Mechanical and Durability Properties of Concrete with Ground Waste Glass Sand

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ABSTRACT

This paper examines the possibility of using finely ground waste glass as partial natural sand replacement in concrete. The reduction of waste glass particle size was accomplished in the laboratory by crushing and grinding the waste glass in a jar mill. The compressive strength at 7, 28 and 90 days, was determined for different ground waste glass sand percentage replacement in concrete.

Absorption and permeability tests were also carried out. A test method was followed to verify the potential concrete expansion caused by the alkali silica reaction.

The results showed a very significant compressive strength improvement with the increasing of percentage replacement of natural sand by ground waste glass. A higher compressive strength was obtained with a lower expansion verified by the bar tests. The same trend for durability properties were also observed in this study.

The results obtained attested the high possibility of recycling and using of the ground waste glass collected in central region of Portugal as natural sand replacement in concrete mixtures.

KEYWORDS

Fine aggregate, Ground waste glass, Concrete expansion, Durability

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1 INTRODUCTION

Nonrecyclabe waste glass constitutes a problem for solid waste disposal in many municipalities in Portugal. Traditionally, most nonrecyclabe mixed-colour broken glass results of the bottling industry. The current practice is still to landfill most of the nonrecyclabe glass. Since the glass is not biodegradable, landfills do not provide an environment-friendly solution. Nowadays, the civil construction industry search the alternatives for satisfy the increasing needs for the concrete production. The attractive use of the waste glass in the construction materials is caused by the fact that not all waste glass can be recycled into new glass. For the glass industry, the impurities, transports costs and mixed colour waste streams difficult the useful raw glass stocks. United Nations estimates the volume of yearly disposed solid waste to be 200 million tons, 7% of which is made up of glass the world over [Topçu & Canbaz 2004]. In Portugal, 7.5% of 4 712 458 tons of solid waste produced during 1999 and 2005 was glass. In fact, only 30% of the total used bottles are actually reuse and recycled, it means 70% is disposed as landfill. The efforts to reduce the landfilling of waste glass, because they are not biodegradable, has been done over past few decades by several others researches by studies using the waste glass as an aggregate, including Schmidt & Saia [1963], Johnston [1974], Figg [1981], Polley at al [1998] and Shayan & Xu [2004]. Our earlier results [Oliveira at al 2007] also showed that glass particles 75µm-150µm size range did not cause expansion in the accelerated mortar bar test, which agree with the observations of Shayan & Xu [2006], but according to Bazant at al [1998] the glass particle around 1.5 mm caused excessive expansions.

Using waste glass, as coarse aggregate in concrete, did not have a marked effect on the workability of concrete, but the compressive strength decrease in proportion to an increase in waste glass [Topçu & Canbaz 2004]. According to Park at al [2004], the increase in the content of waste glass fine aggregate on concrete showed a slump decrease tendency influenced by the grain shape and the fineness modulus of the waste glass aggregates. These authors observed a decreasing compressive strength along with an increase in the mixing ratio of the waste glass aggregate. They found the highest compressive strength in concrete containing 30% of waste glass aggregates.

Thus, taking in account the influence of the waste glass as fine aggregate on the concrete workability an additive was used to maintain the same slump for all mixtures tested in this work. A basic experimental study on the mechanical and durability properties of concrete containing waste glass collected in the central region of Portugal was carried out.

2 METHODS

2.1 Materials

A commercial Portland cement type CEM I 42.5R conforming to European Standards EN–197-1 with Blaine fineness of 384.8 m^2/kg and with a particle density of 3140 kg/m^3 was used for all mixes. A fly ash with Blaine fineness of 400.9 m^2/kg and with a particle density of 2380 kg/m^3 was used for all mixes As the aggregate for producing concretes, natural sand was used with maximum particle size 4.76 mm, a particle density of 2520 kg/m^3 and Modulus of Fineness of 3.47. The coarse aggregate was a 12.7 mm crushed granitic stone with a particle density of 2698 kg/m^3 .The amber waste glass was ground in a jaw crusher to produce a fine glass sand with maximum particle size 4.76 mm, a particle density of 2509 kg/m^3 and Modulus of Fineness of 2.40. Fig. 1 show the grading distribution of fines aggregates determined in according of the ASTM C136.

2.2 Concrete mixtures

A reference mix 1:0.29:1.87:3.14 (cement : fly ash : fine aggregate : coarse aggregate) with a water/cement ratio of 0.60 was used. Other mix proportions were formulated based on this mix to include the fine glass sand mentioned above. The purpose of the trial was to determine the effect of glass sand as natural sand replacement, at 25, 50 and 100% dosage rates. Table 1 gives details of the 4 mixes used in field trial.

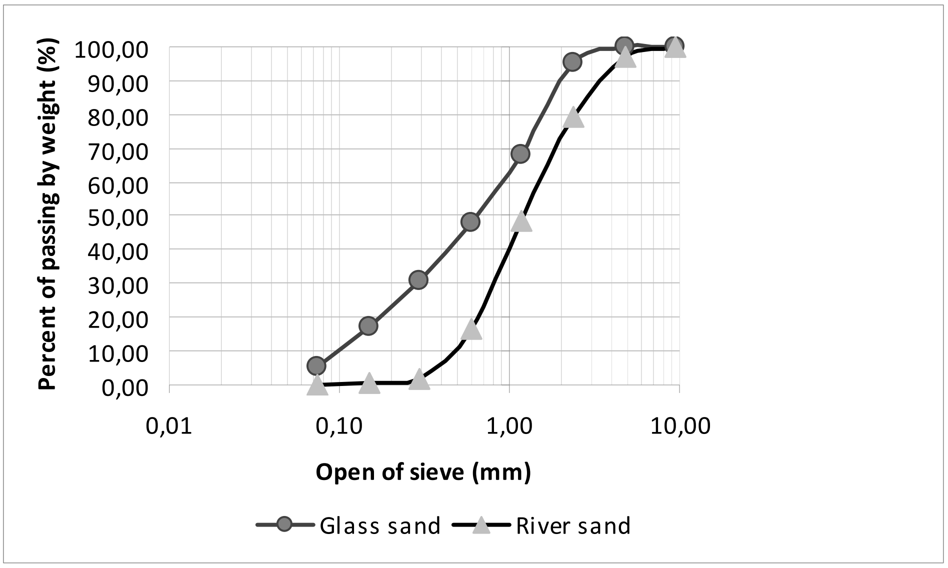

Figure 1. Grading curves of aggregates

Table 1. Mix proportions (kg/m^3).

Description	*Cement*	*FA*	*Coarse aggregate*	*Fine sand*	*Crushed glass*	*Water*
Control mix	350	101.5	1099	654.5	0	210
25%CGS[a]	350	101.5	1099	490.8	163.6	210
50% CGS	350	101.5	1099	327.25	327.25	210
100% CGS	350	101.5	1099	0	654.5	210

[a] GCS = crushed glass sand

2.3 Workability

The tests conducted on the fresh concrete included the slump test and flow table test, in according to EN 12350-2 and EN 12350-5, respectively. The workability was evaluated by conducting slump test in accordance with EN 12350-2. The slump for control mix was was 100 mm ± 10 mm. As the sand content increases, the slump decreases due to the reduction of equivalent fineness modulus. For concretes with sand glass content, high-range water reducer admixture was used to obtain the same workability as indicated for control mix. The dosage of admixture is about 0.2% by weigth of cement for 25% sand glass content and 0.3% for 50% and 100% of sand glass content.

2.4 Compressive strength test

The compressive strength tests were conducted, in according with EN 12390-3, at 7 and 28 days for 150 mm concrete cubes maintained in fog room (21 ± 2ºC, 100% RH).

2.5 Expansion test

The alkali silica reaction (ASR) test was was applied to check the influence of sand glass percentage replacement in concrete expansion. Three concrete bar specimens, with the dimensions 40 x 40 x 160 mm, were made for each mixing containing glass sand. Normal procedure was to cure them for 24 h, immerse them in water for 24 h, and then store them in 1 N NaOH solution at 80ºC in a closed container. Changes in the length of the concrete bars were checked for the following 14 days after their surface was dried by using a comparator, a length comparison measuring device with an accuracy less than 0.002 mm.

2.6 Capillary sorptivity test

The sorptivity tests were carried out on samples, with 7.5 x 7.5 x 15cm, after drying in oven, at a temperature of 60ºC ± 5ºC. The samples were stored until the weight loss was negligible. The preparation of samples also included water impermeability of their lateral faces, reducing the effect of water evaporation. The test started with the registration of samples weight and, afterwards, they were placed in a recipient in contact with a level of water capable to submerge them about 5 mm. After a predefined period of time, the samples were removed from the recipient to proceed to weight registration. Before weighing, the samples superficial water was removed with a wet cloth. Immediately after the weight, the samples were replaced in the recipient till reach the following measuring time. The procedure was repeated, consecutively, at various times such as 10, 20, 30, 40, 50, 60, 70, 90, 130 and 150 min (min = minutes) until the last reading. Because of small initial surface tension and buoyancy effects, the relationship between cumulative water absorption (kg/m2) and square root of exposure time ($t^{0.5}$) shows deviation from linearity during first few minutes [3]. Thus, for the calculation of sorptivity coefficient, only the section of the curves for exposure period from 10 min to 90 min, where the curves were consistently linear, was used. The sorptivity coefficient (k), was obtained by using the following expression:

$$\frac{W}{A} = k\sqrt{t} \qquad (1)$$

where W= the amount of water adsorbed in (kg); A= the cross section of specimen that was in contact with water (m^2); t = time (min); k = the sorptivity coefficient of the specimen ($kg/m^2/min^{0,5}$).

2.7 Water and oxygen permeability test

For determination of concrete oxygen and water permeability it is used a permeability cell and the tests were conducted by the procedures described by Gomes at al [2002]. For these tests, cylindrical test specimens are prepared with 5cm of diameter and about 4 cm of height. This permeability cell allows submitting samples, with the referred dimensions, to a certain pressure, guaranteeing that the flow of oxygen through the sample is uniaxial. So much plus, that in the adopted methodology, specimens are first dried in oven at 60ºC, for 48 hours. The water permeability test can take place after the oxygen permeability test, in a similar way and with in the same specimen.

3 RESULTS AND DISCUSSION

3.1 Compressive strength

The compressive test results for concretes containing amber waste glass fine aggregates are shown in the Fig. 2. It was observed that with increase of amber waste glass content, the strength of concrete increase. For each mixing rate of the amber waste glass (25%, 50% and 100%), the compressive strength increased by 26%, 26% and 34%, respectively, at 7 days. For 28 days the increase was 24%, 25% and 29%. It was observed a strength development coefficient from 7 to 28 days of 1.30 for the reference mix, 1.27 for the mix with 25% of waste glass, 1.29 for 50% mixing rate and 1.25 for 100% mixing rate. These results are in opposition of the results obtained by Park at al [2004] and by Topçu & Canbaz [2004]. In general, the strength of concrete containing glass is lower than that with natural aggregate. Strengths are particularly low when high alkali cement is used. This apparent disagreement was probably caused by replacement of cement with around 30% fly-ash that demonstrated effective in controlling the large retrogression of strength. By the other hand, the use of a more fine aggregate as natural sand replacement can improve the aggregates particle packing by the filler effect. When the specific surface of aggregate is increased for a constant mix proportion, the amount of cement relative to the surface of the aggregate decreases. Lallard & Belloc [1997] state that as the maximum paste thickness between aggregate particles decreases the compressive strength increases. In dry packing of particles, it has been observed that the highest stresses exist at the contact points of aggregate particles. Thus, when paste is introduced into the packing and it is placed between two close aggregates, the paste will be highly stressed, yielding a greater matrix strength.

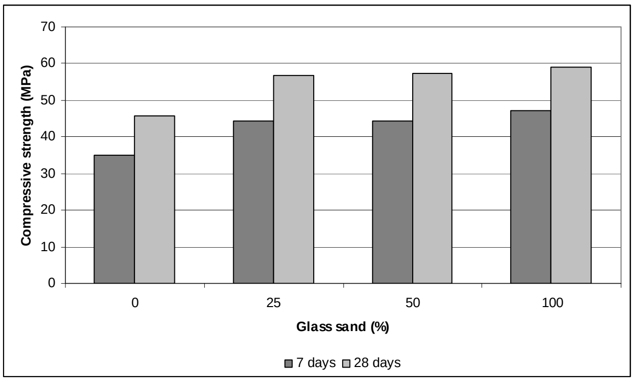

Figure 2. Compressive strength vs sand glass content for 7 and 28 days.

3.2 Influence of glass sand content on the concrete expansion

All the concretes prisms stored at the conditions described in 2.5 showed insignificant expansion (<0.1%) at the age of 14 days (Fig. 3), indicating that no deleterious alkali silica reaction expansion took place by that age. In Fig. 3, curves for mixes with natural sand replaced by 100% and 50% of waste glass sand presents an expansion development with the age inferior or similar to the control mix. Despite the expansion increasing at 14 days, about 60% more than control mix, for the mix with 25% of waste glass sand, it is observed that the fly ash content in the mixes lead for a more stable behaviour. This effect provide ample evidence that both fly ash and waste glass sand can be used together to produce concretes with relative high strength without any adverse reaction.

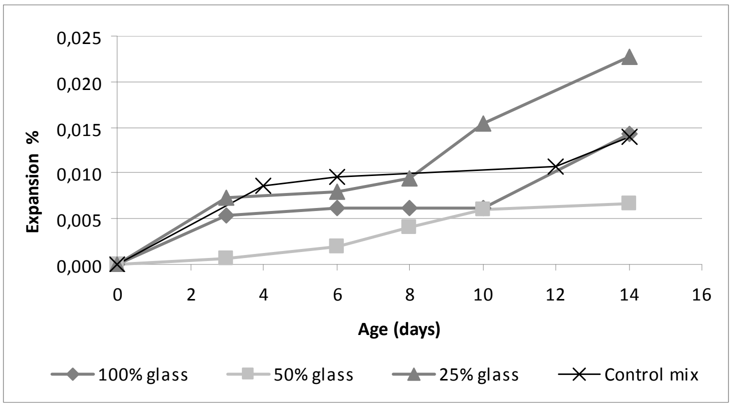

Figure 3. Expansion of concrete bars with various sand glass content imersed in NaOH solution.

3.3 Mix proportions and durability evaluation.

It was observed that the sand replacement by the waste glass sand reduced the concrete sorptivity coefficient. Fig. 4 shows that the reduction attaint a maximum of 39% for 28 days with 100% of natural sand replacement and 29% of reduction at 63 days for the same waste glass rate. This reduction can be influenced by the favorable effect of waste glass sand gradings that improve the particles packing almost certainly reducing the quantity of capillary pores.

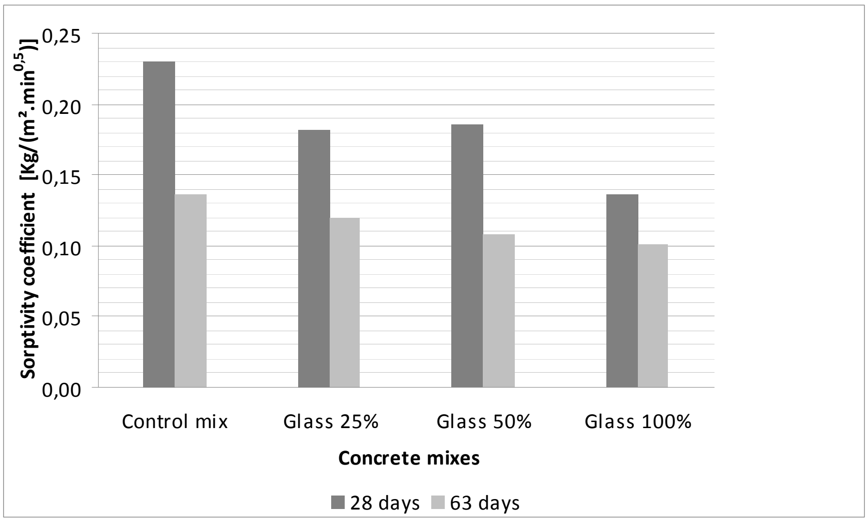

Figure 4. Sorptivity coefficient of different concrete mixes at 28 and 63 days

Figs. 5 and 6 presents the results obtained on concretes produced with different waste glass sand replacement rate. All results presented in both figures are medium values obtained from testing of 4 specimens. Fig.5 shows the influence of natural sand replacement by waste glass sand on the oxygen permeability cofficient at the concrete age 28 and 63 days. At 28 days it was observed an increase, between 20 and 30%, in the oxygen permeability for mixes with 25% and 50% of waste glass sand, but a significantly decreasing when the total natural sand was substituted by waste glass sand. In general, the oxygen permeability is reduced by an half with the concrete age evolution. At the end of 63 days the oxygen permeability of the concrete with waste glass sand is the same order of the concrete with natural sand.

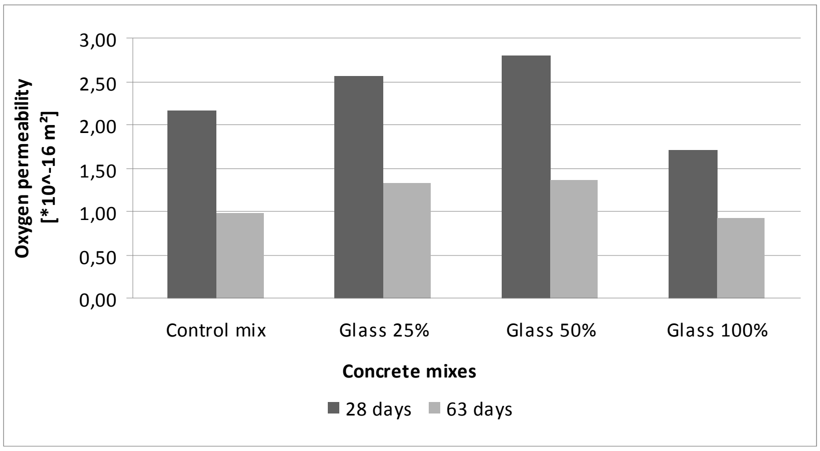

Figure 5. Oxygen permeability coefficient of different concrete mixes at 28 and 63 days.

Fig. 5 shows a similar behaviour for the concrete water permeability, which means a reducing with the time, an increase with combination of natural sand and waste glass sand and the same order values for concrete produced with waste glass sand and for natural sand.

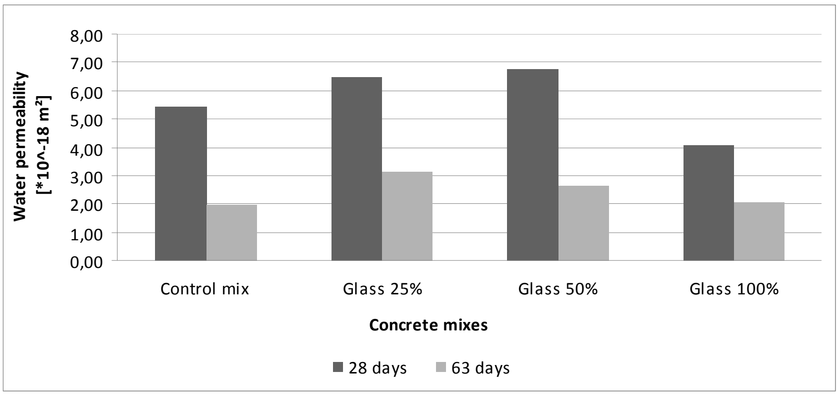

Figure 6. Water permeability coefficient of different concrete mixes at 28 and 63 days.

4 CONCLUSION

The effect of using waste glass sand in concrete mixes has been investigated. Four different mixes having a specified characteristic compressive strength of 40 MPa were prepared. It was necessary to use a high range water reducer with waste glass sand to maintain adequate workability at required constant w/c ratio. The compressive strength was increasead with the waste glass sand rate in concrete, where the alkali silica reaction was largely mitigated by addition of a suitable fly ash. The increase of waste glass sand is also beneficial to reduce the concrete sorptivity coefficient, but give a control mix similar permeability behaviour only for 100% waste sand rate. Finally, the results of this study indicate waste glass sand to be a satisfactory substitute for natural fine aggregate providing considerable economic and environmental benefits to the community.

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REFERENCES

Bazant Z. P., Jin W. & Meier C. 1998, "Fracture mechanics of concrete structures", Proc. FRA MCOS, 3, 1687-1693.

Figg, J. W. 1981, "Reaction between cement and artificial glass in concrete", Proc. Conf. on Alkali-Aggregate Reaction in Concrete, Cape Town, South Africa.

Gomes, J. P.C, Oliveira, L.A.P., Gonilho, C.N.P. & Torgal, F.M.A.S.P. 2002, "Discussion of Aggregate and Concrete Water Absorption and Permeability Testing Methodology**"**, XXX IAHS World Congress on Housing, Coimbra, Portugal, Oktay U, Abrantes V, Tadeu a (Eds.), Vol. III, pp 1761- 1768.

Johnston, C. D. 1974, "Waste glass as coarse aggregate for concrete", J. Testing and Evaluation, **2**(5), 344-350.

Lallard, F. & Belloc A. 1997, "The influence of aggregate on the compressive strength of normal and high-strength concrete", ACI Materials Journal, Vol. 94, No. 5, pp. 417-426.

Oliveira L. A. P., Gomes J. P. C. & Santos P. 2007, "Optimization on pozolanic reaction of ground waste glass incorporated in cement mortars", Portugal SB07 Sustainable Construction, Materials and Practices, L. Bragança et al (Eds.) IOS Press, 2007, Part 2, pp. 928-934.

Park, S.B., Lee B. C. & Kim J. H. 2004, "Studies on mechanical properties of concrete containing waste glass aggregate", Cement Concrete Research, 34, 2181-2189.

Polley, C., Cramer, S. M. & Cruz R.V. 1998, Potential for using waste glass in portland cement concrete" Journal of Materials in Civil Engineering, **10** (4), 210-219.

Schmidt, A. & Saia, W. H. F. 1963, "Alkali-aggegate reaction tests on glass used for exposed aggregate wall panel work", ACI Mat. J., 60, 1235 – 1236.

Shayan A. & Xu A. 2006, "Performance of glass powder as a pozzolanic material in concrete: a field trial on concrete slabs", Cement Concrete Research, 36, 457-468.

Shayan A. & Xu A. 2004, "Value-added utilisation of waste glass in concrete", Cement and Concrete Research, 34, 81-89.

Topçu, I. B. & Canbaz M. 2004, "Properties of concrete containing waste glass" Cement and Concrete Research 34, 267-274.