Optimization of pozzolanic reaction of ground waste glass incorporated in cement mortars

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ABSTRACT: This paper examines the possibility of using finely ground waste glass of the three most common coloured glass bottles used in Portugal as partial cement replacement in mortar and concrete. The pozzolanic activity of ground glass was optimised as function of different particle size. The reduction of waste glass particle size was accomplished in the laboratory by crushing and grinding the waste glass using a jar mill. The particle fineness, to obtain a required reactivity, was studied as function of grinding time. The compressive strength activity index, at 7, 28 and 90 days, was determined for different ground waste glass particle size and partial cement replacement percentage in mortar. Test method described in ASTM C 1260 was applied to verify the potential expansion caused by the alkali silica reaction.
The results obtained confirm the pozzolanic activity of the ground waste glass of different colour collected in central region of Portugal.

1 INTRODUCTION

Nonrecyclabe waste glass constitutes a problem for solid waste disposal in many municipalities in Portugal. Traditionally, most nonrecyclabe mixed-colour broken glass is coming from 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. By the other hand, in Portugal, the pozzolanic materials begin to be not enough to supply all the demands of the construction industry. Nowadays, the civil construction industry search the alternatives for satisfy the increasing needs for the cement and concrete production.

In Portugal, used bottles are partially reutilized. They are collected, sorted, and crushed to be used mostly as a raw material for new bottles. However it is estimated accordingly to relatively recent data that only 30% of the total used bottles are actually currently being recycled (Sousa L, 1995).

Efforts have been made in the concrete industry to use waste glass as partial replacement of coarse or fine aggregates. However, due to the strong reaction between the alkali in cement and the reactive silica in glass (ASR reaction), studies of the use of glass in concrete as part of the coarse aggregate were not always satisfactory due of the marked strength reduction and simultaneous excessive expansion (Shao et al, 2000, Johnson, 1974).

Recent studies have shown that the particle size of glass is a crucial factor for ARS reaction to occur (Karamberi & Moutsatsou, 2005). In particular, aggregate fineness favours ASR expansion since the ASR reaction is a surface area dependent phenomenon. It seams that exists a minimum particle size, depending on the structure of the glass, where the maximum expansion occurs. It was found that if the glass was ground to a particle size of 300 µm or smaller, the alkali-silica reaction (ASR) induced expansion could be reduced (Meyer et al. 1996). In fact, data reported in the literature show that if the waste glass is finely ground, under 75 µm, this effect does not occur and mortar durability is guaranteed (Shao et al., 2000).

It also well know that typical pozzolanic materials might features high silica content, an amorphous structure and have a large surface area.

Taking into consideration all the above factors this paper presents a study on the assessment of the pozzolanic activity of green, amber and flint color waste glass as a component of cementitious materials used as filler or binder in mortar and concrete.

2 MATERIALS AND METHODS

2.1. Materials

The waste glass used in this study was obtained at the waste management and disposal service of Cova da Beira Municipal Association, of interior region of Portugal. The chemical composition of the glass was analyzed using an X-ray microprobe analyzer and is listed in Table 1.

Table 1. Chemical compositions of ground waste glass (by weight percent)

	Flint glass	Amber glass	Green glass
Na_2O	9.94	10.37	10.54
MgO	0.75	0.81	1.18
Al_2O_3	2.57	3.09	2.54
SiO_2	74.07	73.27	72.25
Cl_2O	-	-	-
K_2O	1.14	1.10	1.15
CaO	11.53	11.36	12.35
TiO_2	-	-	-
Fe_2O_3	-	-	-
SO_3	-	-	-

The three types of colored glass have a similar percentage of reactive silica, around 74%. In accordance to NP EN 450 (1995), the glass satisfies the basic chemical requirements for a pozzolan, namely to have a high percent of silica. However, it does not meet the optional requirement for the alkali content because of the high percentage of Na_2O in glass.

Koslova et al, 2004, observed that the introduction of unwashed glass as aggregate exhibits the risk of predicting a false reactivity of multi-component systems increasing the reactivity of tested systems. Thus, the glass used in this work was previous washed before mixing.

To verify the physical requirement for fineness, the glass was grinded in jaw crusher and ball mill, and separated by sieving in three different particle size ranges, as follows: 75µm – 150µm, 45µm – 75µm and < 4µm. The purpose of this size selection was to observe the effect of maximum size related to the minimum grinding time which the pozzolanic activity can be present in a cementitious matrix without a significant alkali silica expansion reaction. The optimization of the grinding time versus particle size obtained with the grinding process was controlled with the determination of Blaine surface area. Figure 1 shows typical micrographs used to analyze the particle size and particle shape of the ground glass obtained in the scanning electron microscope (SEM). In this figure, the ground waste glasses, after grinding, exhibit angular shapes and it is possible to observe a more homogeneous size distribution for 0 - 45µm size range than for 45µm – 75µm size range.

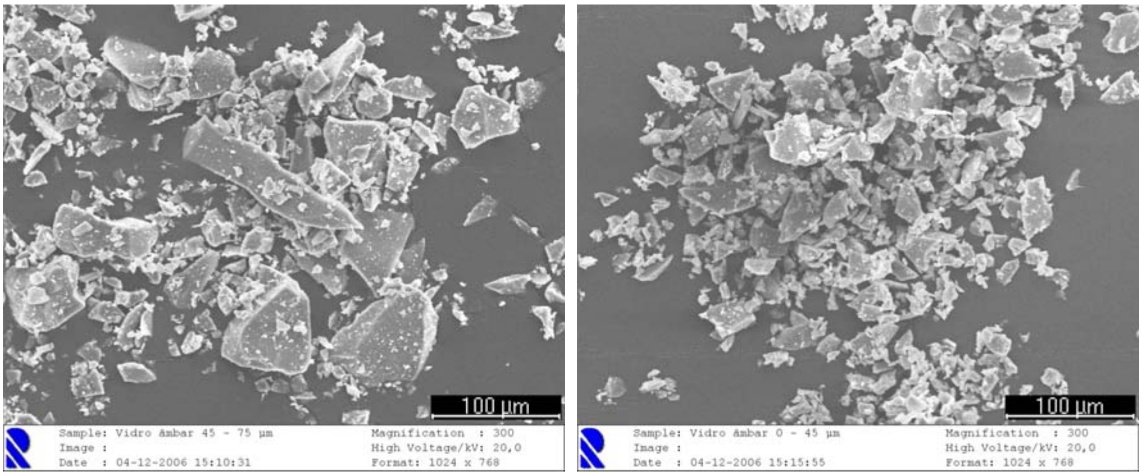

Figure 1. Particle size and shape of ground waste glass of 45 - 75µm (left) and 0 - 45µm (right) particle range, after grinding.

A commercial Portland cement type CEM I 42.5R conforming to European Standards NP EN–197-1 with Blaine fineness of 400.9 m^2/kg and with a particle density of 3140 kg/m^3 was used at all different mixes.

As aggregate for producing mortars, natural sand was used with maximum particle size 4.76mm, a particle density of 2450 kg/m^3 and Modulus of Fineness of 2.97.

2.2. Mixture details

The mortar mixtures were produced with the weight ratio of 1: 3: 0.5 (binder: sand: water). The cementitious material consisted of Portland cement blended in laboratory with each of the three different color waste glasses. Thus, Portland cement was partially replaced by 10%, 20%, 25%, 30% and 40% of each color and size grinded ground waste glass. The mortars mixture proportions used are reported in Table 2.

The control of fresh mortar consistency using the flow-table test conform the EN 1015-3 allowed verifying the influence of glass fineness and cement percentage replacement on the fresh workability for all the tested mortars.

2.2. Mechanical strength of mortars

For each mortar mixture, prismatic specimens of 40 x 40 x 160 mm were manufactured, cast, wet cured for 7, 28 and 90 days. Both compressive and flexural strength were evaluated in conformance with EN 196-1. The results obtained are reported in Figures 2 and 3.

2.3. ASR test method

Study of expansion due to the possible reaction between the alkali in cement and silica in the glass was done in accordance with ASTM C1260. Mortar bars of 40 x 40 x 160 mm sizes were made of standard graded river sand, type CEM I 42.5R Portland cement, and grinded ground waste glass. After 24 h of curing, the bars were placed in water at 80º C for another 24 h to gain a reference length. They were then transferred to a solution of 1 N of NaOH at 80º C. Length bar readings were then taken every day for 14 days. The mortar bars without grinded ground waste glass were also tested as control. The comparison with the control is an indication of whether or not the silica in glass is reactive with the alkali in cement and of the solution. The results obtained are reported in Figure 6.

2.4. Grinding time optimization

The grinding time optimization was performed determining the Blaine specific surface at the end of a certain time of grinding in ball mill of samples previously prepared by a jaw crusher.

The Blaine specific surface was determined at end of each ball mill grinding hour for a total duration of 10 hours. The partial results obtained in this study are shown in Figure 7.

3 RESULTS AND DISCUSSON

3.1. Mechanical strength with various glass powders content

The compressive strength results of 75 – 150µm glass powders mortars are plotted in Figure 2. It can be observed, in case of cement replacement by the glass powder, the reduction in compressive strength increases with the level of cement replacement.

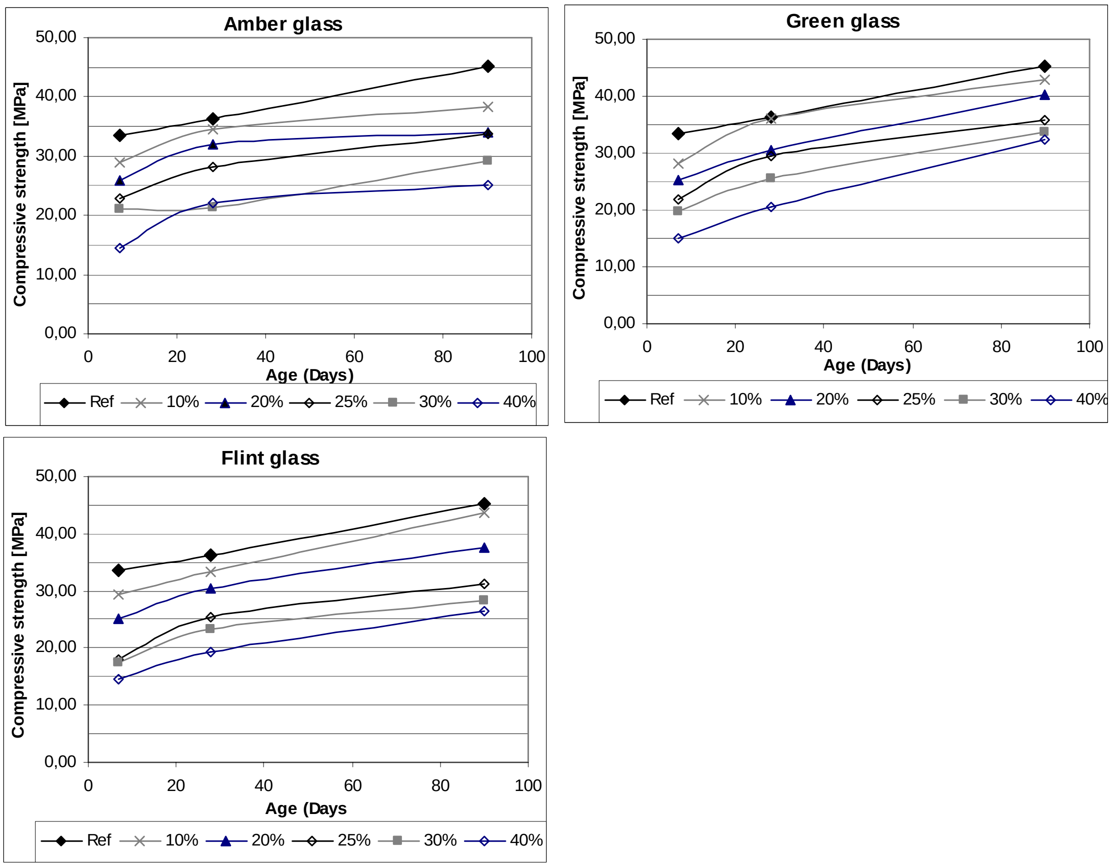

Figure 2. Compressive strength development of glass powders 75 – 150 µm

Figure 3 shows that increasing of compressive strength is obtained with reduction of the glass powder particle sizes. For particle sizes low than 45 µm, the compressive strength of mortar with 25% of cement replacement is closer to the control mortar analogous results.

The result of compressive strength obtained in mortar with different glass color, when analyzed for the same particle glass size range, is similar for amber and flint glass. Mortars containing green color glass powders, in turn, have the highest compressive strength for all particle sizes. This difference is due to the fact that specific surface of the green glass (of about 445 kg/m^2) is slight higher of amber and flint glass (of about 355 kg/m^2).

According to NP EN 450 the pozzolanic activity is evaluated by a strength activity index correspondent of 75% and 85% at 28 days and 90 days, respectively, obtained for a mortar with 25% of cement replacement.

The strength activity index is plotted in Figures 5 and 6. The results presented there show that at 28 days the amber glass attaint a compressive strength higher than the results of 75% control mortar strength for all glass particle size range studied here. In the case of 90 days requirement only the 75 – 150 µm particle range did not attaint the 85% pozzolanic activity index. The green glass powder mortars have a compressive strength higher than 75% at 28 days for all particles size ranges. At 90 days the index of 85% is not attaint for the range of 75 – 150 µm particle, but it is highest for 0 - 45 µm and 45 - 75 µm particle ranges.

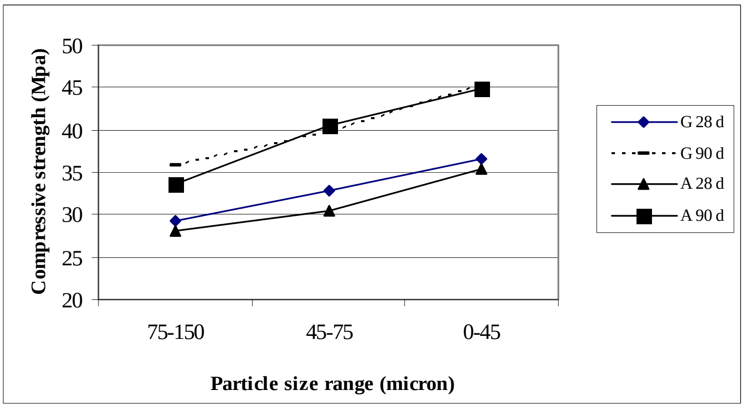

Figure 3. Compressive strength of mortars with different particle size range (G – green glass, A – amber glass)

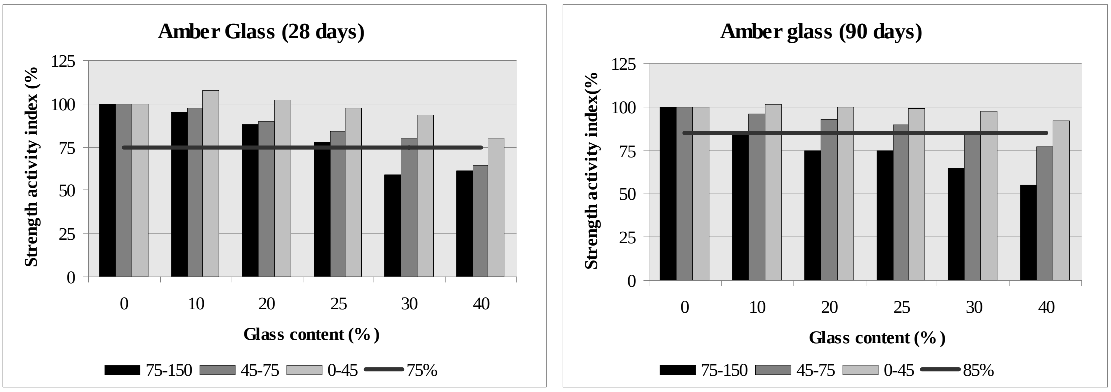

Figure 4. Strength activity index for amber glass mortar

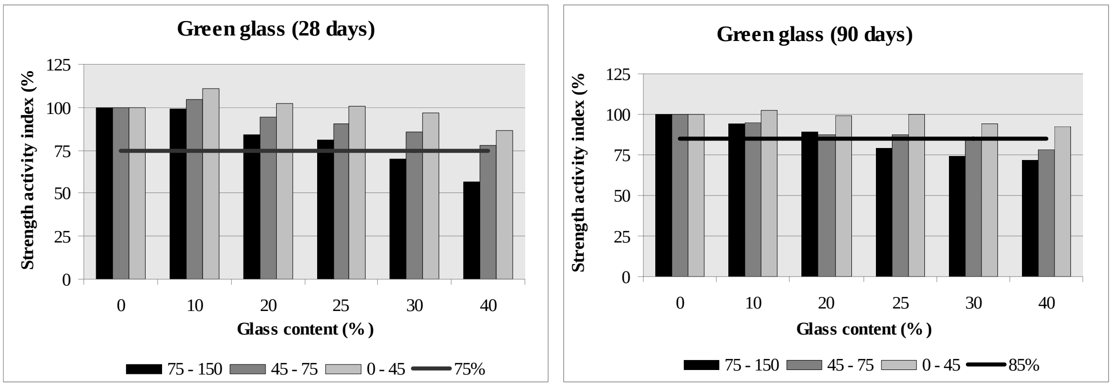

Figure 5. Strength activity index for green glass mortar

The expansion results obtained by the measurements complying with ASTM C1260 in terms of colors waste glasses (amber, green and flint) are partials, but present a trend tendency which confirms the results obtained by Shayan and Xu, 2004, where the expansion for all mortars molded with the different ground glass used in this study is farly lower than the maximum value of 0,1% prescribed in standard specifications. Figure 6 shows that mortar with 25% of cement replacement by the amber ground glass has the highest expansion of all samples tested. This high expansion value is due to the cement content in the mortar which, in turn, is higher than for other mortars prepared with amber ground glass powders.

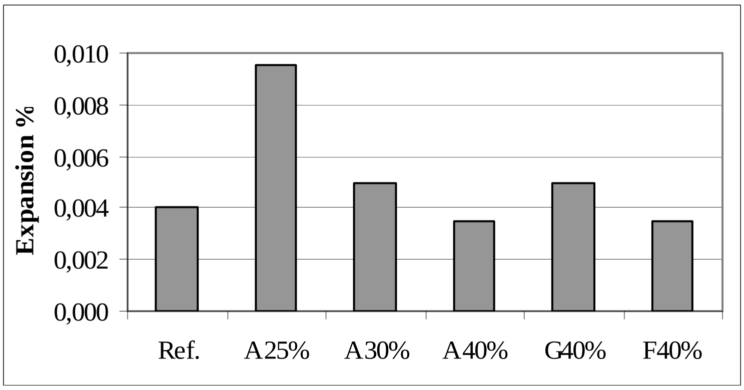

Figure 6. Expansion for mortar bars

Figure 7 shows a linear tendency of the increasing of glass powders fineness measured by the Blaine apparatus. After 9 hours grinding time in a ball mill, it is possible to obtain powders particles sizes that gives a specific surface higher than 250 m^2/kg. This Blaine surface area is a characteristic of the particles that can be classified as being of 45 - 75 µm size range.

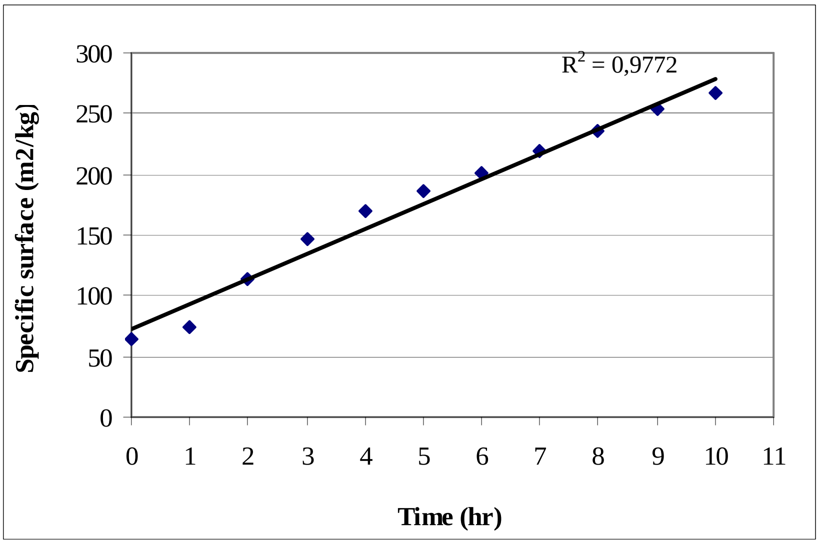

Figure 7. Blaine specific surface as function of grinding time

4 CONCLUSIONS

The aim of this study was to evaluate the “recyclability” of domestic ground waste glass, collected in the municipal service of Portugal interior region, as a cement replacement for mortar and concrete. A basic experimental study on the physical and mechanical properties of mortars containing recycled waste glass as pozzolan material provided the following results and conclusions:

The determination of the oxide contents of selected waste glass samples indicates that, in accordance to NP EN 450, the glass satisfies the basic chemical requirements for a pozzolan. However, it does not comply with the additional requirement for the alkali content because of the high percentage of Na_2O in glass. Despite this situation, finely ground glass powders, higher than 250 m^2/kg Blaine specific surface, exhibited very high pozzolanic activity.

It was also verified that the for finer glass powders, mortars pozzolanic activity is higher. It has been also concluded that 30% of 45 - 75 µm ground waste glasses size range could be incorporated as cement replacement in mortar or concrete without any detrimental effects caused by the expansivity provoked by the alkali silica reaction.

The results present in this paper show that is a great potential for the utilisation of waste glass in mortar and concrete as a partial replacement for expensive materials such as silica fume, fly ash and cement.

5 ACKNOWLEDGEMENTS

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