Physical and Mechanical Properties of Concrete Made with Glass Sand

Filipe Figueiredo, Rayssa Renovato Reis, and Lino Maia

Abstract It is important promoting less generation of urban waste not only for the economy of raw materials, but also for the lesser deposition of waste in landfills. Glass is among the most frequently used materials in packaging and is the easiest to be recycled. Being aware that the construction industry is one of the largest consumers of natural resources in the world, the present study deals with the possibility of replacing part of the fine aggregate of concrete by glass sand. Concrete was produced with the conventional aggregates and then the fine aggregate was partially replaced by glass sand for the percentages of 10, 15 and 20%. The experimental study sought to evaluate the physical and mechanical properties. The slump, compressive strength, tensile strength and water absorption by capillarity and void index testing were measured. Results showed that when replacing the fine aggregate by 10, 15 and 20% of glass sand the results are satisfactory, especially for the substitution of 20% of glass sand which presented an increase of 18% in the compressive strength.

Keywords Glass sand · Fine aggregate · Concrete

F. Figueiredo · L. Maia (✉)
CONSTRUCT-LABEST, Faculty of Engineering (FEUP), University of Porto,
Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
e-mail: linomaia@fe.up.pt

F. Figueiredo · R. R. Reis
UFGD, Federal University of Grande Dourados, Rua João Rosa Góes, nº 1761,
Vila Progresso, Dourados, MS 79825-070, Brazil

L. Maia
Faculty of Exact Sciences and Engineering, University of Madeira, Campus da Penteada,
9020-105 Funchal, Portugal

D. K. Ashish and J. de Brito (eds.), *Environmental Restoration*, Lecture Notes
in Civil Engineering 232, https://doi.org/10.1007/978-3-030-96202-9_2

1 Introduction

The concern with the reuse of waste generated in urban centers, in order to reduce the consumption of raw materials, is an alternative for society, both for the preservation of natural resources and to avoid the deposition of waste in the environment.

As it is known that the adversities linked to solid waste are still recurrent in society, it is necessary not only to find solutions for the correct disposal of these materials, but also to create procedures capable of systematically reinserting them in production. The circular economy emerges at a time when the value of resources, materials and products is preserved as long as possible in the economy, and waste generation serves as a tactic to develop low-carbon resource efficiency and competitive sustainability [1].

Solid waste management and municipal solid waste management are the basis for the circular economy to achieve greater waste recovery and better resource management, extending and closing material cycles creating stockpiles of economic flows [2–4].

The civil construction sector is one of the main pillars of the economy, generating solid waste and consuming natural resources [5]. The concrete industry uses more than 4.2 billion tons of cement per year (in 2016, its worldwide consumption is 4.13 billion tons [6]). Concrete is one of the most used construction materials, with a consumption annual total of approximately 25 billion tons, which equates to more than 3.8 tons per person per year [7]. In this context, some alternatives, including the use of waste as an aggregate in the manufacture of mortar and concrete exist to minimize the consequences of the impact of this sector.

The largest industry with the capacity to be a sustainable alternative for the disposal of various residues is the production of concrete [8]. The replacement of aggregate by some residues can be used to improve the physical and mechanical properties of concrete, as demonstrated by other research the use of some materials, such as pozzolanic substances (materials of volcanic origin, fly ash, among others).

For a material to be considered as an aggregate, the general requirements are that the grains must be hard, compact, stable, durable and clean, and must not contain substances of a nature and in amounts that alter the hydration and hardening of the cement, the protection of the reinforcement against corrosion, the durability and the external visual appearance of the concrete [9].

Glass has several applications, such as being a super-cooled transparent metal oxide of high hardness, essentially inert and biologically inactive, with low porosity, absorptivity, expansion and conductivity thermal and capable of withstanding pressures from 5800 to 10,800 kg/cm^2 [10].

According to CEMPRE—Consortium Business for Recycling (2011), Brazil manufactures around 980 000 tons of glass packaging per year, and only about 47% of the packaging was recycled in 2011. Brazil can further expand the recycling of glass as what happens in other countries, for example, Switzerland with 95%, and Germany with 87%. Glass recycling is extremely useful all over the world, but it is far to be fully recycled in Brazil [11]. At present most of unrecycled glass it becomes glass that ends up in landfills. That must change. Its reuse enables the conservation of materials, reducing energy consumption and the volume of waste sent to landfills [12].

Despite of being a subject studied for decades, the disposal and reuse of glass waste is still a current issue [13–15]. Research on the use of glass waste in concrete to partially replace sand is always relevant to reinforce the incentive of its use and provide improved results from new methodologies with different natural states of waste in different world regions. It is expected that studies such as this one justifies the investment and contribute to increase recycling and use of glass waste in countries like Brazil, especially in regions where glass waste is a problem, with no recycling, with no perspective for the circular economy.

In order to contribute to solve the problem of the large amount of sand extracted and the improper disposal of glass waste, this work explores the feasibility of partially replacing fine aggregate by glass sand in concrete. In this exploratory study 10, 15 and 20% of the fine aggregate was replaced by glass sand in concrete compositions tested. Here, this document regards to the part of the study wherein the physical and mechanical properties of concrete are investigated. The workability in assessed through the slump test, the compressive and tensile strength are measured to discuss the effect of the glass sand on the mechanical properties and the water absorption was determined to compare the effect on the physical properties. Issues regarding to the pozzolanic activity or related to the alkali-silica reactions are not addressed in the present document.

2 Environmental Problem and the Glass Waste

2.1 Environmental Impact

The most used mineral inputs in the world is the construction of aggregates [16]. Concrete production consumes large amounts of natural aggregates, about half of world production [17]. Therefore, eliminating or reducing the consumption of concrete aggregates can produce eco-friendly building materials. Figure 1 shows the graph of the evolution and projection of aggregate consumption in Brazil in the period 1997 to 2022, which was a survey carried out by Anepac (National Association of Aggregate Products for Construction Companies).

Mineral exploration will never be a sustainable activity, as the extracted material will never be replaced. The environmental impacts are not only due to the extracted material, but are also directly associated in the exploration phases, such as the opening of the pit, (removal of vegetation, excavations, earth movement and modification of the local landscape), to the use of explosives in the blasting from rock (under atmospheric pressure, ground vibration, ultra-release of fragments, fumes, gases, dust, noise), to the transport and processing of ore (generation of dust

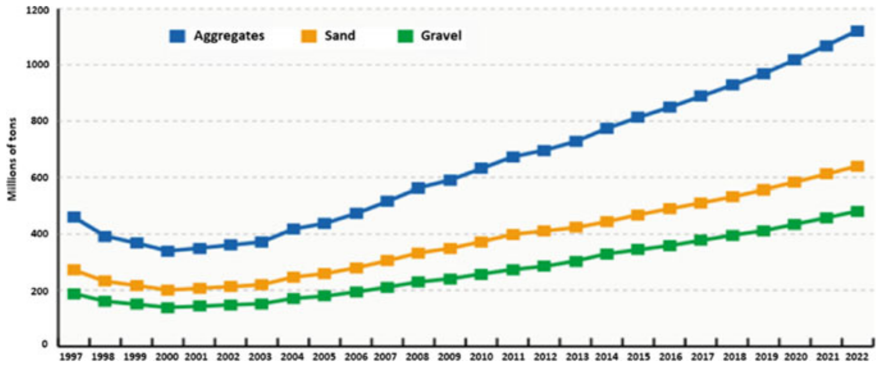

Fig. 1 Consumption of aggregates in Brazil

and noise), affecting the media such as water, soil and air, in addition of the local population.

CONAMA Resolution No. 01 [18], of January 23, 1986, in its article 1, considers that environmental impact is any change in the physical, chemical and biological properties of the environment, caused by any form of matter or energy resulting from human activities that directly or indirectly affect: (i) The living conditions of the population; (ii) The economy; (iii) Social relationships; (iv) Any set of living beings; (v) The characteristics of environmental resources; (vi) Environmental property aesthetically or sanitary. Some of the environmental impacts arising from the mining of aggregates for civil construction, especially sand, are listed in Ref. [19], such as: (i) Silting, which is caused by the high content of suspended sediment; (ii) Removal of vegetation cover; (iii) Change in relief; (iv) Change of watercourse; (v) Emergence of holes; (vi) Sedimentation of materials in water courses; (vii) Destruction of permanent preservation areas; (viii) Biota destruction; (ix) Erosion; (x) Gullies; (xi) Changing hydrogeology.

2.2 *Glass Waste*

Glass waste has several applications, one of which is its insertion in civil construction as an aggregate, which is feasible due to the characteristics shown in Tables 1 and 2. According to CONAMA Resolution No. 431 [20], glass is classified as Class B of solid waste, in the document it is reported that all material in this class is considered recyclable for other destinations. All Class B waste must be reused, recycled or sent to temporary storage areas, being arranged in such a way as to allow for its future use or recycling. However, the glass, in Brazil, ends up being, most of the time, destined to sanitary landfills or simply discarded in sanitary landfills. Therefore, the best alternative for the final disposal of the glass would be recycling. Recycling involves manufacturing the product from a used material, that

Table 1 Main physical properties of glass

Physical properties
Excellent resistance to water and salty liquids as well as organic substances, alkalis and acids, with the exception of hydrofluoric and phosphoric acid
High durability
Low electrical conductivity
Very low thermal expansion

Source Adapted from Ref. [21]

Table 2 Glass's biggest attractions

Attractions
Transparent
Inert
Practical and versatile
Reusable
Waterproof
Returnable

Source Adapted from Ref. [21]

is, transforming the materials. In this context, it would be possible to fully reuse glass packaging with enormous ecological, economic and social benefits, for example, providing less waste disposal, increasing the life of landfills, which would help preserve the environment and increase economic viability through reducing the costs of urban collection, promoting the generation of jobs with the installation of a collection process that does not require specialization.

2.3 *Pozzolanic Reactions*

Pozzolanic materials are siliceous or silicoaluminous compounds that have little or no binding activity when isolated, however, when they are transformed into fine particles and added with water, they react with calcium hydroxide at room temperature forming substances with binding properties [22]. Glass can contain a large amount of silicon and calcium, making the material, in theory, pozzolanic [23].

According to the research carried out by [24], the results of the performance index with Portland cement indicate pozzolanic activity for the glass fractions #200 and #325 in the criteria of the American standard. Although the strength gain was slower in concrete with glass powder, as mixtures containing glass powder have a satisfactory performance in relation to drying shrinkage and alkaline reactivity, and there were indications that glass powder reduces the penetrability of the chloride ion of concrete, as well as the risk of chloride-induced corrosion of steel reinforcement in concrete [25].

The insertion of glass powder in cementitious composites presents positive results in several aspects [12, 25–27]. Research shows that the incorporation of glass powder is satisfactory in concrete at dosage rates of up to 30% to replace cement without adverse effects [25, 27]. The greatest strength improvement reported is 17% for a 30% cement replacement [27].

2.4 Alkali-Silica Reactions

The use of recycled glass dust residues in civil construction as a substitute for cement or even natural aggregates will bring double benefits, with environmental and economic advantages. The use of glass dust provides a value-added use of reinforced glass residues in concrete and reductions connected in the production of greenhouse gases by the cement industry and natural aggregate extraction [25, 27].

However, there is a durability problem with concrete with glass aggregates, that is, an Alkaline Silica Reaction (ASR), as the glass contains a large amount of alkalis [28]. It is well known that the ASR of glass particles depends on particle size. An incorporation of glass slag as a fine powder can benefit the concrete in terms of improved strength and reduced porosity [28, 29]. The ASR fine/coarse glass particles can be reduced by adding particles or mixed minerals. For example, metakaolin, fly ash and lithium compounds have been used to control the expansion of ASR in glass concrete or to be pretreated with three different solutions: $Ca(OH)_2$, NaOH and a mixture of $Ca(OH)_2$ and NaOH [28–31].

Studies have shown that the use of glass powder is a viable alternative to ultrafine silica sand, as its addition favors the durability of the mixture [28–31]. As the glass powder increases the porosity, absorption percentage, absorption depth, sensitivity and chloride penetration of the mixture decrease. This enhancement effect is attributed to the physical properties of the glass. In this regard, although there are concerns about the use of glass in cementitious materials, confirmed that the use of glass with a smaller particle size will not cause harmful ASR.

3 Experimental Program

3.1 Aggregates

The materials were chosen taking into account NBR 15,900-1/09 and NBR 6118/14. The materials used in this work are: Portland cement CP II Z 32; Standard sand with 5% humidity; Crushed gravel; Tap water; Glass sand.

The specific gravity tests were carried out in accordance with the provisions of NBR NM 27/01 and NBR NM 52/09. The glass sand was donated by Eco Vidros, which was ground to a granulometry ranging between 0.15–1.18 mm, specified

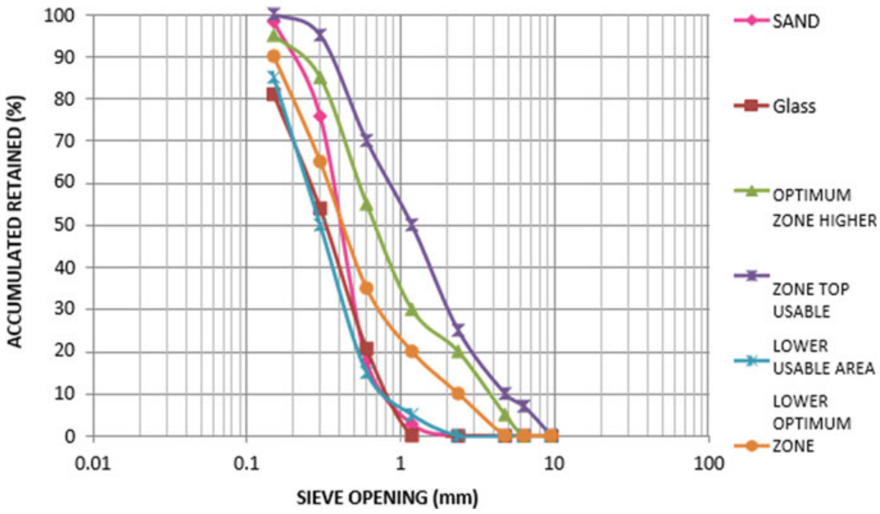

Fig. 2 Granulometric curve of fine aggregates (NBR 7211/09)

following the guidelines of NBR 7217/87, NBR NM-ISO 2395/97 and NBR 7211/09. The granulometric tests were carried out according to NBR NM 248/03, NBR 7211/09. The particle size analysis, which were performed on the fine aggregates used in the composition of the concrete mixtures, are shown in Fig. 2. As shown in the granulometric analysis, most sand and glass sand are within the range stipulated by NBR 7211/09. However, there are small percentages outside the use zone, which can generate problems in the microstructure of the concrete studied, such as greater porosity, lower resistance and high-water absorption, among others.

3.2 Concrete

The mix with 355 kg of cement, 1030 kg of gravel, 745 kg of sand and 195 kg of water was chosen to produce a 25 MPa concrete (reference mix). The tests were carried out on specimens with proportions of 10, 15 and 20% of replacement of the fine aggregate by glass sand. To enable the comparison between the traits evaluated, constant factors were adopted, such us: origin of materials; milling procedure and waste granulometry; preparation, molding of specimens; three-day immersion cure of specimens; ages of 7, 21 and 28 days to break the specimens in the compressive strength test; 10 × 20 cm cylindrical specimens; C25 concrete grade. These parameters were stipulated with the help of NBR 7215/96, NBR 6118/14 NBR 12,655/15 and NBR 5738/15. The specimens were classified according to the change of the mix in relation to the percentage of glass sand existing in its

Table 3 Concrete compositions

Mix	Glass sand (%)	Cement (kg)	Gravel (kg)	Sand (kg)	Water (l)	Glass sand (kg)
G0	0	10.1	29.98	21.10	5.3	–
G10	10	10.1	20.98	18.99	5.3	2.11
G15	15	10.1	20.98	17.93	5.3	3.17
G20	20	10.1	20.98	16.88	5.3	4.22

composition, whose nomenclatures were G0, G10, G15, G20, respectively, the reference mix and the partial replacements of the sand by glass sand in 10, 15 and 20%.

3.3 Mix Compositions

During the molding of the cylindrical specimens in accordance with standard NBR 5738/03, the slump test was carried out following the guidelines of NBR NM 67/98. To determine the void index of the samples, it was necessary to discover the specific mass of the dry and saturated specimens, this test was carried out following NBR 9778/05. To identify the absorption of water by capillary action, the test was carried out according to NBR 9779/12.

For the test of compressive strength of the specimen, the guidelines of NBR 7215/96 and NBR 5739/18 were used. The tensile strength test was carried out with the consent of NBR 7222/11, which was carried out through the diametral compression of the cylindrical specimens. Table 3 shows the mix compositions.

4 Results and Discussion

4.1 Slump and Compressive Strength

The slump test revealed that the concrete composed of vitreous sand presents a decrease in its workability. The slump test results were 90, 65, 45 and 35 mm for the G0, G10, G15 and G20 mixtures, respectively. The trend is likely due to the roughness of the glass sand surface compared to conventional sand. The reference concrete (G0) showed 90 mm slump, which was in the range of targeted slump of 80–100 mm. However, the workability decreased significantly with an increase in the quantity of glass sand. Although for [32] the angular nature of the glass waste can provide a better bond with the cement paste in concrete, this decreasing trend agreed with the study by Adaway and Wang [33].

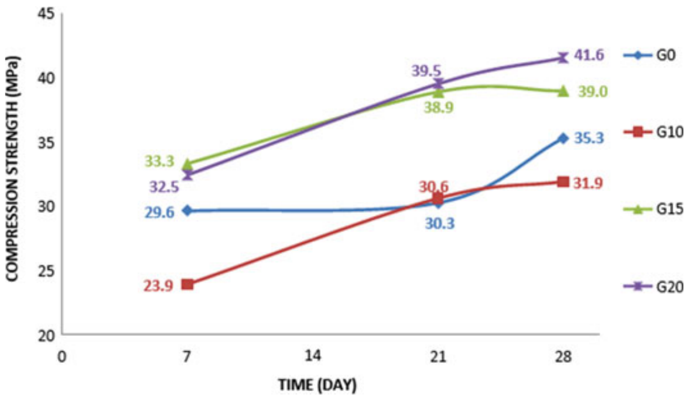

Fig. 3 Compressive strength evolution

The G10 e G15 exhibited 28 and 50% slump values of reference concrete, respectively. The G20 showed even lesser slump compared to any other mixtures, only 39% slump value of reference concrete. Similar decrease pattern was observed by Tan and Du [34] and Tamanna et al. [13] on the flowability of mortar.

Regarding to the compressive strength, Fig. 3 presents the results obtained. In Fig. 3, it is observed that the highest strength was from G20 (20% of glass sand), which had an improvement of 17.85% in relation to the G0 (reference mix). For the mix G15 the compressive strength improvement was of 7.65% when compared to G0.

These results are in agreement with the compressive strength results of Adaway and Wang [33] that for 15 and 20% replacements obtained results superior to the control concrete. Tan and Du also obtained results superior to the control concrete for 25% replacement [34].

The increase of the concrete strength in mixes wherein the fine aggregate was replaced is probably due to the angular shape of the glass waste, which affects the connection between the glass sand and the cement matrix [13, 33].

Concerning to the tensile strength by diametrical compression (NBR 7222/11), the tensile strength obtained were 2.5, 2.8, 3.1 and 3.2 MPa for the mixes G0, G10, G15 and G20, respectively. The results found are according to the ones of Ref. [35]—the higher replacement of sand by glass sand, the higher tensile strength. The higher mix being the G20 (20% of replacement) obtained an increase in its tensile strength by 27.77% compared to the reference mix.

4.2 Water Absorption

Table 4 presents the relation of the water absorption by capillarity as a function of time. Roughly speaking, results show that the higher glass sand replacement, the lower absorption by capillarity. Bearing in mind that specimens that reaches higher

Table 4 Relation water absorption by capillarity (g/cm^2) as a function of time (NBR 9779/12)

Mix	Cross height (cm)	Time (h)				
		3	6	24	48	72
G0 (ref.)	5.5	0.0001401	0.0002419	0.0005220	0.0007385	0.0008531
G10 (10%)	6	0.0001655	0.0002547	0.0005475	0.0007512	0.0008658
G15 (15%)	5	0.0001146	0.0001910	0.0004456	0.0005730	0.0006621
G20 (20%)	4	0.0001019	0.0001783	0.0003820	0.0005093	0.0006112

Table 5 Relation of water absorption by immersion, void index and specific masses of specimens (NBR 9778/05)

Mix	Water absorption by immersion (%)	Empty index (%)	Specific gravity dry (g/cm^3)	Specific saturated gravity (g/cm^3)	Specific gravity real (g/cm^3)
G0 (Ref.)	10.00	14.29	1.429	1.571	1.667
G10 (10%)	10.14	14.89	1.468	1.617	1.725
G15 (15%)	8.45	12.50	1.479	1.604	1.690
G20 (20%)	8.22	12.24	1.490	1.612	1.698

compressive strength are assumed as those that have lower open porosity, the obtained results were the expected ones. Table 5 shows the results obtained in the void indices test, in this test it is possible to determine the void indices, the specific masses and the water absorption by immersion of the specimens.

By analyzing the Table 5, water absorption by immersion promoted the same conclusion as the capillary absorption test, which reported that the highest percentages of absorption were in traces of lower strength. It was observed, also, that the lowest percentages of absorption of water by immersion are those that have lower void rates.

These results diverge from the observations of Turgut and Yahlizade [36] and Limbachiya [37] that the water absorption of glass concrete increases with increasing percentage of glass waste. Penacho et al. [38], also reported similar behavior of increased water absorption used in mortar mix.

5 Conclusions

From the results observed it is concluded that the mix that had the highest water absorption, was the one with the worst performance in its tensile and compressive strength.

Through a special analysis of the results of the tests carried out with the G10 mixture (10%), it can be seen that at 28 days, its compressive strength was lower than that of the reference, however it exceeded the expected 25 MPa. One of the factors that may have influenced this result was its microstructural composition, as the void index test concluded that it was the structure that presented the most porosity.

With the concrete slump test, it was observed that the workability of concrete decreases as the replacement of fine aggregate by glass sand increases. Therefore, for replacements greater than 20%, there would be a need to add water, which would promote a change in the water/cement ratio.

Despite the experimental variants, glass with a partial substitute for sand in concrete promoted satisfactory results, as it managed to achieve all the objectives of this work. With the analysis of all tests, it can be seen that the best results obtained in ascending order, in relation to the reference mix, were G10 (10%), G15 (15%) and G20 (20%).

Acknowledgements The authors are grateful to the Federal University of Grande Dourados (UFGD). This work is financially supported by: Base Funding—UIDB/04708/2020 of the CONSTRUCT—Instituto de I&D em Estruturas e Construções—funded by national funds through the FCT/MCTES (PIDDAC). This work is funded by national funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., under the Scientific Employment Stimulus—Institutional Call—CEECINST/00049/2018.

References

1. Pires A, Martinho G (2019) Waste hierarchy index for circular economy in waste management. Waste Manag 95:298–305. https://doi.org/10.1016/j.wasman.2019.06.014
2. Kalmykova Y, Sadagopan M, Rosado L (2018) Circular economy - from review of theories and practices to development of implementation tools. Resour Conserv Recycl 135:190–201. https://doi.org/10.1016/j.resconrec.2017.10.034
3. Zeller V, Towa E, Degrez M, Achten WMJ (2019) Urban waste flows and their potential for a circular economy model at city-region level. Waste Manag 83:83–94. https://doi.org/10.1016/j.wasman.2018.10.034
4. Tsai FM, Bui TD, Tseng ML, Lim MK, Hu J (2020) Municipal solid waste management in a circular economy: a data-driven bibliometric analysis. J Clean Prod 275:124132. https://doi.org/10.1016/j.jclepro.2020.124132
5. Sauer AS (2013) Estudo do potencial de aplicação do resíduo de vidro laminado em argamassas de recuperação estrutural
6. Khozin V, Khokhryakov O, Nizamov R (2020) A «carbon footprint» of low water demand cements and cement-based concrete. IOP Conf Ser Mater Sci Eng 890(1). https://doi.org/10.1088/1757-899X/890/1/012105
7. Petek Gursel A, Masanet E, Horvath A, Stadel A (2014) Life-cycle inventory analysis of concrete production: a critical review. Cem Concr Compos 51:38–48. https://doi.org/10.1016/j.cemconcomp.2014.03.005
8. Ganesh Babu K, Surya Prakash PV (1995) Efficiency of silica fume in concrete. Cem Concr Res 25(6):1273–1283. https://doi.org/10.1016/0008-8846(95)00120-2
9. NBR 7211.pdf - PDFCOFFEE.COM.pdf
10. Akerman M (2000) Natureza, Estrutura e Propriedades do Vidro, pp 1–37
11. Rodrigues LC, Marin SR, Alvarenga SM (2017) RECICLAGEM DE RESÍDUOS SÓLIDOS URBANOS EM FLORIANÓPOLIS/SC: um estudo de caso. Rev Gestão Sustentabilidade Ambient 6(1):470. https://doi.org/10.19177/rgsa.v6e12017470-486

12. Glass wastes as coarse aggregate in concrete. J Environ Nanotechnol 3(1):67–71 (2014). https://doi.org/10.13074/jent.2013.12.132059.
13. Tamanna N, Tuladhar R, Sivakugan N (2020) Performance of recycled waste glass sand as partial replacement of sand in concrete. Constr Build Mater 239:117804. https://doi.org/10.1016/j.conbuildmat.2019.117804
14. Arivalagan S, Sethuraman VS (2020) Experimental study on the mechanical properties of concrete by partial replacement of glass powder as fine aggregate: an environmental friendly approach. Mater Today Proc 45:6035–6041. https://doi.org/10.1016/j.matpr.2020.09.722
15. Steyn ZC, Babafemi AJ, Fataar H, Combrinck R (2021) Concrete containing waste recycled glass, plastic and rubber as sand replacement. Constr Build Mater 269:121242. https://doi.org/10.1016/j.conbuildmat.2020.121242
16. Valverde FM (2001) Agregados para construção civil. Balanço Mineral Brasileiro, pp 1–15
17. Hilal N, Mohammed Ali TK, Tayeh BA (2020) Properties of environmental concrete that contains crushed walnut shell as partial replacement for aggregates. Arab J Geosci 13(16). https://doi.org/10.1007/s12517-020-05733-9
18. Nacional C, Meio DO, Ambiental I, Ambiente M (2018) 03/09/2018 Resoluções, no D, pp 2–5
19. Dan Gavriletea M (2017) Environmental impacts of sand exploitation. Analysis of sand market. Sustain 9(7). https://doi.org/10.3390/su9071118
20. BRASIL (2011) Resolução n^{o} 431 de 24 de maio de 2011. Ministério do Meio Ambient, p 1
21. Pinto-Coelho RM (2009) Produção, consumo e reciclagem de vidro no Brasil. Reciclagem e Desenvolv sustentável no Bras 169–189
22. Ju N (1992) N B R 1 265 Mater Ma teria iais is pozol po zolân ânico icos s NBR 12653 Materiais ozolânicos
23. Strength C (2001) C Hemical R Eactions of G Lass C Ullet. J Mater 412–417
24. Borges AL, Soares SM, Freitas TOG, de Oliveira Júnior A, Ferreira EB, da Ferreira FGS (2021) Evaluation of the pozzolanic activity of glass powder in three maximum grain sizes. Mater Res 24(4). https://doi.org/10.1590/1980-5373-mr-2020-0496.
25. Shayan A, Xu A (2006) Performance of glass powder as a pozzolanic material in concrete: a field trial on concrete slabs. Cem Concr Res 36(3):457–468. https://doi.org/10.1016/J.CEMCONRES.2005.12.012
26. Tavakoli D, Hashempour M, Heidari A (2018) Use of waste materials in concrete: a review. Pertanika J Sci Technol 26(2):499–522
27. Kalakada Z, Doh JH, Zi G (2020) Utilisation of coarse glass powder as pozzolanic cement—A mix design investigation. Constr Build Mater 240:117916. https://doi.org/10.1016/J.CONBUILDMAT.2019.117916
28. Adesina A, Das S (2020) Durability evaluation of green-engineered cementitious composite incorporating glass as aggregate. J Mater Civ Eng 32(12):04020354. https://doi.org/10.1061/(asce)mt.1943-5533.0003444
29. Yang S, Ling TC, Cui H, Poon CS (2019) Influence of particle size of glass aggregates on the high temperature properties of dry-mix concrete blocks. Constr Build Mater 209:522–531. https://doi.org/10.1016/j.conbuildmat.2019.03.131
30. Sun L, Zhu X, Kim M, Zi G (2021) Alkali-silica reaction and strength of concrete with pretreated glass particles as fine aggregates. Constr Build Mater 271:121809. https://doi.org/10.1016/J.CONBUILDMAT.2020.121809
31. Mohammadi A, Ghiasvand E, Nili M (2020) Relation between mechanical properties of concrete and alkali-silica reaction (ASR); a review. Constr Build Mater 258. https://doi.org/10.1016/j.conbuildmat.2020.119567
32. An J, Kim SS, Nam BH, Durham SA (2017) Effect of aggregate mineralogy and concrete microstructure on thermal expansion and strength properties of concrete. Appl Sci (Switzerland) 7(12). https://doi.org/10.3390/app7121307
33. Adaway M, Wang Y (2015) Recycled glass as a partial replacement for fine aggregate in structural concrete -effects on compressive strength. Electron J Struct Eng 14(1):116–122

34. Tan KH, Du H (2013) Use of waste glass as sand in mortar: Part i - fresh, mechanical and durability properties. Cem Concr Compos 35(1):109–117. https://doi.org/10.1016/j.cemconcomp.2012.08.028
35. Choi Y, Yuan RL (2005) Experimental relationship between splitting tensile strength and compressive strength of GFRC and PFRC. Cem Concr Res 35(8):1587–1591. https://doi.org/10.1016/j.cemconres.2004.09.010
36. Turgut F et al (2009) Pro-hepcidin levels in peritoneal dialysis and hemodialysis patients. Dial Transplant 38(6):203–209. https://doi.org/10.1002/dat.20297
37. Limbachiya MC (2009) Bulk engineering and durability properties of washed glass sand concrete. Constr Build Mater 23(2):1078–1083. https://doi.org/10.1016/j.conbuildmat.2008.05.022
38. Penacho P, De Brito J, Rosário Veiga M (2014) Physico-mechanical and performance characterization of mortars incorporating fine glass waste aggregate. Cem Concr Compos 50:47–59. https://doi.org/10.1016/j.cemconcomp.2014.02.007