Concrete Production Using Fine Glass Aggregates as Partial Replacement of Sand

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Abstract

Waste reuse is considered an excellent alternative for sustainable development. For the World Commission on Environment and Development in Our Common Future, sustainability is "one that meets the needs of the present without compromising the ability of future generations to meet their needs." One way to provide a sustainable solution for glass would be the reuse of glass waste in the production of concrete. Glass residues when suitably crushed and sieved, to assume appropriate granulometry, may exhibit characteristics similar to natural aggregates. The use of glass waste when used in concrete manufacturing reduces production costs. The main objective of the research was to replace, as much as possible, in percentage, the quantity of sand and gravel aggregates by glass waste with the same granulometry, as a way to reduce costs, reduce the use of raw materials and reduce the quantity of wastes that were inadequately disposed of in landfills. Samples of glass waste were collected in the construction industry itself, in works and glassware companies that work with cutting and delivery of the product. Comparisons were made between concretes produced with natural and concrete aggregates produced with the substitution of 20%, 30%, 40% and 50% of the fine aggregate, all of which glass was used as a substitute. The comparative analyzes were the mechanical properties of compression strength and diametral compression traction at 7, 14, 21, 28 and 90 days.

Keywords: Reuse, glass waste, substitution, fine aggregate, mechanical properties.

1. Introduction

The concrete industry is one of the main consumers of non-renewable natural resources (gravel, sand and limestone), because concrete is the most used building material in civil construction due to its ease of being worked and molded, which makes it incompatible with the sustainable development model that has been progressively adopted by several countries around the world, including Brazil.

According to data from the Glass Sector Panorama (2015) of the National Confederation of the Chemical Branch (CNQ) (1), the production of soda-lime glass corresponded, in 2011, to about 87% of the glass production in Brazil. Soda-lime glass (also called common) is basically a natural sand mass (about 70% of the raw material present in the glass) melted at high temperatures and then cooled quickly enough to prevent crystallization. , which produces flat window glass, food and beverage packaging, non-food (pharmaceutical and cosmetic) packaging and others.

Although glass is a 100% theoretically recyclable material (1 kg of glass can be recycled to produce another 1 kg of glass numerous times, for example), in Manaus, most post-consumer glass is deposited in landfills along with other types of waste. Although they are not biodegradable and do not generate toxic waste, disposing of waste glass in landfills is not an environmentally friendly solution as it represents waste of raw material and energy and increases the need for space for disposal. According to the Brazilian Institute of Applied Economic Research (IPEA) (2), in its recent research report on Urban Waste Diagnosis, the estimated average gravimetric concentration of glass in waste collected in Brazilian cities is 2.4% and according to the Secretary Municipal Cleaning Department (SEMULSP) (3), the daily input of solid waste into the landfill corresponded to 2,654.5 tons in 2014, ie, a waste of approximately 23,253 tons of glass per year in Manaus.

So it is plausible to think that post-consumer glass is useful as a small aggregate in concrete when particles smaller than 4.8 mm thus avoiding unnecessary disposal in landfills.

Glass waste, when properly ground and sifted to an appropriate particle size, may exhibit characteristics similar to natural aggregates. The use of glass waste when used in the manufacture of concrete reduces production costs (4).

The main objective of the research is to replace, as much as possible, as a percentage, the amount of natural aggregates sand and gravel with glass waste with the same grain size, as a way to reduce financial costs, reduce the use of raw materials and reduce the amount. solid waste improperly disposed of in landfills. The samples of glass waste will be collected in the construction industry itself as works and glass companies that work with cutting and delivery of the product. Comparisons will be made between conventional concretes, control mixtures produced with natural aggregates, and concretes produced with glass aggregates in the percentages of 20%, 30%, 40% and 50% by weight of substitution to natural aggregates, where the comparative analyzes will be as follows. mechanical properties of compressive strength and diametral tensile strength at 7, 14, 21, 28 and 90 days.

2. Theoretical revision

Emissions of greenhouse gases contribute significantly to global warming, carbon dioxide CO_2 contributes approximately 65% of that warming. The world cement industry is one of the most emitting CO_2, accounting for 7% of greenhouse gas emissions to the atmosphere. The world cement industry is one of the most emitting CO_2, accounting for 7% of greenhouse gas emissions to the atmosphere. Several attempts are being made in the concrete industry to use glass waste as a partial substitute for Portland cement and coarse and fine aggregates (5).

Second Bauer (2005) (6) concrete is a mixture of Portland cement, coarse aggregate (gravel or pebble), fine aggregate (sand) and water. Cement when mixed with water forms a tough paste that has the function of adhering the aggregates, and which in fresh form can take different forms. Granular material is called aggregate, such as pebbles, gravel, sand, or construction and demolition waste. Particles larger than 4.75 mm are called coarse or coarse aggregate, whereas fine or fine aggregate refers to particles between 0.075 and 4.8 mm in diameter (7).

Concrete accounts for a significant portion of the human impact on the environment. Approximately one ton of carbon dioxide is released into the atmosphere for every ton of cement produced, in addition to the large amount of natural resources and energy demand to produce it. Even with all this impact, the concrete remains one of the building materials most used and important today, with more than 10 billion tons of this material produced worldwide each year (8).

The recycling of construction waste has a great benefit for the environment by having a proper destination, besides saving in cement production and energy consumption, reducing the pollution generated. For Lima (2010) (9) during the manufacturing process one ton of cement is released around 659 kg CO_2 in the atmosphere. So, more and more scholars are interested in this subject, realizing an interest in the technical environment for the production of pozzolanas in real scale for the production of concretes.

Os resíduos sólidos são substâncias que resultam das várias atividades humanas, geralmente incluem resíduos domiciliares, originários de atividades residenciais urbanas, resíduos industriais, resíduos de serviços de saúde e resíduos da construção civil. Especificamente, resíduos de construção são os gerados nas construções, reformas, reparos e demolições de obras de construção civil.

Glass is a material obtained by melting some materials such as silica, sodium carbonate and calcium carbonate, followed by rapid cooling where solidification occurs without crystallization. It is a material widely used through manufactured products such as flat glass for construction, automotive glass, bottles, glasses and medical materials. It is a material that has great potential for recycling because it is an inert material that can be recycled and used many times, helping to save energy with raw materials and decreases the volume of waste sent to municipal landfills (10), (11).

Making glass is cheaper than storing and recycling because procedures that require collection, cleaning, sorting, pre-packaging and recycling make the process expensive but an economical way to reuse glass that would shorten storage time and provide a solution. More sustainable is the use of glass waste as aggregates in concrete.

The application of glass residues in concretes and mortars becomes limited due to the expansion effects caused by concretes and mortars, which occur by the alkali chemical reaction of the cement paste and the

reactive silica in the form of silica gel aggregates that make In the mixtures of concrete and mortar occur expansions above the allowable for the mixtures allowing the appearance of cracks that accelerate the oxidation processes of reinforcement, such as the reduction of mechanical strengths. However, the use of finely ground glass powder, in addition to the optimal dosage in concrete and mortar mixtures, nullifies the effects of this reaction, as well as the addition of some mineral additives such as silica and metakaolin when incorporated into the mixtures reduces the effects. expansion caused by glass aggregates (12), (13).
Recently some studies show that the ground glass used as mortar aggregate no harmful chemical reaction was found, as long as the particle size is fine, making it possible to use glass residues as fine aggregate in the use of concrete and mortar. Finely ground glass waste contributes positively to microstructural properties, clearly improving the mechanical performance of the mixtures (14) (15).
Park, Lee and Kim (2004) (11) produced concretes using ordinary glass as aggregate replacing the natural fine aggregate in the proportions of 30, 50, and 70% by weight and observed that both the abatement and mechanical behavior of the concrete with glass had lower results than the reference concrete at the ages of researched cures that were 7, 28 and 90 days.
With small proportions (5%, 15% and 20%) and smaller glass particles (less than 2.36 mm), (Abdallah and Fan (2014) (16) also produced soda-lime glass aggregate concretes and obtained similar results to Park, Lee and Kim (2004) (11) regarding mechanical behavior and slump, however, noted that 20% sand replacements with glass improved the mechanical properties of concrete at 28 days of cure.
Similar results with 20% replacement of sand by glass were also observed by Ismail and Al-hasmi (2009) (17), who also used glass particles smaller than 2.36 mm in diameter, and Malik et al (2013) (18), used particle size less than 1.18 mm, with respect to compressive strength at 28 days of cure. However, Malik et al (2013) (18) observed that the abatement increased as the glass content in the concrete increased.

3. Methodology

3.1 Glass waste

The glasses were collected from the company Rios Ltda Glass, in the form of leftovers from the flat glass cutting used mainly in the civil construction in Manaus, in the composition of facades of commercial and residential buildings, frames and balconies, and furniture making in general. In all glass aggregate experiments of this research, glass of the same species was employed to minimize uncontrolled variations of concrete formulations.
After collection and referral to the Building Materials Laboratory of the Federal Institute of Education, Science and Technology of Amazonas - IFAM, the glass fragments were washed with water to remove impurities, air dried and ground in a ball mill.

3.2 Portland cement

The cement used in the concrete formulations was Portland, named CP IV-32, manufactured by the company Mizu, which is widely traded in Manaus. The cement was fractionated and stored in small quantities in a dry environment, and used within the expiration date, so that its original properties were not altered.

3.3 Aggregates

The aggregates used in the production of the studied concretes are mineral in nature and commercialized in the city of Manaus. The fine aggregate used was terra sand, while the coarse aggregate was gravel.

The fine aggregate was a natural sand acquired from the Arco Iris deposit, Figure 1a. For characterization of this material, tests of granulometry, unit mass and specific mass were performed, according to the procedures recommended by the norms ABNT NBR NM 248 (2003) (19); ABNT NBR NM 45 (2006) (20) and ABNT NBR MN 52 (2009) (21), respectively.

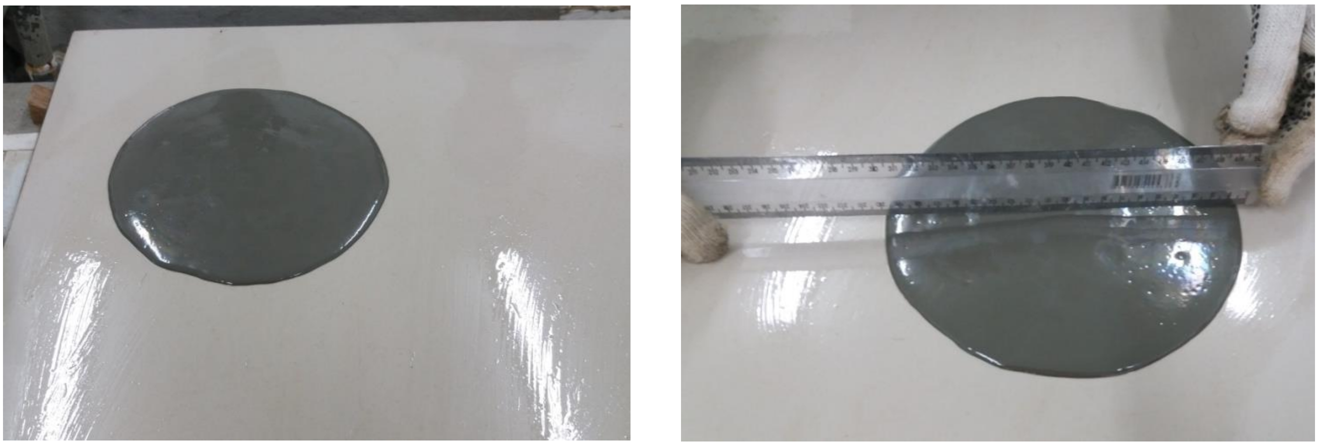
The large aggregate originated from Jazida Figueiredo 150 km from Manaus, Figure 1b. All aggregates underwent particle size testing and their physical characteristics, namely, unit mass, specific mass, fineness modulus and maximum diameter, were experimentally determined.

(a) (b)

Figure 1 - Origin of the aggregates: (a) Terra fir sand, Arco Iris deposit 120 km from Manaus; (b) Granite gravel, Jazida Figueiredo 150 km from Manaus.

3.4 Glenium 51

Glenium 51 is a superplasticizer additive, recommended for the manufacture of all types of concrete when low water / cement (a / c) and high flowability is required, and compatible with all types of Portland cement. It is an additive based on a modified polycarboxylic ether chain that acts as a dispersant of cementitious material, providing superplasticization and high water reduction. Polycarboxylic ether polymers have long side chains that deposit on the surface of cement particles, causing dispersion by electrostatic repulsion. Figure 2 presents the mini-abatement test that verifies the cement compatibility and the additive employed.



(a) (b)

Figure 2 - Mini-slaughter test.

The technical data of the product are presented in Table 1.

Table 1 - Glenium Technical Data 51

Test	Specification
Viscosity (cps)	< 150
Solids (%)	28,5 - 31,5
Especific mass (g/cm³)	1,075 - 1,115
Function	Superplasticizer Additive for Concrete
Chemical base	Polycarboxylic Ether
Aspect	Liquid
Color	Opaque white

Fonte: Basf Company.

3.5 Concrete production

Concrete with 1: 1.60: 2.40 mass content was produced with 0.40 w / c and 0.8% fine aggregate substitution additive at 0, 20, 30, 40 and 50%. as shown in Table 2.

Table 2 - Dosage table of constituent materials

	Cement (kg)	Sand (kg)	Glass kg)	Gravel (kg)	Water (kg)	Glenium (kg)
Standard	12,00	19,20	0,00	28,80	4,80	0,096
20%	12,00	15,36	3,40	28,80	4,80	0,096
30%	12,00	13,44	5,76	28,80	4,80	0,096
40%	12,00	11,52	7,68	28,80	4,80	0,096
50%	12,00	9,60	9,60	28,80	4,80	0,096
60%	12,00	7,68	11,52	28,80	4,80	0,096

The materials were mixed in an inclined shaft concrete mixer with a capacity of 150 liters of concrete. Production followed the following execution steps:

So that there was no need to control the humidity of the materials, especially the sand, the coarse and fine aggregates were placed in the greenhouse for later weighing.

After homogenization, concretes were evaluated for workability, which is the energy required to handle fresh concrete without considerable loss of material homogeneity, by the Slump Test, Figure 3.

For these tests, five concrete batches were cast, with verification of the resistances at ages 7, 14, 21, 28 and 90 days. Three specimens (replicates) were broken for each age, thus producing fifteen specimens for each formulation.

Figure 3 - Concrete abatement test

The compression tests of the cylindrical specimens were performed according to ABNT NBR 5739 (2018) (22), at the Laboratory of Building Materials and Material Resistance of the Federal Institute of Education, Science and Technology of Amazonas - IFAM. Fifteen 10 x 20 cm cylindrical specimens were cast by mixing, sulfur capped and tested as shown in Figure 4 below.

(a) (b)

Figure 4 - (a) Axial compression strength test and (b) diametral compression traction

4. Results and Discussions

For the characterization of the materials, each test was performed twice to calculate an average value and the following results were obtained:

Specific cement mass: 3.15 g/cm^3; specific mass of natural sand: 2.60 g/cm^3; specific mass of glass aggregate: 2,49 g/cm^3; sand unit mass: 1.47 kg/dm^3; unit mass of gravel: 1.54 kg/dm^3.

The particle size curves of sand and glass were found to be within the limits established by ABNT NBR NM 248 (2003) (23). The sand has better grain size distribution (due to the "S" characteristic of its curve) when compared to the glass distribution, justified by the glass grinding process. Figure 5.

The ideal particle size of the aggregate is related to a distribution that has a uniformity of distribution, which generally leads to a considerable decrease in the voids of the concrete. It generally has sufficient amounts of fine particles to completely fill in the voids left by the thicker aggregates. In concretes, the increase of the average rupture stresses are related to several factors among which is the best particle size distribution of aggregates (13).

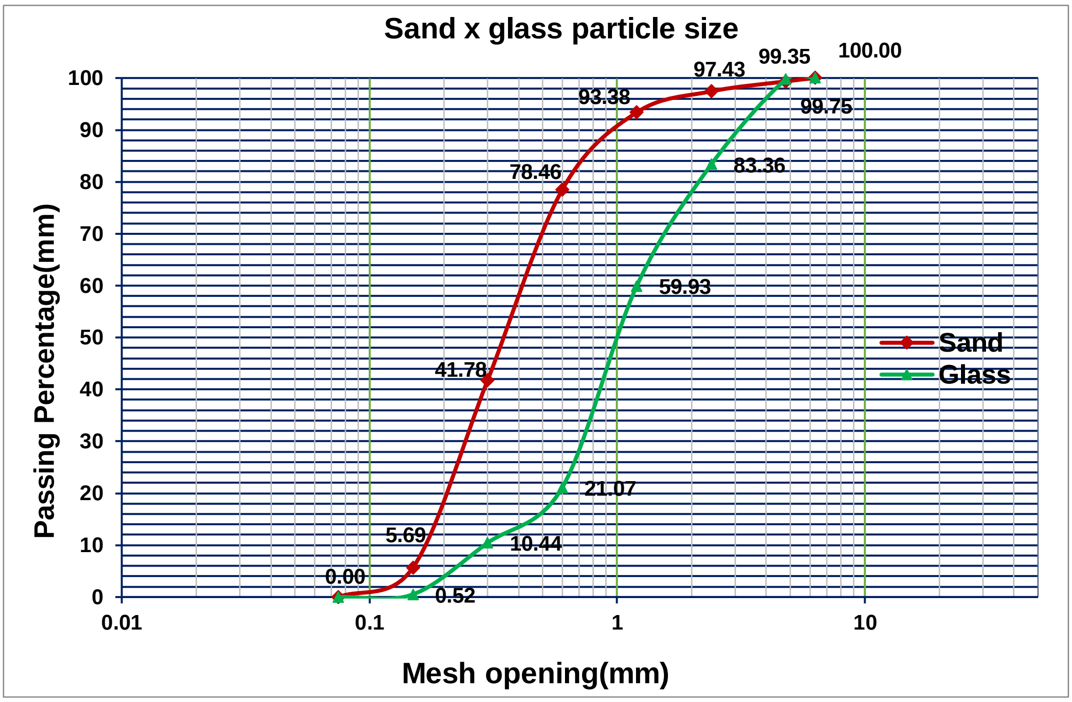


Figure 5 - Particle size curves of fine sand and glass aggregates.

4.1 Consistency of concretes

Consistency is the property of freshly mixed concrete that determines the possibility that it can be properly worked and molded without segregation, and was measured using the conventional drop test. Fresh concrete abatement was measured using the slump test drop cone.

The results of consistency tests (slump) are presented in Figure 6. It can be seen that slump values increase as more glass aggregate is replaced as a percentage of the natural aggregate. The increase in slump observed is related to the smooth surface of the aggregate, which results in greater flowability of such mixtures, since the same water and binder ratios were used for all mixtures.

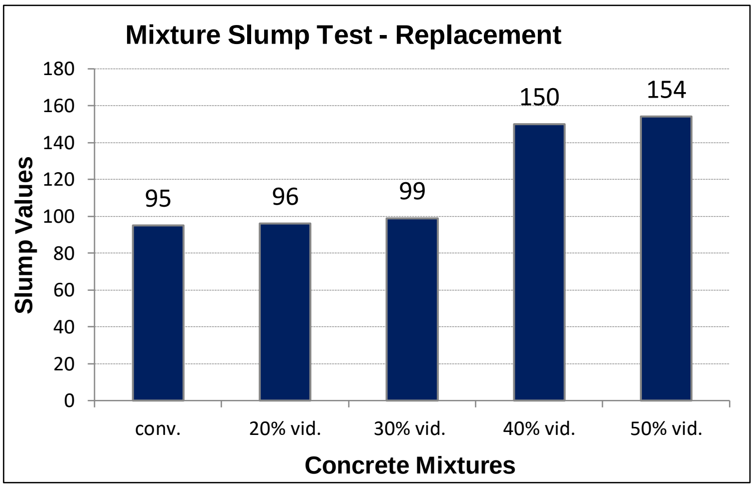


Figure 6 - Consistency Test Results

4.2 Axial compressive strength

The compressive strength of each mixture was evaluated as a function of cure time at ages 7, 14, 21, 28 and 90 days. The average axial compression results are expressed in Figure 7 and show the variation in axial compressive strength with substitution of natural aggregate for glass aggregate compared to the results of the control mixture.

The points on the graphs correspond to the average values of the resistances determined from three specimens for each disruption date. Error bars correspond to confidence intervals according to Student's[1] t distribution. Results showed relatively low standard deviations.

Through the graphs of Figure 7 it is verified that the resistances presented evolution of the axial compression resistance with increasing age, besides normal development until the resistance of the control mixture. After comparing the graphs, although the average values of axial compressive strength of concrete produced with 20% and 30% substitution by glass aggregate were systematically smaller than the control mixture, it was verified that there was no significant difference between them.

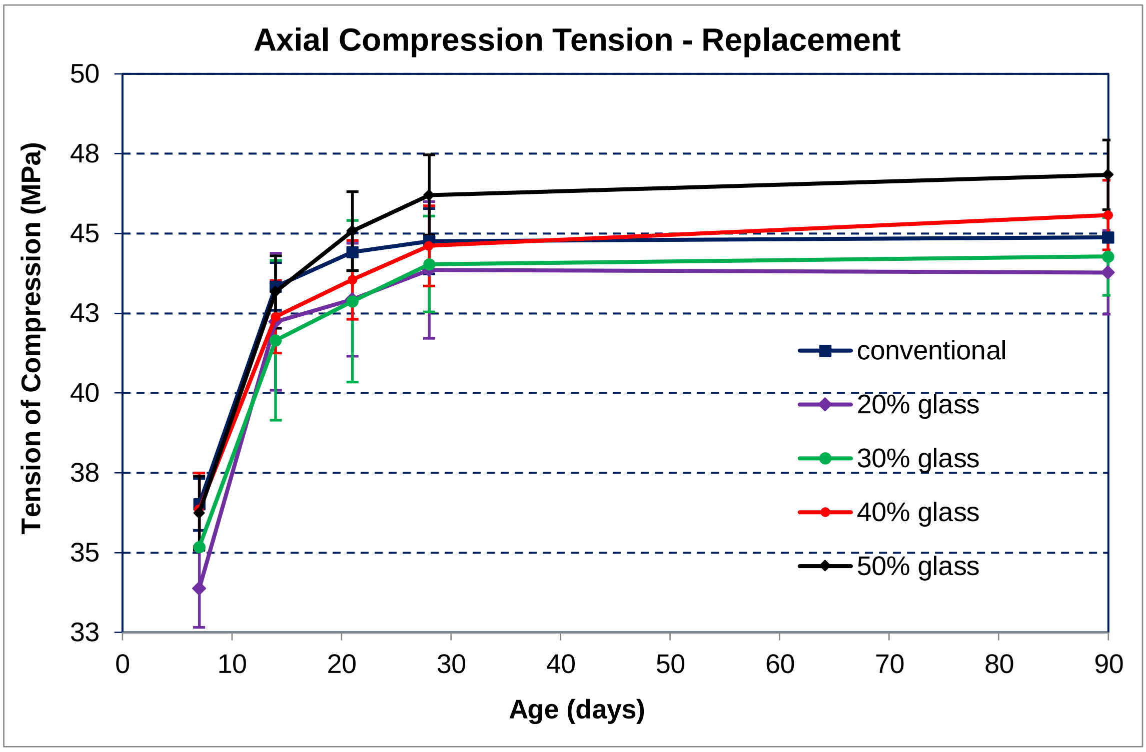


Figure 7 - Result of axial compression tests

The diametric tensile strength values of concretes prepared with and without glass aggregates are shown in Figure 8. These values were on average 12% and 14% of the axial compressive strength values at 90 days. The concretes produced with 30%, 40% and 50% of glass aggregates presented average strengths slightly higher than those obtained with conventional concrete from 28 days. However, in none of the cases the tensile strength by diametral compression was not significantly different between all tested mixtures.

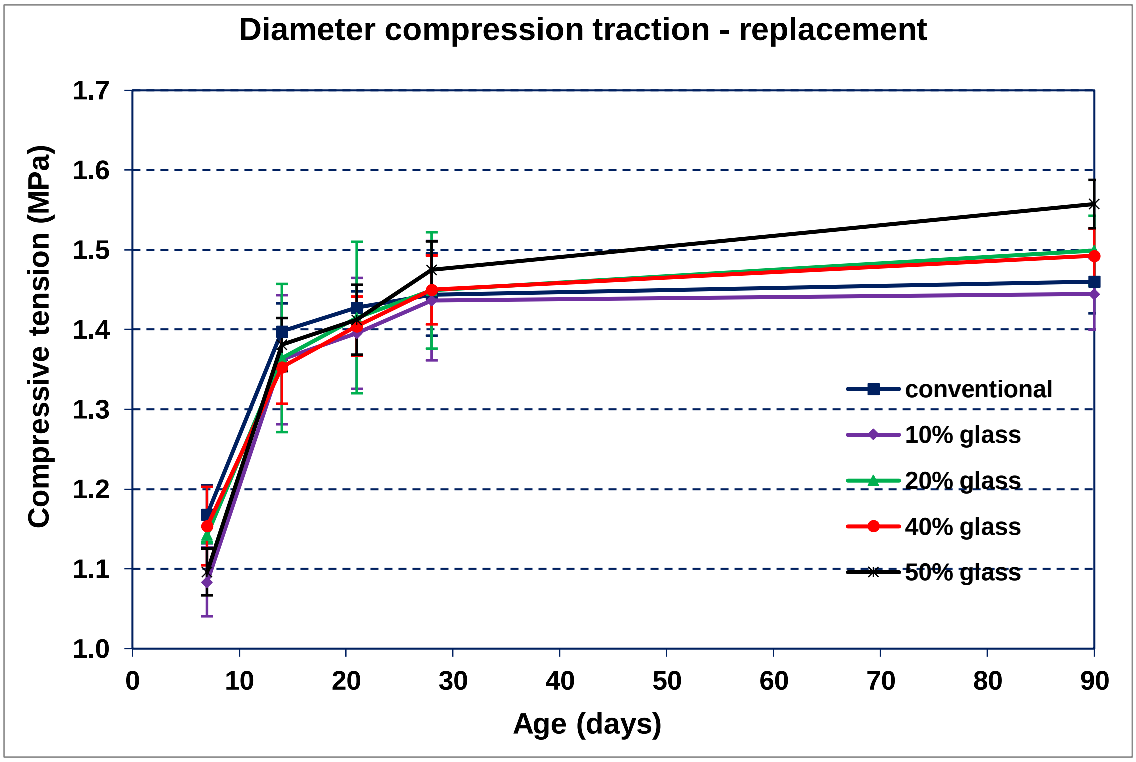


Figure 8 - Diametric Compression Tensile Test Results.

The graphs in Figures 7 and 8 show that the axial compression and diametric compression tensile strengths of concrete increase with age, but there is no direct proportionality relationship between the strengths of the studied mixtures, which are relatively high strengths.
Likewise, it cannot be said that the same characteristics are found in concretes of lower resistance, with a higher degree of porosity.

5. Final Considerations

The average axial compression and tensile compressive tensile strengths of specimens of 30%, 40% and 50% glass aggregate concretes were systematically higher than mixtures produced with natural aggregates after 28 days, however there were no significant differences between the mixtures at all ages.
Glass replacing the natural fine aggregate produced better workability in mixtures with a higher substitution ratio, as they exhibited smooth texture particle size, but because of their weaker bonding with cement paste, they showed slightly lower strengths at early ages in mechanical tests. axial compression and diametral compression traction.
Compression and tensile compression tests indicated that the strength gain in glass-replacing concretes increases at a slightly lower rate than in reference concretes, but glass-aggregate concretes have the potential to achieve higher strengths than normal concrete. for longer cure times. The long-term advantages of glass-containing concrete can be attributed to the better bonding qualities of hydrated calcium silicate resulting from the pozzolanic reaction of glass with calcium hydroxide, and improved adhesion and strength gain of the cementitious mass at older ages.

6. Acknowledgement

The Amazonas State Research Support Foundation - FAPEAM, the Federal Institute of Education, Science and Technology of the Amazonas - IFAM, Manaus Centro Campus.

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