.68%, 4.92% and 4.14% for traits 1, 2 and 3, respectively, which indicates that the incorporation of glass residues in concrete blocks leads to a reduction in the material's water absorption at later ages, similar to what was observed by Malik et al. (2013), Abdallah et al. (2014) and Warnphen et al. (2019), and this can be explained by the fact that the greatest water absorption occurs in the early ages due to the cement's hydration reaction (WARNPHEN et al., 2019).

Unlike the natural aggregate, the glass residue has practically zero absorption rate, which justifies the tendency of reduction in the blocks' absorption values as the amount of glass residue in the mixture increases. Thus, it can be stated that the absorption capacity of each material directly influences the absorption values of the cementitious material (POON et al., 2008; NISHIKANT et al., 2016; LU et al., 2019).

According to NBR 6136 (ABNT, 2007), the absorption values for blocks must not exceed the rate of 10%, thus even the highest values obtained, such as 9.18% at 7 days and 8.75% at 28 days, referring to trait 1, are within the limits specified by the standard.

Compressive strength

The results of compressive strength fbk, est Equation (2) for each mix at 7 and 28 days, considering 6 blocks for each mix, are shown in Figure 8 and the statistical analysis of these data is shown in Figure 9.

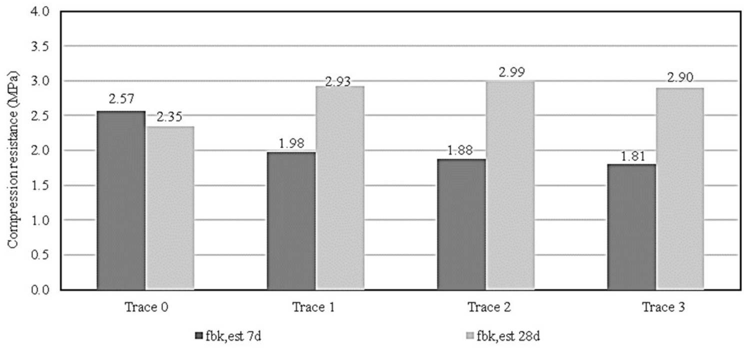

Figure 8: Compressive strength of concrete blocks in different mixes at 7 and 28 days.

The addition of glass residue in the concrete mix for blocks tends to negatively interfere with the gain in compressive strength, when analyzing the strength at 7 days, with a reduction in strength of 23%, 27% and almost a third of the strength with the addition of 10%, 20 and 30% respectively when compared to trace 0 (Figure 8).

Similar results were obtained by Lee et al. (2013) with a reduction of 8.65% in strength at 7 days, replacing 25% of the sand in concrete blocks with a VR with a particle size greater than 4.75 mm. The decrease in strength, linked to the high absorption values obtained by these materials, may be related to the irregular and very smooth surface of the glass grains present in these concretes, providing a weak connection between the cement paste and the aggregate, causing cracks that make this more vulnerable connection, not allowing the cement paste to offer satisfactory mechanical strength when present in large quantities in concrete (LEE et al., 2013; DU et al., 2014; RASHID et al., 2018; LU et al., 2019; WARNPHEN et al., 2019).

When analyzing the values between mixes at 28 days, there was a trend of increase in compressive strengths with larger additions of VR. Warnphen et al. (2019) also observed this trend, reaching 7.61% more compressive strength at 28 days in concrete bricks with 20% VR, with particle size in the order of 4.75 mm. As can be seen in Figure 8, at 28 days there was an increase of 24.68% in mix 1, 27.23% in mix 2 and 23.24% in mix 3, in relation to mix 0.

Between ages, there was an increasing trend from 7 to 28 days, where the greatest increases in resistance occurred with the addition of 20% and 30% of VR at 28 days. The highest value of compressive strength (2.99 MPa), corresponding to mix 2 at 28 days, is directly linked to the lowest absorption value obtained (7.34%), corroborating the behavior observed by other authors who justify that how much the greater the porosity of the concrete, the lower the compressive strength (LEE et al., 2013; DU et al., 2014; RASHID et al., 2018; LU et al., 2019; WARNPHEN et al., 2019).

Ismail et al. (2009) (plastic concrete) and Abdallah et al. (2014) (concrete blocks) also obtained the best results with 20% addition of glass residue with a particle size of less than 4.75 mm at 28 days. The authors relate this strength gain at later ages due to the pozzolanic effect, that is, the presence of fine materials in the mixture and its ability to improve the porosity of the concrete, which even with the presence of larger grains, contributes to filling the voids.

However, analyzing the results of compressive strength between ages (7 and 28 days) statistically, there was no significant difference. Considering the estimated statistical means for age-independent traits, it can be observed through regression analysis that the trend line is linear, that is, the greater the addition of the glass residue, the greater the resistance values obtained (Figure 9).

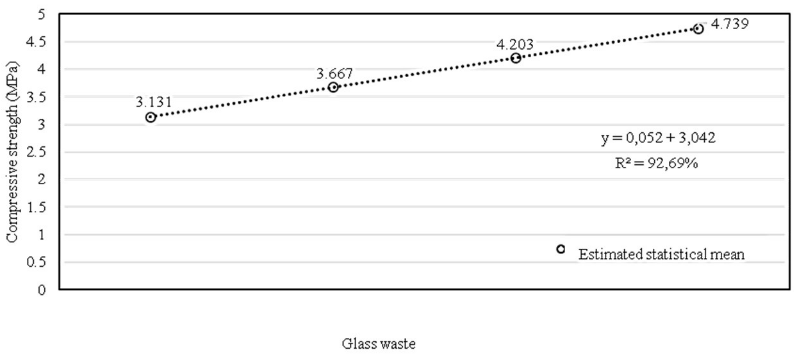

Figure 9: Statistical analysis of traces x compressive strength.

Thus, it is possible to observe in Figure 9 that the additions of 20% and 30% of RV to the mixture tend to increase the strength of the blocks by 34.23 and 51.35%, respectively, compared to the mix without addition. Therefore, it can be stated that the addition of glass residue in concrete blocks, even with a particle size not as fine as sand (VR <9.5 mm), tends to contribute to strength gain in larger replacements, when compared to trace without the residue.

With the statistical analysis it can be observed that the estimated mean for the traces with 20 and 30% of glass residue tends to be higher than the results obtained by the specifications of the Standard 6136 (ABNT, 2007). Thus, according to the regression model for this study model, it can be concluded that the greater the replacement of glass waste in the mixture for concrete blocks, the better the compressive strength, being technically and ecologically feasible the replacement with 30% VR.

CONCLUSIONS

The incorporation of "long neck" type glass waste in concrete blocks can offer a more ecological destination for these types of bottles with the incorporation of additions of up to 30% of VR. The results were satisfactory regarding the gain in compressive strength and lower water absorption rates in concrete blocks.

Furthermore, the partial replacement of sand by this glass residue with a better particle size distribution than the natural aggregate, leads to a technically more viable use than the sand commercially used by the factory. Therefore, it is recommended to use 30% of VR in the mix for concrete blocks, since around 458400 bottles could be reused monthly in the production of these artifacts, being a technically and ecologically viable alternative.

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