ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research

Vol. 13, Issue, 02, pp. 61592-61596, February, 2023

https://doi.org/10.37118/ijdr.26257.02.2023

RESEARCH ARTICLE **OPEN ACCESS**

CHARACTERIZING THE USE OF VITREOUS WASTE AS A SUBSTITUTE FOR FINE AGGREGATE IN NON-STRUCTURAL CONCRETE

Borges, W. M., Holzbach, J. C. and *Krauser, M. O.

Química Ambiental – Universidade Federal do Tocantins

ARTICLE INFO

Article History:

Received 07th January, 2023
Received in revised form
20th January, 2023
Accepted 19th February, 2023
Published online 25th February, 2023

KeyWords:

Concrete; Glass wast; Compression; Capillary absorption.

****Corresponding author: Krauser, M. O.***

ABSTRACT

The pursuit of economic development while ensuring environmental preservation represents a significant challenge. Recycled vitreous waste may provide a sustainable alternative to the large quantities of natural aggregate required by the civil construction industry for concrete production, but has been seldom explored. The objective of this study was therefore to evaluate the mechanical characteristics of non-structural concrete specimens in which different quantities of ground glass were used as fine aggregate in place of sand. Tests were conducted by following the ABNT NBR 9779, ABNT NBR 5739, and ABNT NBR 7222 standards for water absorption by capillarity, axial compression, and diametral compression tests, respectively. The results show that substituting 10% and 20% of sand volume with glass provided the closest performance to an equivalent conventional concrete owing to the different particle gradations in the sand and glass and their effects on porosity. Thus, the lower the substitution level of sand with glass, the better the performance of the concrete.

Citation: ***Borges, W. M., Holzbach, J. C. and Krauser, M. O. 2023.*** "Characterizing the use of vitreous waste as a substitute for fine aggregate in non-structural concrete*", International Journal of Development Research*, 13, (02), 61592-61596.

INTRODUCTION

The issue of solid waste in Brazil has been widely discussed in society, permeating several areas of knowledge including basic sanitation, the environment, and the social and economic implementation of sorting and recycling processes (Ho and Lewis, 2010). The solution to the problem of solid waste disposal may lie in the development of integrated and sustainable models that consider the generation of waste, maximization of its reuse and recycling, treatment processes, and final disposal; that is, the integrated and sustainable management of solid waste (Dias 2003). Several prominent industries have adopted measures to preserve the environment, including the concrete industry, which requires large quantities of natural aggregates such as sand and gravel that must be mined from alluvial deposits. Such extractive practices require the installation of permanent preservation measures for the implementation of boxes, yards, and accesses, causing changes in the profile and balance of rivers and exacerbating pressures from deforestation; introduce slopes and embankments, causing erosion and silting; produce noise during the operation of dredges; increase the turbidity and contamination of water by fuel oil, grease, and other effluents; compact soil owing to heavy machinery traffic in accesses; and contaminate soil and water through improper disposal of solid wastes (Oliveira *et al*., 2012). Owing to its high consumption of natural resources and significant generation of waste, the construction industry is well-suited for the implementation of actions to reduce environmental impacts. As a result, various novel materials and processes that can be more profitable and sustainable for the sector have been investigated (Angulo *et al*., 2001; Mehta and Monteiro, 1994). Among the most popular approaches is the reuse of waste by incorporating it into construction materials. Waste recycling is a suitable option for environmental preservation and the creation of new concrete materials, and is considered to represent an appropriate technique for preserving natural raw materials, saving energy, reducing pollutant emissions, and eliminating landfill costs (Karpinsk *et al*., 2009). Vitreous waste is not typically reused owing to difficulties including the transportation logistics associated with the high volume occupied by this material, which increase the cost of transport to recycling facilities. As a result, the added value of glass recycling is relatively low and the collection of the material is generally unfeasible. Thus, non-biodegradable vitreous waste is often routed to landfills where it permanently occupies a significant volume of space, eventually requiring the construction of more landfills. One solution to these problems may be the development of non-structural concrete that uses vitreous materials instead of sand to increase durability and resistance while decreasing reliance on extracting natural sand. This study accordingly analyzed the use of glass as an alternative to sand by evaluating concrete materials containing different substitution levels of sand with glass in terms of capillary absorption, axial compressive strength, and tensile strength to meet the principles of durability required by regulatory standards.

METHODOLOGY

Mix Designs: The mix designs developed in this study were based on a liter of cement, and all materials were measured in terms of volume according to common practice. The concrete to be evaluated was a non-structural concrete for use in construction stages with no structural function. For this type of concrete, a cement: sand ratio of 1:3 was employed.

Specimens: As shown in Figure 1, the specimens were cast in cylindrical PVC molds 50 mm in diameter and 100 mm in height, as per the ABNT NBR 5738 standard. A plug was used at the base of each cylinder provide a flat bottom surface. To prevent the concrete from sticking to the PVC and potentially rupturing when the specimen was removed, the interior surface of each mold was lined with parchment paper, which does not react with concrete. Butter paper was also used to cover the top surface of the concrete and thereby retain moisture within, keeping free water for longer and improving curing conditions. This is known as blanket curing, which retains water in the capillary voids and prevents evaporation.

Figure 1. Molds used to cast specimens

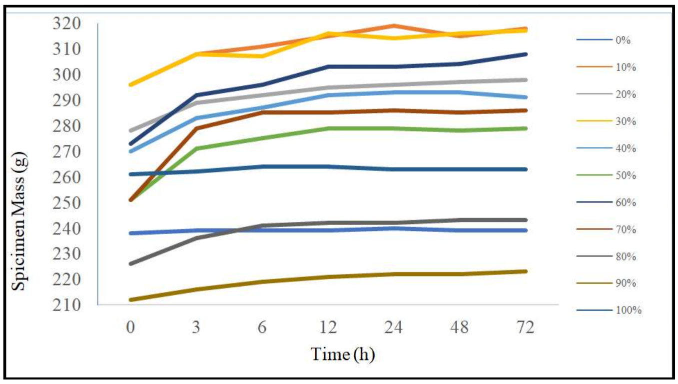

Figure 2. Results of the capillary water absorption test over 72 h

Concrete Preparation: The volumes of sand, cement, and glass were calculated according to the percentage of these materials to be used in each mix, with glass substitution levels varying from 0% to 100% in intervals of 10%. Six specimens were made for each mix, resulting in a total of 66 concrete specimens. Each mixture was manually produced in a 20 L container to realize an extremely homogeneous mixture with good consistency. The mixed concrete was poured into the molds in layers and agitated to reduce entrained air and prevent the development of large pores. Once the specimens were poured to the top of the molds, they were placed on a tray and stored in the laboratory at room temperature. After approximately 7 d, the specimens were removed from the forms, identified, and stored for an additional 21 d to complete the curing process.

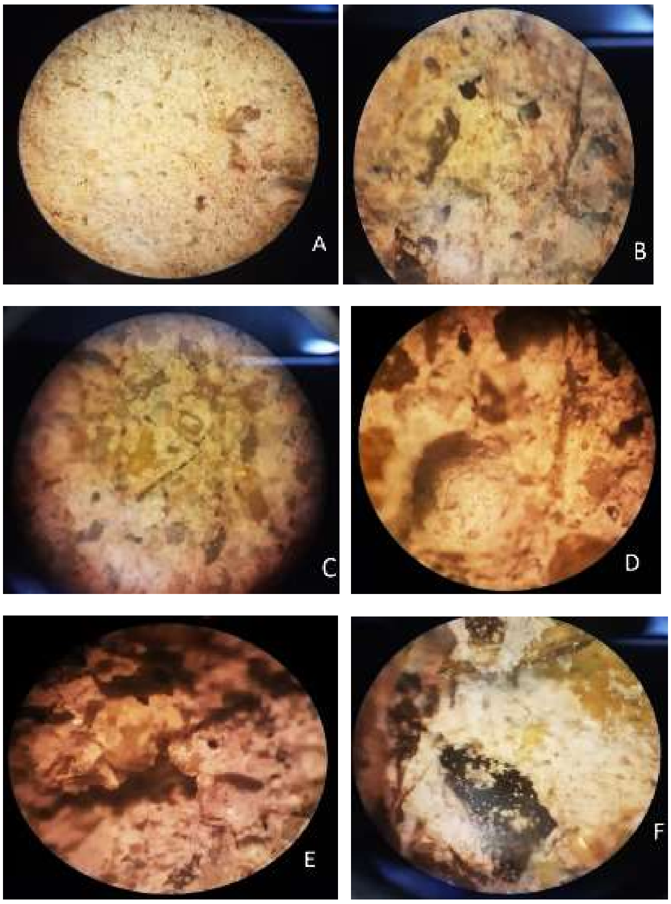

Figure 3. Macropore photographs of specimens with: a) 0%, b) 10%, c) 20%, d) 60%, e) 70%, and f) 100% glass substitution levels. Images acquired using a Micros 10 X stereoscopic magnifying glass

Testing: Three specimens of each mix were tested in each physicochemical analysis, and the arithmetic mean of the results was reported as the value for that mix. The tests to determine the capillary water absorption and strengths of the cured concrete were performed in accordance with the procedures provided by the ABNT NBR 9779 – Absorption of Water by Capillarity (2012), ABNT NBR 7222 – Diametral Compression (2011), and ABNT NBR 5739 – Axial Compression (2007) specifications.

***Capillary water absorption**:* The capillary water absorption tests were performed according to the ABNT NBR 9779 standard using an oven, container, supports, ruler, and scale. All specimens were checked to ensure that they were free of oils or other materials that could have adhered during casting. Each specimen was first weighed after demolding, dried in an oven at a wax temperature of 105 ±5 °C until a constant mass was achieved, then cooled at room temperature and weighed again to obtain its final mass. Soon after, each specimen was marked at a height of 5 cm above its base to ensure a constant water level throughout the test period. After 3 h, 6 h, 24 h, 48 h, and 72 h of water absorption, each specimen was briefly dried with a damp cloth and weighed using an analytical balance. The height of water absorption was also measured. The following equation was subsequently used to determine the capillarity coefficient:

$$C = \frac{(A-B)}{S} \qquad (1)$$

where C is capillarity coefficient in g/cm², A is the mass of the wet specimen in g (after 72 h), B is the mass of the dry specimen in g, and S is the cross sectional area of the specimen in cm²

Table 1. Results of capillary water absorption tests

Glass substitution level	Mass (g)							H (cm)
	0 h	3 h	8 h	12 h	24 h	48 h	72 h	
0%	238	239	239	239	240	239	239	3,0
10%	296	308	311	315	319	315	318	11,0
20%	278	289	292	295	296	297	298	10,5
30%	296	308	307	316	314	316	317	10,8
40%	270	283	287	292	293	293	291	13,8
50%	251	271	275	279	279	278	279	14,0
60%	273	292	296	303	303	304	308	14,0
70%	251	279	285	285	286	285	286	14,5
80%	226	236	241	242	242	243	243	12,0
90%	212	216	219	221	222	222	223	8,5
100%	261	264	264	263	263	263	263	6,0

Table 2. Calculated capillarity coefficients

Glass substitution level	Capillarity coefficient (g/cm²)
0%	0,08
10%	1,75
20%	1,59
30%	1,67
40%	1,67
50%	2,23
60%	2,79
70%	2,79
80%	1,35
90%	0,88
100%	0,16

Table 3. Results of axial compression tests

Glass substitution level	Compressive strength (MPa)				
	C1	C2	C3	Average	Standard deviation
0%	6,1	8,2	10,2	8,15	1,36
10%	5,1	7,1	7,1	6,46	0,91
20%	5,1	7,1	9,2	7,14	1,36
30%	6,1	1,0	1,0	2,72	2,27
40%	2,0	4,1	3,1	3,06	0,68
50%	5,1	8,2	2,0	5,10	2,04
60%	3,1	5,1	4,1	4,08	0,68
70%	3,1	5,1	3,1	3,74	0,91
80%	3,1	3,1	5,1	3,74	0,91
90%	5,1	6,1	5,1	5,44	0,45
100%	5,1	6,1	7,1	6,12	0,68

Strength tests: The compressive and tensile strengths of the cylindrical specimens were determined according to the ABNT NBR 5739 standard for axial compression tests and ABNT NBR 7222 standard for diametral compression tests using a pachymeter and 10-ton hydraulic press from Bovenau (Brazil) with a 120 mm hydraulic ram. The compressive strength (in MPa) of each specimen was calculated from the test results as follows:

$$RCA = \frac{Fa}{\left(\frac{\pi D^2}{4}\right)} \quad (2)$$

where *Fa* is the axial rupture load in N and *D* is the specimen diameter in mm. Similarly, the tensile strength (in MPa) of each specimen was calculated as follows:

$$Ftd = \frac{2*Fr}{\pi*D*H} \quad (3)$$

where *Fr* is the diametral rupture load in N and *H* is the specimen height in mm.

RESULTS AND ANALYSIS

Capillary Water Absorption: The results of the capillary water absorption tests are described in Table 1 and presented in Figure 2. The data obtained from these tests were subsequently inserted into Equation 1 to calculate the capillarity coefficients, as shown in Table 2; a lower capillarity coefficient is considered to reflect a concrete with less exposure to the action of external agents.

The results indicate a general increase in capillarity coefficient with increasing glass substitution level, reaching a maximum value for the 60% and 70% glass substitution specimens early in the tests. However, the capillarity coefficients for the 90% and 100% glass substitution specimens were considerably lower than those for all other specimens except the reference specimen (0% glass substitution), indicating the best results. Although capillary water absorption is not considered a concrete quality parameter, according to Neville (1997), the best concretes exhibit a total absorption rate smaller than 10% of the specimen mass. Considering that most of the concrete specimens evaluated in this study met this criteria except those with 50%, 60%, and 70% glass substitution levels, a target water absorption rate of less than 5% was set as per Kosmatka *et al.* (2002). The 90% and 100% glass substitution specimens were both within this range. The sudden reduction in the capillarity coefficient for glass substitution levels above 80% can be explained by the increasing homogeneity of the particle diameters and shapes in the concrete system, which served to fill more of the existing voids in the concrete. The resulting denser microstructure therefore had smaller pores, reducing the diameter and extent of capillaries. Indeed, a reduction in porosity has been found to lead to a lower total capillary absorption, while a smaller pore size has been found to lead to a decrease in the absorption rate (a lower capillarity coefficient) (Magalhaes *et al.*, 2004). Figure 3 shows that the 0%, 10%, 20%, and 100% glass substitution specimens exhibited greater compactness with fewer and smaller pores than the 60% and 70% specimens. In the specimens substituting glass for sand, a high rate of absorption was observed in the first 6 h of contact with water; after 24 h, the quantity of water absorbed had stabilized. This behavior appears to be related to the small diameters of the capillary pores in the concrete, which provide faster capillary absorption owing to increased pressure (Cascudo, 1997). However, according to Ho and Lewis (1987), rapid capillary water absorption is also related to the number of capillaries, their size, and the distance between them. Therefore, when a material has a large volume of capillaries separated by a short distance and a large number of pores, a greater quantity of water will be absorbed at higher speed.

Axial Compression: The axial compressive strength results are presented in Table 3 and illustrated in Figure 4, indicating that the reference specimen exhibited the highest strength, followed by the 10%, 20%, and 100% glass substitution specimens. The 30% and 90% glass substitution specimens exhibited the highest and lowest standard deviations of their test results, respectively. Thus, specimens with more homogeneous characteristics and lower levels of glass substitution exhibited better strength and consistency. According to Polley *et al*. (1998), an increasing mass of ground glass in concrete reduces compressive strength owing to the difference between the paste-to-aggregate bond strengths. The bonds between the paste and glass particles are weaker than those between the paste and natural aggregate particles owing to the higher moisture absorption of natural aggregates compared to the more inert nature of glass. Therefore, the higher the glass substitution mass in the concrete, the weaker the bonds between the aggregate and paste.

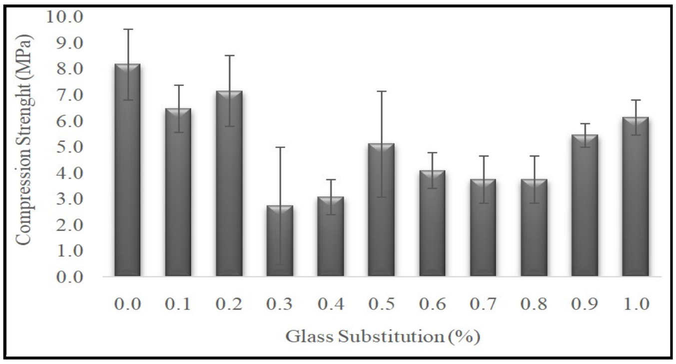

Figure 4. Compressive strength results

Diametral Compression: The diametral compressive strength results presented in Table 4 and illustrated Figure 5 indicate that the 10% and 20% glass substitution specimens exhibited the highest tensile strength, exceeding that of the reference specimen by 7.1%. However, the test results for the 10% glass substitution specimen exhibited a comparatively high standard deviation. The highest standard deviation was observed for the 30% glass substitution specimen, and the lowest standard deviations were observed for the 40%, 50%, and 70% specimens. These results demonstrate that specimens with more homogeneous characteristics and lower glass contents generally exhibited better strength and consistency. Indeed, the 20% glass substitution specimen provided the best tensile strength and consistency.

Table 4. Results of diametral compression tests

Glass substitution level	Tensile strength (MPa)				
	M1	M2	M3	Average	Standard deviation
0%	3,06	6,12	5,10	4,76	1,13
10%	3,06	6,12	6,12	5,10	1,36
20%	4,08	6,12	5,10	5,10	0,68
30%	1,02	1,02	6,12	2,72	2,27
40%	1,02	1,02	1,02	1,02	0,00
50%	1,02	1,02	1,02	1,02	0,00
60%	2,04	1,02	3,06	2,04	0,68
70%	1,02	1,02	1,02	1,02	0,00
80%	1,02	2,04	2,04	1,70	0,45
90%	2,04	3,06	1,02	2,04	0,68
100%	3,06	5,10	5,10	4,42	0,91

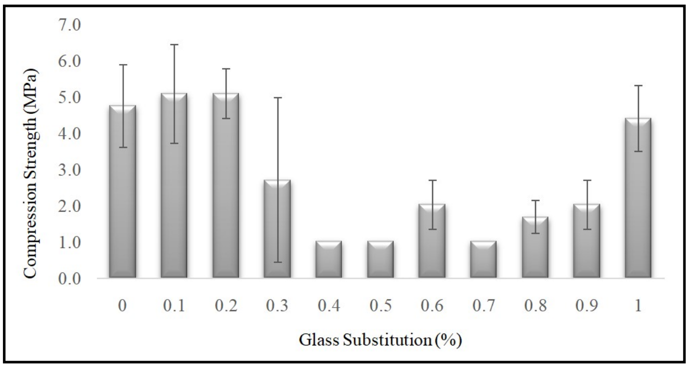

Figure 5. Tensile strength results

Correlation between Axial Compressive Strength and Capillary Water Absorption: To undertake a more in-depth analysis of the obtained results, the correlation between the results of the absorption and compressive strength tests was evaluated with the results shown in Figure 6, which indicates that an increase in absorption was generally correlated to a reduction in strength. This is related to the increase in porosity, as explained by Sun and Chen (2002), who found that the use of ground glass to replace more than 5% of sand by mass reduced the strength of concrete owing to the hydrophobic characteristics of glass, which acted to decrease hydration and thereby increased the number of voids, in turn increasing the capillary water absorption.

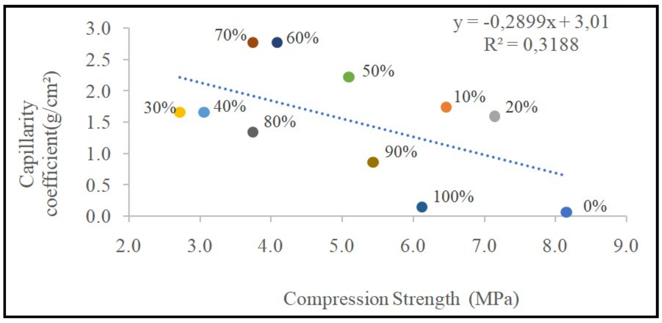

Figure 6. Correlation between the capillarity coefficient and compressive strength

CONCLUSIONS

This study substituted different quantities of fine aggregate (sand) with ground glass to evaluate the physical and mechanical properties of the resulting concrete. The ABNT standards for capillary water absorption, axial compressive testing, and diametral compressive testing were employed to obtain clearer and more objective results than reported in previous studies. These results indicate that:

- The test specimens exhibited an increase in capillarity coefficient with increasing glass substitution levels up to 70%, above which absorption decreased with higher glass substitution levels. Notably, most of the test specimens exhibited water absorption rates of less than 10% by mass, indicating suitable quality.
- The axial compressive test results indicated higher strengths for specimens with glass substitution levels up to 20% than for the reference specimen. However, the strength decreased with the ongoing increase in the glass substitution level. The diametral compression tests similarly indicated a higher tensile strength for concrete specimens with glass substitution levels of 10% and 20% than for the reference specimen. This initial improvement in performance can be attributed to the filling effect of the heterogenous materials with different particle sizes, which acts to reduce the porosity of the concrete specimen and increase its strength.

Overall, the results show that the substitution of up to 20% of fine aggregates with glass is a viable option for improving the quality of non-structural concrete while reducing waste. Future studies should evaluate the effects of different particle gradations in this replacement range on the characteristics of the concrete as well as the effects of various additives, especially with regard to water absorption.

ACKNOWLEDGMENT

The authors acknowledge support from Universidade Federal do Tocantins.

REFERENCES

ÂNGULO, S.C.; ZORDAN, S.E.; JOHN, V.M Desenvolvimento sustentável e a reciclagem de resíduos na construção civil. São Paulo, Departamento Engenharia de Construção civil da Escola Politécnica, Universidade de São Paulo, p 1-13, 2001.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 5739:2007 Concrete -Cylindrical specimens compression test - Test method. Rio de Janeiro, 2007.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 7222: Concrete and mortar - Determination of tensile strength by diametrical compression of cylindrical specimens - Test method. Rio de Janeiro, 2011.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 9779: Hardened mortar and concrete - Determination of water absorption by capillarity -Test method. Rio de Janeiro, (2012).

CASCUDO, O. O controle da corrosão de armaduras em concreto: inspeção e técnicas eletroquímicas. p. 237. São Paulo: Pini, 1997.

HO, D. W. S.; LEWIS, R. K. Carbonation of concrete and its prediction. Cement and Concrete Research. v. 17, p. 489-504, 1987.Instituto Brasileiro de Geografia e Estatística

(IBGE). Pesquisa Nacional de Saneamento Básico, PNSB -2008. Rio de Janeiro: IBGE;2010.

KARPINSK L. A., PANDOLFO A., REINEHR R., KUREK JU., L. PANDOLFO, GUIMARÃES J., Gestão diferenciada de residuos da construção civil uma abordagem ambiental EDIPUCRS, Porto Alegre (2009) 163p.

KOSMATKA, S. H.; KERKHOFF, B.; PANARESE, W. C. Design and Control of Concrete Mixtures. Ed: PCA Portland Cement Association. English, p.358 2002

MAGALHÃES A.C., MORAGUES A., VEIGA M.R. Application of some methods on evaluation of porous systems of wall renderings. VII Congress international de rehabilitation del patrimony y edification, Lanzarote, Spain, 2004.

MEHTA, Kumar P., MONTEIRO, PAULO J.M., Concreto: Estrutura, Propriedades e Materiais. Editora Pini Ltda, 1st Edition. São Paulo, 1994.

NEVILLE, A. M. Properties of Concrete. Translation of: GIAMMUSSO, S. E. 2. ed. rev. e atual. São Paulo: Pini, 1997.

OLIVEIRA, M. S. SILVEIRA J. S. MORATO J.B. AVELLAR, G. Impactos ambientais decorrentes da extração de areia, cachoeira da prata - MG. 9TH SINAGEO –

POLLEY, C. CRAMER, S. M. LA CRUZ, R. V. DE J. Mater. In Civil Eng. ASCE 10, 4 (1998) 587

SUN, N. CHEN, J. S.: Resources, Conservation and Recycling 35 (2002) 259.

****