Replacement of Natural Aggregate by Glass Waste in Granolithic Concrete

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Abstract

The study of polished concrete floors is relevant when related to technical and durability requirements, since its use is very common in places with large extensions. In this exploratory work, a comparison between the granolithic floor and the floor produced with glass waste was undertaken in order to verify the performance of the specimens, in addition to seeking a purpose for the glass, which is barely reused by society. The analyses carried out were: visual observation of the specimens, flexural tensile strength, compressive strength, and hard body impact strength test. Visual analysis identified more intense shine and larger amounts of holes on the surface of the specimens in which the glass waste was used. In the hard body impact strength test, the specimens produced with the glass waste presented superior results when compared to the reference specimens. In the flexural tensile strength test, the specimens produced with the glass waste presented lower results than the reference specimens, nevertheless both specimens showed satisfactory results. In the compressive strength test, the results obtained in both specimens were below the minimum required for industrial floors. The hard body impact strength test demonstrated the opposite: the specimens produced with the glass waste presented higher value than the specimens made with the granite.

Keywords: Floors; Glass waste; Recycling; Strength.

Introduction:

According to Brazilian Micro and Small Business Support Service **[1]**, the waste generated by human activity is in excess of nature's ability to adapt and absorb the impacts caused by them. Thus, it is necessary to use waste reuse techniques. Furthermore, the practice of recycling brings numerous benefits to society, such as increased employment and income generation, reduced extraction of natural resources and reduced space used to deposit the waste generated **[1]**. The impact of using ground glass powder as either a cement replacement material or as an aggregate replacement material on the mechanical properties of Portland cement concrete were already investigated **[2, 3, 4, 5, 6, 7, 8]**.

National Confederation of the Chemical Industry **[9]** highlights that glass is one of the materials that is easier to recycle, becoming 100% recyclable. However, despite having properties that make it highly recyclable, the recycling rate of glass in Brazil is approximately 18%, that is, it is a material little reused in society, which brings consequences such as irregular disposal **[9]**.

The Article 1 of Law No. 5.177, of September 6, 2019, of the Municipality of Montes Claros-MG (Brazil) **[10]** states that the collection, storage and final destination of non-returnable glass bottles, long neck model, by resellers, suppliers or manufacturers is mandatory. However, companies and industries that buy this waste are located in other states, such as São Paulo and Rio de Janeiro, incurring the cost of transport and making the process unfeasible.

Although glass has a great recyclable potential, the glass waste is a little used material due to the financial impossibility of transporting it to reuse points. Thus, this paper seeks to analyze the application of glass waste as an aggregate in polished concrete floorboards, seeking an alternative to the final disposal of this material. Being aware that, there are no standards in Brazil that regulate polished concrete floors, the analysis was based on adapted technical regulations and was carried out comparing the results between specimens of floors manufactured with recycled glass and specimens produced with natural aggregate.

Material and methods:

Granolith, a concrete coating that has granite and marble as the commonly used natural aggregates, has its main application in floors that need good strength and high durability, as it is frequently used in places that demand an intense movement of people **[11]**. For the comparison between specimens produced with natural aggregate (granolith) and recycled glass, tests were performed on impact strength of hard body, flexural tensile strength and compressive strength, in addition to visual analysis of the specimens.

(a) Obtaining the materials

The granite used in the production of the specimens was supplied by a company specializing in the manufacture of polished floors in the city of Montes Claros (Brazil). The glass waste was supplied by the company Viva Verde Recycling, which specializes in the processing of construction waste for reuse. The glass waste is crushed and then subjected to vibration and washed in order to remove impurities.

A visual particle size comparison was performed between the aggregates, according to Figure 1. It is noticeable that both the natural aggregate, in the lower left corner of the image, and the recycled glass, in the lower right corner of the image, have similar particle size dimensions. Furthermore, when compared to gravel #1 (see the upper part of Figure 1) which has a maximum characteristic dimension equal to 19 mm, they present smaller grain dimensions.

Figure 1. Particle size comparison of aggregates (typical large gravel is used for reference only).

(b) Production of specimens

For molding the specimens, wooden molds were produced. Plywood sheets was used as a base and slats as dividers, in addition to nails for fixing the pieces. The slats were cut using a portable, circular, electric saw.

The specimens were produced in specific dimensions and quantities according to the tests performed, as shown in Table 1. For the flexural tensile strength tests, a total of 6 specimens, with dimensions of 4 x 4 x 16 [cm], were produced. After that, the 12 ends of the specimens were subjected to the compression test. For the hard body impact strength test, a total of 10 specimens, with dimensions 20 x 20 x 1.5 [cm], were produced. For the visual analysis, among those manufactured to carry out the hard body impact strength test, two specimens were selected.

Table 1. Quantities and dimensions of specimens according to tests.

Test	Specimen produced with natural aggregate	Specimen produced with glass residue	Specimen size [cm]
Flexural Tensile Strength	3	3	4x4x16
Compressive Strength	6	6	4x4x4
Hard body impact strength	5	5	20x20x1.5
Visual analysis	1	1	20x20x1.5

For the production of the concrete used in the specimens, the mix 1 : 1.6 (cement : aggregate – by mass) was adopted, commonly used by the makers of granolith flooring in the city of Montes Claros. In addition, a water/cement ratio of 0.45 was used, also applied by local companies.

The preparation of the concrete took place manually and then the molding of the specimens was carried out. The densification was carried out using a socket, with 60 blows being applied to the specimens with dimensions 4 x 4 x 16 [cm] and 30 blows to the specimens with dimensions 20 x 20 x 1.5 [cm]. The deformation was carried out after 24 hours and the specimens were submitted to cure, submerged in water for 28 days.

After the curing process, the specimens were polished. Initially, the pieces were submitted to polishing using a circular grinding wheel attached to a manual sander to remove imperfections on the surfaces, leaving them flat. After that, a roughing sandpaper P36 was used and then a roughing sandpaper P60 to finish the polishing of the specimens. After polishing, the specimens were washed with water to remove dirt and, after drying, two layers of acrylic resin were applied to the surface of the specimens.

(c) Visual analysis of specimens

A visual comparison was carried out between the two specimens with dimensions 20 x 20 x 1.5 [cm], one being produced with natural aggregate and the other using recycled glass as aggregate. After completion, the specimens with the greatest apparent defects were selected and observed, seeking to identify differences between the surfaces of the pieces, such as gloss and undulations or irregularities.

(d) Hard body impact strength

The hard body impact strength of the specimen was obtained according to procedures similar to those proposed in the Brazilian standard NBR 15845-8 **[12]**, in which it was necessary to find the drop height (cm) of a steel ball to cause cracking and rupture of the specimens.

The specimens were placed on a sand mattress with the polished face facing up and then the 1 kg steel ball with a diameter of 6 cm was dropped at an initial height of 20 cm, with 5 cm being added, if necessary, up to the point at which the specimen broke (Figure 2(a)).

(e) Flexural tensile strength and compressive strength

The flexural tensile strengths of the specimens were obtained according to procedures described in NBR ABNT 13279 **[13]** (Figure 2(b) and Figure 2(c)). To determine the flexural tensile strengths, a force at constant increase was applied transversely to the center of the upper face of the specimen until rupture.

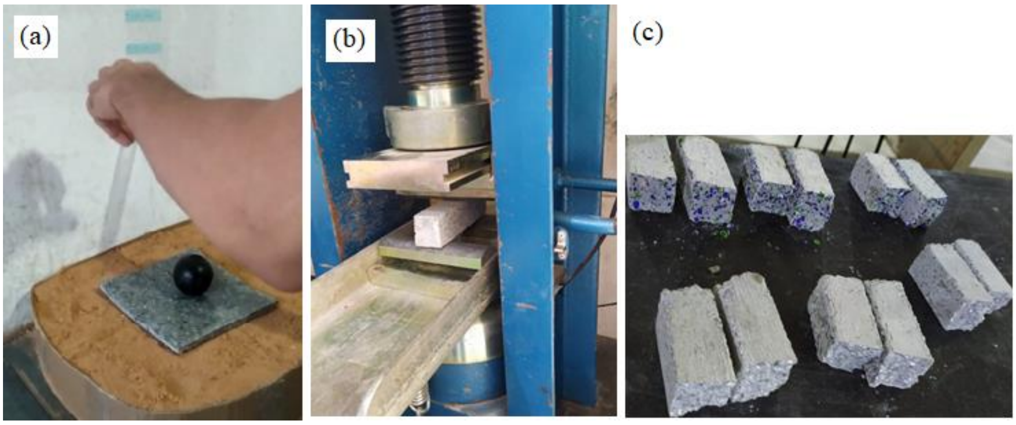

Figure 2. Tests procedures. (a) Hard body impact strength, (b) Tensile strength, and (c) Halves of specimens.

After the break, the flexural tensile strength was calculated according to Equation (1):

$$R_f = \frac{1{,}5F_f L}{40^3} \quad (1)$$

where:

R_f is the flexural tensile strength, expressed in MPa;

F_f is the load applied to the center of the prism, expressed in N;

L is the distance between the supports, expressed in mm.

To determine the axial compressive strength, the halves of the specimens used in the flexural tensile strength test were used, and they were subjected to a force at constant increase, until the specimens rupture.

After breaking, the compressive strength was calculated according to Equation 2:

$$R_c = \frac{F_c}{A} \quad (2)$$

where:

R_c is the compressive strength, expressed in MPa;

F_c is the maximum load applied, expressed in N;

A is the area of the top face of the specimens, expressed in mm².

Results and Discussion:

(a) Visual analysis of specimens

The specimens chosen to perform the visual analysis were those with the greatest apparent imperfections among those produced for the hard body impact strength test, as they are the worst situations.

The specimens were analyzed in order to verify the irregularities on their surfaces, where the two specimens had small holes on the upper face in the places marked on the Figure 3. The specimen produced with the granite (Figure 3(a)) presented lower number of holes and with smaller dimensions when compared to that of the specimen made with glass (Figure 3(b)). The same was investigated by Guimarães **[14]**, which detected the presence of cracks and surface irregularities in specimens with the glass aggregate during the comparative analysis of scanning electron microscopy between specimens produced with the glass and with natural aggregate.

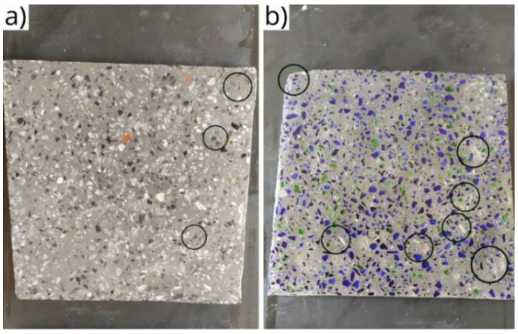

Figure 3. (a) Specimen with natural aggregate, and (b) Specimens with glass waste aggregate.

During polishing, the specimens manufactured with the glass waste presented greater difficulty in the process when compared to the reference specimens, because when coming into contact with the sander, the glass grains detached from the surface, causing small holes.

Then, the gloss on the surfaces of the specimens was compared. It was noticeable, as shown in Figure 4, that the specimen with the glass waste had a more intense shine than the specimen with granite. The application of the resin provided a greater expression of shine on the surfaces, especially when under the action of natural light.

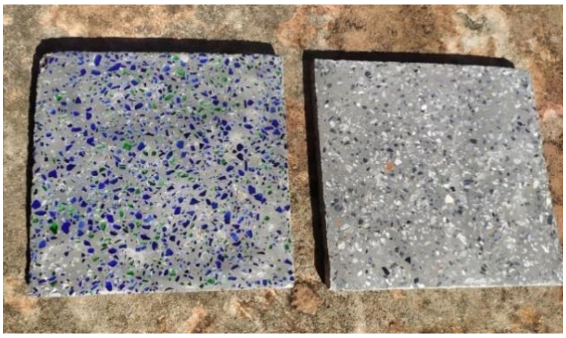

Figure 4. Shine on the surface of the specimens.

(b) Hard body impact strength test

The breaking heights of the specimens obtained in the hard body impact strength test are expressed in the Table 2.

Table 2. Hard body impact strength test.

Aggregate	Specimen	Height of fall (cm)
Glass waste	1	25
	2	30
	3	35
	4	30
	5	30
		Average breaking height: 30
Granite	1	25
	2	30
	3	25
	4	25
	5	25
		Average breaking height: 26

Based on the results found, 80% of the specimens used as reference presented rupture in the second contact with the sphere, released at a height of 25 cm, while 80% of the specimens produced with recycled glass waste resisted the impact of the sphere released at that same height. The specimens produced with the glass waste presented a satisfactory result, since the average rupture height was 30 cm, which was higher than the average rupture height of 26 cm obtained in the reference specimens made with the granite.

(c) Test of flexural tensile strength and compressive strength

The results obtained in the flexural tensile strength test in the specimens produced using the granite are presented in Table 3. The flexural tensile strength of each specimen was calculated. Then, the average strength of the three specimens was calculated and it was found that the maximum absolute deviation (5.5 MPa) by extrapolating the limit allowed by standard, of 0.3 MPa. Thus, a new average strength was calculated, disregarding specimen 1 (considered as being an outlier), whose strength was farther from the initial average strength. An average strength of 8.0 MPa was found, and it was verified that the maximum absolute deviation met the requirements established in the aforementioned standard.

Table 3. Flexural tensile strength test on specimens with natural aggregate.

Specimen	**Distance between supports L (mm)**	**Burst load F_f (N)**	**Flexural tensile strength R_f (MPa)**
1	120	5 782	16.3
2	120	2 842	8.0
3	120	2 842	8.0
1st Average strength			10.8
1st Maximum absolute deviation			5.5
2nd Average strength			8.0

For specimens with glass waste, the results are shown in Table 4. The maximum absolute deviation found after the calculation of the average strength of the three specimens was 1.4 MPa, being necessary to perform the calculation of a new strength, disregarding specimen 2 (considered as being an outlier), which obtained the most discrepant result. A new average strength of 4.3 MPa was found, and it was verified that the new maximum absolute deviation was met.

Table 4. Flexural tensile strength test on specimens with the glass waste aggregate.

Specimen	**Distance between supports L (mm)**	**Burst load F_f (N)**	**Flexural tensile strength R_f (MPa)**
1	120	1 470	4.1
2	120	2 254	6.3
3	120	1 568	4.4
1st Medium strength			4.9
1st Maximum Absolute Deviation			1.4
2nd Medium strength			4.3

It can be seen in the Tables 3 and 4 that the average strength of the specimens produced with the glass waste was lower than that found in the reference specimens. Comparing with the literature, it is reported in Ref. **[13]** that the minimum strength for industrial floors is 4.2 MPa, therefore one may conclude that the results obtained in the tests of both specimens were satisfactory.

Table 5 below presents the results of the compressive strength test on the specimens used as reference. The length of the upper face of each specimen was measured and the identified value was multiplied by the width, 40 mm, and the area of the section to be submitted to loading was found, making it possible to determine the individual and average compressive strengths of the specimens. The maximum absolute deviation identified, 10.2 MPa, was higher than that allowed by the standard, 0.5 MPa. Therefore, a new average strength was calculated, disregarding the specimen with the most discrepant strength, specimen 4, and it was verified that the new maximum absolute deviation, 2.7 MPa, was also greater than the allowed one. Thus, a new calculation procedure was performed, disregarding specimen 1, when a new average strength of 18.4 MPa was found. It was then verified that the new maximum absolute deviation was acceptable for the compressive strength test.

For specimens produced with glass waste, the results of the compressive strength test are presented in Table 6. The calculation procedures of individual and average strengths and maximum absolute deviations were the same used to determine the results of Table 5. The average to final compressive strength found, which obtained maximum absolute deviation with a value of less than 0.5 MPa, was 13.8 MPa.

Table 5. Compressive strength test on specimens with natural aggregate.

Specimen	Length of top face (mm)	Top face area A (mm²)	Load F_c (N)	Compressive strength R_c (MPa)
1	80	3 200	48 020	15.0
2	80	3 200	57 330	17.9
3	75	3 000	55 076	18.4
4	85	3 400	101 626	29.9
5	85	3 400	64 190	18.9
6	75	3 000	54 684	18.2
1st Average strength				19.7
1st Maximum absolute deviation				10.2
2nd Medium strength				17.7
2nd Maximum absolute deviation				2.7
3rd Average strength				18.4

Table 6. Compressive strength test on specimens with the glass waste aggregate.

Specimen	Length of top face (mm)	Top face area A (mm²)	Load F_c (N)	Compressive strength R_c (MPa)
1	75	3 000	98 882	33.0
2	85	3 400	45 864	13.5
3	65	2 600	36 750	14.1
4	95	3 800	53 900	14.2
5	65	2 600	35 182	13.5
6	95	3 800	46 256	12.2
1st Average strength				16.8
1st Maximum absolute deviation				16.2
2nd Medium strength				13.5
2nd Maximum absolute deviation				1.3
3rd Average strength				13.8

Analyzing the Tables 5 and 6, the average compressive strength of the specimens produced with the granite, to the specimens produced with the glass waste can be seen. For high-performance industrial floors, the minimum compressive strength is 30MPa **[13]**. However, the compressive strength most used for the production of concrete floors is 20 MPa **[15]**, a value that is close to the result obtained in the specimens with natural aggregate.

After performing the tests of flexural tensile strength and the compressive strength, it was possible to notice, in the specimens produced with the glass waste, a greater fragmentation and a smaller adhesion between the aggregate and the paste when compared to the reference specimens. The same was observed for A.H. Pereira **[15]**, which identified that the glass waste aggregate, because it has a smooth surface, did not obtain a satisfactory bond with the cement paste, causing slippage rupture of the aggregate and resulting in lower compressive strength.

However, another research found that the addition of glass powders decreased alkali-silica reaction expansions of the modified cementitious materials when mixed with reactive sands and enhanced resistance to chloride permeability and electrical resistivity of cementitious materials **[4]**.

With the results found, practical applications can be attributed to the material. Its use is not restricted to indoor floors in environments, but it can be used to manufacture sinks, countertops and ornaments. However, further analysis is needed to assess durability parameters, as well as to find results that present strength values higher than those obtained.

Conclusions:

- Regarding the visual aspect of the specimens, those produced with the glass waste showed a more intense shine when compared to the reference specimens, enhancing the aesthetics of the piece. However, it presented a higher number of imperfections on the surfaces.
- The results found in the hard body impact strength test were satisfactory. This is because the reference specimens had an average rupture height of 26 cm, while the specimens manufactured with the glass waste aggregate had a higher average rupture height of 30 cm.
- In the flexural tensile strength test, the results were not satisfactory, since the average strength found in the specimens with the glass waste aggregate was 4.3 MPa and the average strength of the reference specimens (8.0 MPa) were less than the minimum allowed for high performance industrial floors (30 MPa).
- The inferior performance of the specimens produced with the glass waste in the tests of flexural tensile strength and in the compressive strength may be related to the lower adhesion between aggregate and paste associated to the greater number of cracks identified on the surface in the visual analysis test.

Finally, it is concluded that the use of recycled glass waste in the production of concrete for application on floors can be an alternative to the final disposal of this material for low traffic, given the importance of these solutions for the environment.

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