Analysis of the mechanical properties of the concrete with partial substitution of the kind’s aggregate glass powder

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Abstract

In this study, the influence of partial introduction as glass as fine aggregate on the composition of simple concrete is analyzed, considering that sand (fine aggregate currently used) has been used on a large scale in civil construction over the years and has been affecting the environment. The main objective of this research was to analyze the mechanical properties of concrete, partially replacing the natural sand with another fine aggregate made from glass residues, evaluating the behavior presented at the end of each test using different percentages of this material as fine aggregate in the concrete composition. From an experimental methodology that consisted of determining an object of study (concrete), selecting the variable that would possibly be able to influence it (glass powder) and defining the ways of controlling and observing the effects that the variable would produce on the object, an interpretation of how the mechanical properties of the glass powder that affect the performance of structural concrete is presented. The granulometry was subsequently analyzed, the tests carried out both in the fresh and hardened state of the concrete, and identified that the glass in a certain percentage proves to be viable. Finally, it can be concluded that the partial inclusion of glass affects the mechanical properties of structural concrete, and can present quite satisfactory results, both related to the environment, since the sand would not be used entirely as fine aggregate or in reaching a resistance suitable for its final use.

Keywords: glass powder, fine aggregate, influence, concrete, sand.

1. Introduction

The construction sector has grown a lot over the years and concrete structures are among the most used, so there was a need to pay special attention to the aggregates that are used in their composition, since the final strength of the structure it is directly linked to the materials and the way they are used.

For the composition of the concrete some natural elements are used, among them we have sand, fine aggregate that plays an essential role due to its great influence on the final properties of the concrete.

The United Nations Environment Program estimates that 40,000 million tons of sand are extracted each year, however, due to the market being corrupted, until now, comprehensive studies have not been carried out to obtain an exact value (MSUYA, 2019).

Because of this, over time this raw material has become increasingly scarce due to the great increase in its demand, this scarcity has reflected in the value of this aggregate and with this, also caused an increase in the cubic meter of concrete, whether it is done on the job itself or even bought ready-made.

Currently, environmental agencies are increasingly restricting the extraction of natural sand from river beds, since these extractive activities degrade whatever vegetation species are located near the banks of water courses, areas known as areas of permanent preservation since the Brazilian Forest Code (2012), through Law 12.727 / 2012, considers forests and other forms of natural vegetation located along rivers or water courses as permanent preservation areas (SILVA; DEMETRIO; DEMETRIO , 2015).

Because of these and other problems, the exchange of this fine aggregate partially by “glass powder” proved to be a significant possibility. With this, the need arose to analyze the technical and economic feasibility of this substitution, verifying the environmental impact caused and thus showing the viability of this fine aggregate in conventional concrete dosing, remembering that it would undergo a crushing process until it acquired the granulometry proper.

Glass is an element that is recyclable in most cases, and its use as a new aggregate in civil construction would collaborate with the sustainability area because it is not biodegradable and takes years to decompose; in addition, its use in the composition of concrete could improve the income of people who work in waste pickers' cooperatives, in addition to improving the price of a cubic meter of concrete.

In view of the information presented, the research problem that guides this work can be expressed with the following question: Glass powder is economically, environmentally and technically feasible for its partial use as fine aggregate in the composition of concrete instead of sand Natural?

Therefore, the general objective becomes to analyze the mechanical and physical properties of concrete, replacing the natural sand partially with another fine aggregate made from glass waste in works in the city of Caxias-MA through laboratory tests.

In order to achieve the objective in a consistent way, the glass granulometry was analyzed and the percentage of replacement suitable for the use of glass powder aggregate in the concrete and finally, mechanical tests were carried out on specimens using both natural sand as the glass powder.

2. Literature Review

2.1. Concrete

Lopes, Peçanha and Castro (2020) define concrete as a heterogeneous material with complex behavior, both in the fresh and in the hardened state. In addition, it is the most widely used construction material today and in recent years, studies have been developed in search of materials with mechanical performance and superior durability.

The production of concrete is not an ecologically friendly process, since the manufacture and obtaining of its constituent materials have negative impacts on the environment, especially when it comes to the mining activities carried out for the extraction of these products (Fig. 01), which can result in damage to the landscape, interruption of the ecosystem, contamination of water, soil and air (BRAGAGNOLO; KORF, 2020).

Figure 1: Sand mining.
Source: MESQUITA (2019).

According to Bastos (2006), concrete is a composite material, consisting of cement, water, fine aggregate and coarse aggregate, and air. It may also contain chemical additives and additives in order to improve or modify its basic properties.

Schematically, it can be indicated that the paste is the cement mixed with the water, the mortar is the paste mixed with the sand, and the concrete is the mortar mixed with the stone or gravel, also called simple concrete (concrete without reinforcement) (Fig 02).

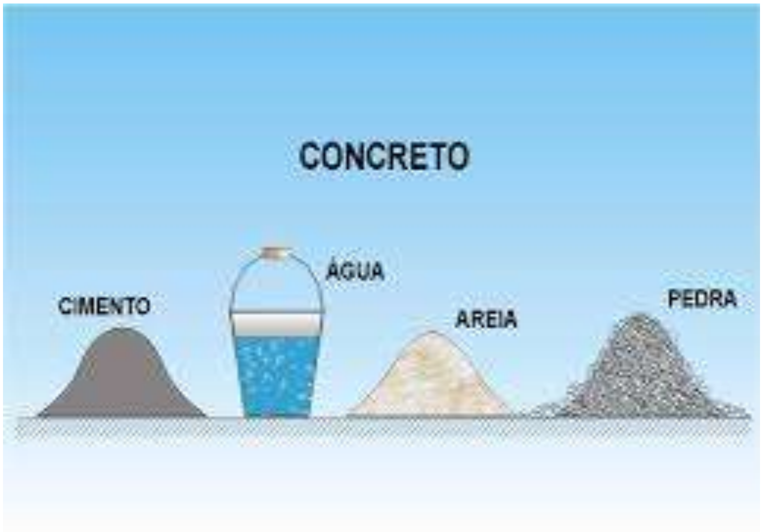


Figure 2: Concrete composition
Source: PINHEIRO (2016).

The design of concrete structures has, over time, experienced a series of advances that range from the materials used to the calculation methods practiced by engineers and designers (SCHERER; MORSCH; REAL, 2019).

According to Pinheiro (2016) conventional concrete has a number of advantages, including: adequate resistance to compression; moldable; low labor cost; barely permeable to water; ease and speed of execution; durable and protects the reinforcement against corrosion;

Adequate measures should mitigate the consequences of some concrete restrictions. The main restrictions are: retraction and fluency; low tensile strength; small ductility; cracking; high self-weight; cost of molds for molding; reinforcement corrosion.

2.2. Mechanical properties

The mechanical properties in the design of concrete structures are of paramount importance, as they define the behavior of the material (response) when subjected to external loads, its ability to resist or transmit these efforts without fracturing or deforming in an uncontrolled manner.

The determination of these mechanical properties in a material are essential tools in the generation of knowledge regarding the way in which the materials will behave in service, as well as relevant indications of the fundamental causes of damage that occurred in these materials under the same conditions (OLIVEIRA; BOFF; PRESTES, 2015).

The main properties of concrete are mechanical. For the calculation and execution of concrete structures, values of several properties are used as a reasonable approximation due to their resistance to compression (Fig. 03). This consideration is opportune in the absence of test results that can show more realistic results (QUADROS, 2014).

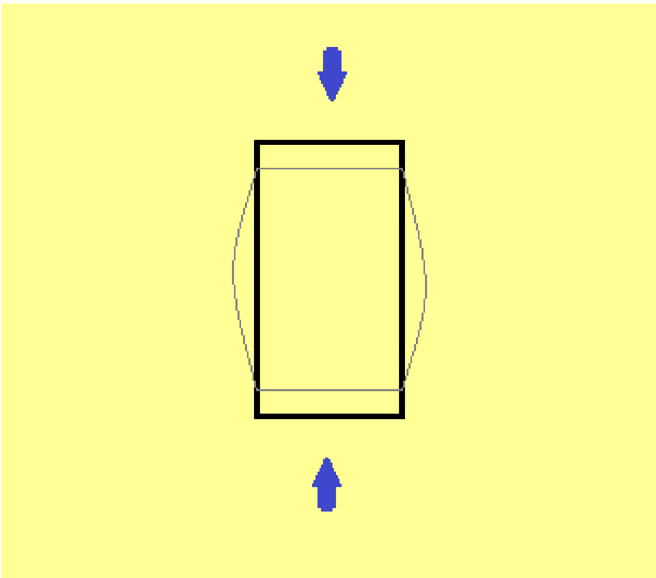


Figure 3: Schematic representation of compaction.
Source: VITOR (2016).

Also, according to Quadros (2014), several standards, including NBR 6118/2014, present a series of expressions from which, depending on the characteristic resistance to compression, the other mechanical properties such as tensile strength are obtained (Fig. 04) and the modulus of elasticity.

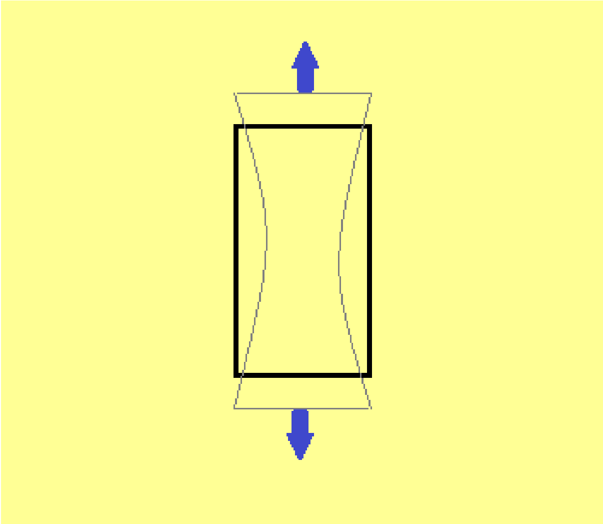


Figure 4: Schematic representation of traction.
Source: VITOR (2016).

Continuing on the mechanical properties, it is necessary to talk about traction. According to NBR 6118 (2014), the indirect tensile strength fct, sp and the tensile strength in flexion fct, f must be obtained in tests carried out according to ABNT NBR 7222 (2011) and ABNT NBR 12142 (2010), respectively. The resistance to direct traction fct can be considered equal to 0.9 fct, sp or 0.7 fct, f, or, in the absence of tests to obtain fct, sp and fct, f, its average value or characteristic using the following equations:

$$\text{fctk, inf} = 0{,}7 \text{ fct, m} \tag{1}$$

$$\text{fctk, sup} = 1{,}3 \text{ fct, m} \tag{2}$$

Where:

- for concretes of classes up to C50: fct, m = 0.3 fck2 / 3.
- for concrete from classes C55 to C90: fct, m = 2.12 ln (1 + 0.11 fck).

In the case of modulus of elasticity or Young's modulus, the same is the ratio between a stress applied to a body and the immediate specific deformation verified in it. Unlike idealized materials that, according to Robert Hooke, maintain a proportionality between the applied force and the verified deformation, it is observed that in concrete, based on certain levels of resistance, due to the nature of the material, this proportionality does not occur, being dependent and variable according to the level of the applied load (PACHECO et. al., 2014).

According to Andrade (2018) the water / cement ratio is the main factor that influences the mechanical properties of concrete. The water / cement ratio influences the porosity of both the cement paste matrix and the transition zone between the matrix and the coarse aggregate, making them less resistant.

The vast majority of specifications that allow for predicting the durability of concrete mixtures are linked to the physical properties of the material, and this line of reasoning is traditional and well disseminated worldwide. The durability of concrete is related to permeability, that is, it depends on the connectivity between the pores present in the material. (LOPES; PEÇANHA; CASTRO, 2020).

2.3 Aggregates

According to NBR 9935 (ABNT, 2011), aggregate (Fig. 05) is defined as a granular stone material, with no defined shape or volume, most of the time chemically inert, with dimensions and properties useful for use in engineering works. As for the origin, they can be classified as natural - those mined directly in the form of fragments, such as sand and gravel, and artificial - those that are subjected to fragmentation processes, such as crushed stone and sand.

Figure 5:Aggregates of various particle sizes.
Source: FABRO *et. al*. (2011).

According to Pinheiro (2016), depending on the characteristic dimensions ϕ, they are divided into two main groups: small aggregates (0.075mm <ϕ <4.8mm) and coarse aggregates (ϕ ≥ 4.8mm) (Fig. 06).

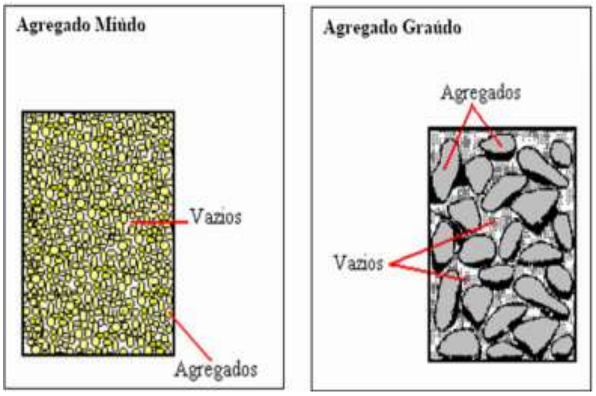


Figure 6: Small and coarse aggregate.
Source: ULSEN (2011).

Aggregates can also be classified according to their properties and size of fragments. As for the properties, the aggregates can be classified as light (vermiculite, expanded clay and others), normal (sands, boulders and crushed or crushed stones) or heavy (barite, magnetite, limonite and others), according to their apparent specific mass, or they can be classified according to the mineralogical composition, which can come from the decomposition of three types of rocks: igneous, sedimentary or metamorphic

(RODRIGUES, 2000).

It is necessary to be very careful about the quality of the aggregates that are used in the production of concrete, knowing that the characteristics of the aggregates have a significant influence on the properties of the fresh and hardened state of the concrete (SANTOS et. Al., 2018).

The fine aggregates used in the production of concrete are basically natural sands (Fig. 07) from river beds and artificial aggregates (Fig. 08) from rock crushing. The main difference between these two aggregates is in the shape of their grains, the natural sands, which are formed by friction, a process by which the loss of vertices occurs, have more rounded grains, while the crushing sands generally have their most angular grains (FABRO et. Al., 2011).

Figure 7: Natural aggregate.
Source: MORAES (2016).

Figure 8: Artificial aggregate.
Source: MORAES (2016).

The high consumption of aggregates and the resulting scarcity has resulted in a search for alternative materials, which are capable of meeting the great demand of civil construction. (BRAGAGNOLO; KORF, 2020).

According to Nogueira (2016), for the selection of materials that have the potential to serve as substitutes for aggregates, one must essentially observe their particle size distribution and other physical indices, such as specific gravity, fineness module, mass density, absorption of water, humidity, silt content, flaccidity, elongation index and particle size distribution.

2.3. Glass

Brazil produces an average of 980 thousand tons of glass containers per year, occupying about 45% of recycled raw material in the form of shards. In 2010, only 47% of the total packaging used in Brazil was recycled, that is, more than half of these packaging have an inappropriate destination (TRENTIN; MANICA; VANZETTO, 2020).

Also, according to Trentin, Manica and Vanzetto (2020), in the last decades, the ecological awareness of consumers has been growing and causing authorities and productive sectors to seek more and more information about the environmental impacts associated with production processes, use and final disposal. of the products.

The glass used for packaging (Fig. 09), as bottles, is an amorphous material, of high chemical resistance, non-porous and fragile, composed mainly of silica. At the end of its use, glass-based utensils are discarded; however, most ordinary glasses are fully recyclable and can be reused and incorporated into other manufacturing processes (ZACCARON et. al., 2019).

Figure 9: Glass packaging
Source: VIEIRA (2017).

Despite being reused in the manufacturing process of new bottles, the bottling glasses still generate environmental problems, due to the lack of proper management of these residues, which consequently causes significant amounts to be deposited in landfills. For these cases, it becomes necessary to find viable technological alternatives that allow the recycling of these glasses in an economical and sustainable way (ZACCARON et. Al., 2019).

The recycling of materials for use in civil construction is seen as a potential source of generation of aggregates. In addition to providing the reuse of waste, it reduces the dependence on natural aggregates, which contributes to the preservation of natural resources, and can also generate savings for the construction process (SILVA; CAPUZZO, 2020).

Several works have been developed with the objective of evaluating the feasibility of incorporating the most diverse residues in civil construction. Among them, glass stands out, which has high chemical durability, which makes it capable of composing cementitious materials such as mortars and concrete (TRENTIN; MANICA; VANZETTO, 2020).

The processing (production) of glass (Fig. 10) in civil construction, in this context, generates basically two types of waste: the “shards” or large chips (which can be recycled by the glass industry in the form of household utensils, packaging, etc.) and a fine powder, resulting from the cutting, drilling and finishing of the glass plates, which are rejected in the recyclers for causing damage to the ovens, due to the fineness of the material. The reuse of fine waste can offer advantages such as reduced costs, reduced negative environmental impact and reduced consumption of natural resources (RIBEIRO; SANTOS, 2020).

Figure 10: Glass powder.
Source: RIBEIRO and SANTOS (2020).

3. Materials and Methods

3.1. Kind of study

The research carried out in this work can be classified as descriptive, since it aimed to produce data regarding the mechanical properties of concrete using glass powder as fine aggregate. The methodology of the work was of an experimental character, since it consisted in determining an object of study (concrete), selecting the variable that would possibly be able to influence it (glass powder) and defining the forms of control and observation of the effects that the variable would produce on the object.

3.2. Materials and equipment

The materials used to carry out the research were all the elements that make up the concrete, namely: the cement, which in this case was CP IV; the water; glass powder, an artificial fine aggregate that was used to partially replace natural sand and gravel as coarse aggregate.

In addition to the materials, it was also used and the sieve was used to carry out the granulometry test and in this way definition of the grains considered to be small; the grinder, used to remove the imperfections of the specimen and the mechanical press, an equipment that is used to determine the strength of the concrete through the execution of compression tests.

3.3. Experimental program

At first, the glass was crushed so that it reached the sand's granulometry and thus could be used as fine aggregate, this process was done using a grain crusher. Subsequently, the first test was carried out to determine the fineness module (Mf), which is regulated by the ABNT NBR 7211 (2019) standard, which determines that the Fineness Module is the sum of the accumulated mass percentages of an aggregate, in the sieves of the normal series, divided by 100 (Fig. 11).

Figure 11: Granulometry test.
Source: AUTHOR (2020).

The second is the concrete slump test, also known as the Slump Test (Fig. 12), which was carried out to verify the workability of the concrete in its plastic state, seeking to measure its consistency and assess whether it was suitable for the use to which would target. The standard that regulates this test is ABNT NBR 10342: 2012.

Figure 12: Slump test.
Source: AUTHOR (2020).

After these tests, the specimens were assembled, altogether 18 (eighteen), in which six of them were assembled only with sand, six with 25% glass powder and six with 50% glass powder in partial replacement to the sand. After being assembled, the specimens were immersed in the water for a few days (Fig. 13).

Figure 13: Spicemens submerged in water.
Source: AUTHOR (2020).

The third test performed was the compression rupture (Fig. 14) standardized by ABNT NBR 5739 (2018) in this test had a specificity, because the specimens were broken with 7, 14 and 28 days of cure, on each day three of them (one with only sand, one with 25% glass powder and one with 50% glass powder) and thus, due analysis and comparisons were made.

Figure 14: Compression rupture.
Source: AUTHOR (2020).

The fourth was rupture by diametrical compression. (Fig.15). For its realization, the cylindrical specimens were placed with the horizontal axis between the plates of the testing machine, and the contact between the specimen and the plates should occur only along two generatrices, being applied a force until there was a cracking of the concrete due to indirect traction.

Figure 15: Diametrical compression.
Source: AUTHOR (2020).

4. Results and discussion

4.1 Characterization of aggregates

4.1.1 Particle size analysis

The aggregates are regulated by the ABNT NBR 7211 (2019) standard, which indicates which parameters are necessary to meet the quality indexes. In order for the materials to be classified as fine or coarse, it is necessary to carry out the granulometry test, such test is standardized by ABNT NBR NM 248 (2003). This test consists of using sieves with several openings that are used to obtain the percentage of the retained and passing mass, and finally a table is created containing all the data obtained. Table 1 shows all the results that were found using 0.800g of the fine aggregate, glass powder.

Table 1. Granulometry test

Sieves (mm)	*Retained Mass (g)*	*% Retained*	*% Accumulated Retained*
6.30	***0,014***	***1,75 %***	***1,75 %***
4,75	***0,022***	***2,75 %***	***4,5 %***
2,36	***0,254***	***31,75 %***	***36,25 %***
1,18	***0,210***	***26,25 %***	***62,5 %***
600 µm	***0,134***	***16,75 %***	***79,25 %***
Fundo	***0,162***	***20,25 %***	***99,5 %***

Source: AUTHOR (2020).

In Table 1, it can be seen that the data demonstrate that the glass powder can be considered and can be used as fine aggregate, since its concept concerns grains that pass through the sieve with a 4.75 mm mesh opening and are retained in the sieve with 150 μm mesh opening, in the test carried out according to ABNT NBR NM 248, with defined sieves (granulometry test by sieving). As shown in the table, the glass when crushed acquires the desired granulometry to suit the role of small aggregates.

It is possible, by adding the retained percentages accumulated in mass of the aggregate, in the sieves of the normal series, divided by 100, to determine the fineness module, which was 2.84%, and with this value it can be considered a magnitude module. fineness of the optimum zone as it ranges from 2.20 to 2.90.

4.2 Concrete properties

4.2.1 Workability

The workability of concrete is the property in the fresh state that determines the ease and homogeneity with which it can be mixed, cast, compacted and finished. Such quality is assessed by the consistency of the concrete.

There is no specific test for determining the workability of concrete, but the most used today is the "slump test", which is a test adopted by the Americans to measure the concrete consistency index. Various factors can interfere with workability, such as the concrete mix, the granulometry, the shape of the aggregate grain, mixture, transport and densification.

This test was carried out for the three specimen models (one with only sand and the other two using percentages of 25% and 50% glass as fine aggregate), the results are shown in Table 2.

Table 2. Slump Test.

AGGREGATE	*MEASURE (cm)*
0% glass + 100% sand	***12***
25% glass + 75% sand	***14***
50% glass + 50% sand	***15***

Source: AUTHOR (2020).

The value may vary according to the purpose of the concrete, for large volumes and with little reinforcement, as in shoes and foundation blocks, the minimum "slump" is 4 cm; for beams, columns and slabs with manual concrete launching or through buckets, the minimum “slump” varies between 6 and 8 cm. For pumped concretes, due to the mobility required, the lower limits rise to the range of 8 to 12 cm. As seen, according to the data in table 2, it can be seen that only the concrete using 100% sand as fine aggregate is within the desirable limit of workability of the concrete, which is 12 cm, this is possibly due to the fact that the sand has a better grip with water, unlike what happens with glass.

4.2.2 Compressive strength

The compressive strength of concrete is known as Fck, an acronym that in English means Feature

Compression Know. It is measured in megapascals (MPa), and each 1 Mpa corresponds to approximately a resistance of 10 kgf / cm². The Fck indicates the stress that the concrete has the capacity to resist, this stress is obtained by dividing the force and the area in which it will act. In this way, the compressive strength tests in the concrete allow to find out what the maximum stress it will resist before properly suffering the rupture.

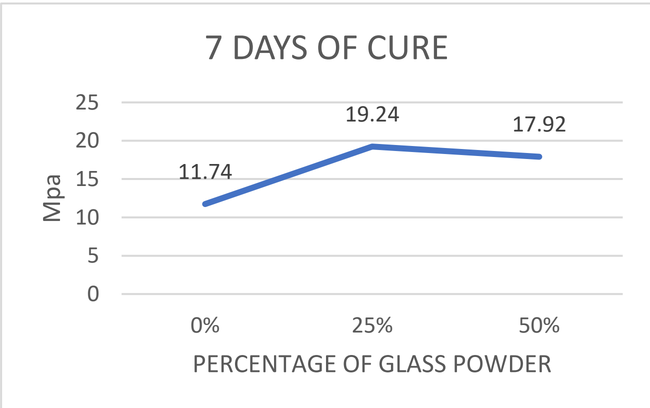
This test was carried out and the strengths were analyzed at 7, 14 and 28 days, it is worth mentioning that only after 28 days, the concrete reaches 100% of its compressive strength. The fck values at 7, 14 and 28 days are shown in Table 3.

Table 3. Compressive strength in MPa

AGE	7 DAYS	14 DAYS	28 DAYS
0% glass + 100% sand	11,74	15,15	16,52
25% glass + 75% sand	19,24	21,38	24,32
50% glass + 50% sand	17,92	20,61	23,34

Source: AUTHOR (2020).

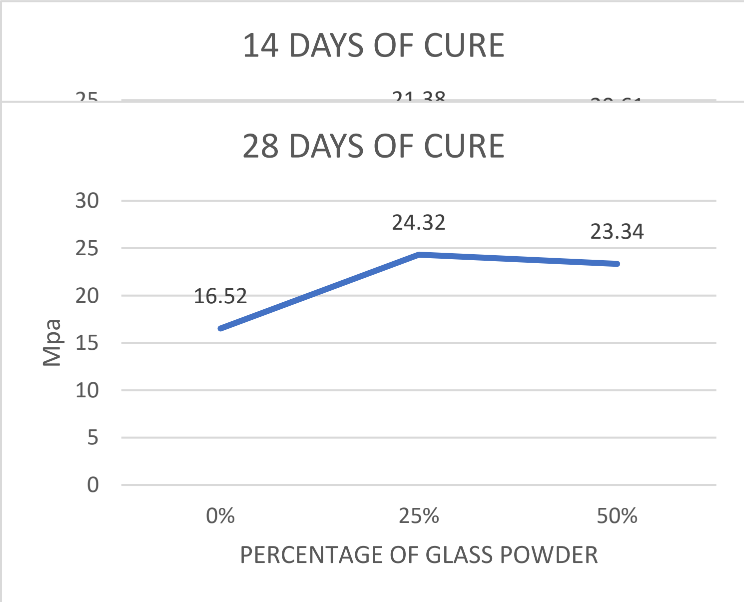
From the analysis of the data in Table 3, referring to the compressive strength of concrete at 7, 14 and 28 days, we can observe that for all cases analyzed, the concrete whose composition was 25% glass and 75% sand presented the best compressive strength. Thus, it can be inferred that concrete made with glass and sand as fine aggregates has a positive influence on the final compressive strength of the same. Such results can be better visualized with Graphics 1, 2 and 3.



Graphic 1. Compressive strength in MPa – 7 days

Source: AUTHOR (2020).

Graphic 2. Compressive strength in MPa – 14 days



Source: AUTHOR (2020).

Graphic 3. Compressive strength in MPa – 28 days

Source: AUTHOR (2020).

4.2.3 Resistance to diametrical compression

The diametrical compression test, or the Brazilian test as it is also known, is an experimental test method for determining the mechanical resistance to traction efforts of great popularity in the area of material characterization, being applied to concrete, mortars, asphalt mixtures, rocks, soils, among others.

Such an assay was carried out and Table 4 shows the results obtained by the assay done at 7, 14 and 28 days.

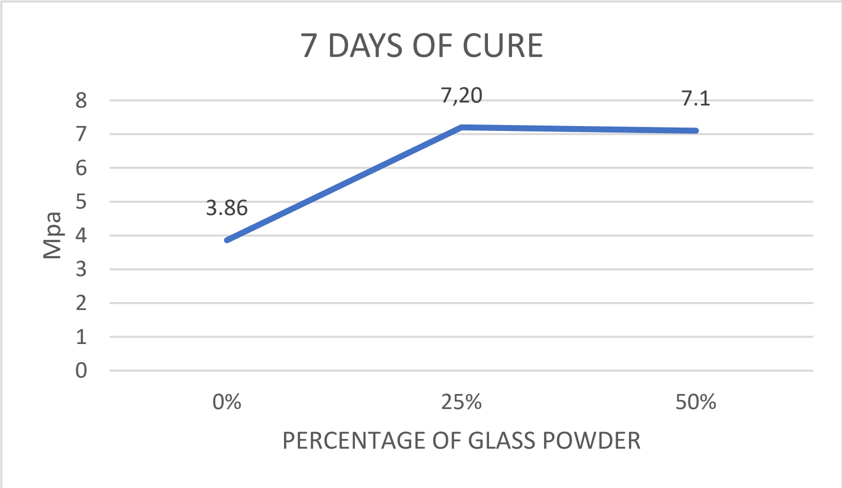
Table 4. Diametrical compressive resistence in MPa

AGE	7 DAYS	14 DAYS	28 DAYS
0% glass + 100% sand	3,86	6,03	7,49
25% glass + 25% sand	7,20	7,98	11,01
50% glass + 50% sand	7,10	9,37	9,65

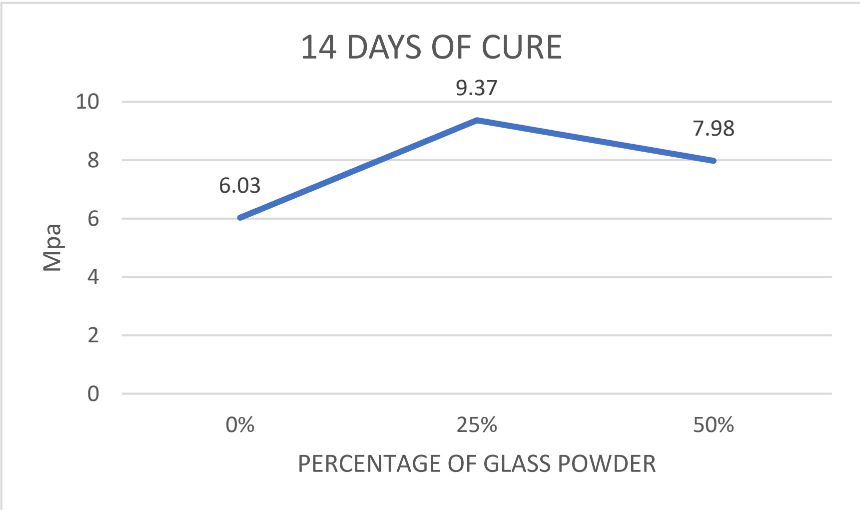
Source: AUTHOR (2020).

After analyzing the results in table 4, it can be concluded that, just as it happened for the compressive strength, the values of the diametrical compressive strength of concrete that have 25% glass and 75% sand as fine aggregate in the composition of the concrete were superior to the other results obtained, either with sand alone or with 50% sand and 505 glass.

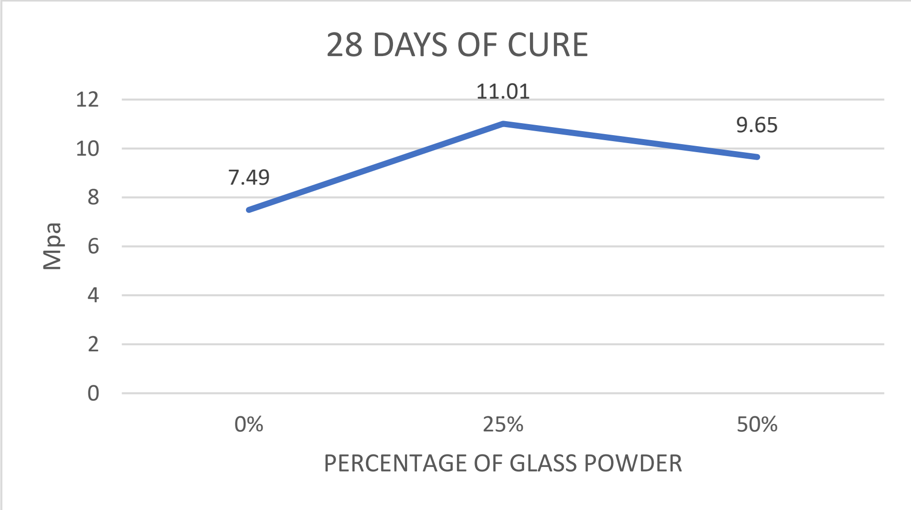
These results, which can be better visualized in Charts 4,5 and 6 and prove through the data obtained that the resistance to compression and the resistance to diametrical compression indicate that with the use of glass powder in the composition of the concrete we can obtain mechanical properties better when compared to concrete with only sand in its composition.



Graphic 4. Diametrical compressive strength in MPa – 7 days
Source: AUTHOR (2020).



Graphic 5. Diametrical compressive strength in MPa – 14 days
Source: AUTHOR (2020).



Graphic 6. Diametrical compressive strength in MPa – 28 days

Source: AUTHOR (2020).

5. Conclusion

It can be concluded that with the partial inclusion of the glass powder as fine aggregate, the concrete presented a satisfactory amount and even better of its mechanical resistance than it being composed entirely by the fine aggregate sand, this implies that the glass in the composition of the concrete directly and positively interferes with the properties of the concrete.

The results obtained through the tests carried out showed that glass can be a proposal for a solution to reduce the use of sand in concrete, since it has been used on a large scale in recent years. This result was only possible due to the mixing process carried out, since sand absorbs water better than glass.

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