# Application of crushed glass residues in mortars

A. Fragata
*LNEC, Laboratório Nacional de Engenharia Civil, Lisboa, Portugal*

H. Paiva
*UA/CICECO, University of Aveiro, Portugal*

A.L. Velosa
*UA/MIA, University of Aveiro, Portugal*

M.R. Veiga
*LNEC, Laboratório Nacional de Engenharia Civil, Lisboa, Portugal*

V.M. Ferreira
*UA/CICECO, University of Aveiro, Portugal*

ABSTRACT: The need to add value to wastes and the opening towards the use of cement replacement materials, both in mortars and concretes, with the purpose of promoting increased sustainability of building materials, were the grounds for this work that aims the formulation of mortars with crushed glass residues. Flat construction glass is a material with a high percentage of amorphous silica, favouring pozzolanic reactivity. This property was evaluated using a chemical test based on the standard EN 196-5 - Methods of testing cement - Part 5: Pozzolanicity test of pozzolanic cement. The results obtained by this test indicate the material's capacity to react with calcium hydroxide, forming hydrated calcium alumino-silicates. Mortars with several binders (air-lime, hydraulic lime and cement) and this waste were formulated and tested in terms of mechanical strength. Results indicate pozzolanic reactivity of this waste and open possibilities for the use of this material in mortars.

## 1 INTRODUCTION

Pozzolans are materials of current use in mortars and concrete. Their main purpose is usually the mitigation of Alkali Silica Reaction (ASR), especially deleterious in concrete structures, which is achieved by the development of a faster pozzolanic reaction. Moreover, they are incorporated as cement (or binder) replacement materials, conferring additional strength to mortars and concretes, again due to the pozzolanic reaction, in which pozzolanic materials will react with the free $Ca(OH)_2$ originating from the binder (lime, hydraulic lime) or from hydration reactions (cement), creating calcium silicate and/or aluminous-silicate hydrates, that contribute towards a more resistant chemical structure. The formation of these reaction products also allows mortars with an air lime binder, with added pozzolans, to harden under water or in very high relative humidity conditions.

When finely ground, these materials attain a higher specific surface and therefore, become more reactive. Furthermore, this fineness confers additional strength to mortars by increasing their compacity.

Various materials of natural or artificial origin may be used as pozzolans, depending mainly on their content in amorphous silica and, therefore, potential to develop a pozzolanic reaction. Many waste materials have pozolanic properties and there is an opening toward their use as pozolanic additions (Polettini, Pomi & Carcani, 2004, Taha & Nouno, in press, Tay, 1990, Terro, 2005), contributing towards environmental sustainability. Waste glass is a potential material for this purpose as abundant glass residue is available and its composition favours pozolanic reaction. Glass may produce ASR and this has been a major drawback for its use in cementitious materials, but recent studies suggest that finely ground glass produces a fast pozolanic reaction inhibiting ASR (Terro, 2005). Recently, efforts to characterize and re-use waste glass as cement or aggregate replacement have already been made, with some positive results (Özkan & Yüksel, in press, Taha & Nuonu, 2006, Terro, 2005, Shi, Wu, Riefler & Wang, 2004).

The use of waste materials in mortars can be an important step towards sustainability as the construction industry is significant and mortars worldwide use cement as their main binder; the use of alternative mortars with binders that are less pollutant and/or the use of residues could impact the mortar industry towards the production of mortars with less environmental impact. In order to achieve this, mortars must have adequate characteristics to be used as renders and/or as joint mortars, implying that certain mechanical characteristics and water behaviour must be achieved. This paper deals with the issue of mechanical characterization, especially focusing on the pozzolanic effect of the glass residue.

## 2 CHARACTERIZATION OF GLASS RESIDUE

A fine glass powder, from flat glass wastes was used. It was characterized in terms of Blaine's specific surface using a Blaine apparatus, mineral composition, using X-Ray Diffraction (XRD) and chemical composition using X-Ray Fluorescence (XRF). These analyses revealed a specific surface of 3060cm$^2$/g, an amorphous material by XRD and a chemical composition (Table 1) of $SiO_2$ (74%); $Na_2O$ (12,5%) and CaO (8,5%), typical of a plane sodocalcic glass.

Table 1: Chemical characterization of glass residue by FRX (main constituents)

| Oxide | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ |
|---|---|---|---|---|---|---|---|
| Percentage by mass | 73,99 | 1,02 | 0,18 | 8,56 | 3,33 | 12,55 | 0,24 |

These characteristics, a high specific surface, an amorphous material and a high content in silica indicate a reactive pozzolan. However, a pozzolanic reactivity test was performed following standard EN 196-5 - Methods of testing cement - Part 5: Pozzolanicity test of pozzolanic cement. This test is based on the chemical reaction between the pozzolan and calcium hydroxide produced by the hydration reaction of cement: after mixing a certain quantity of cement and pozzolan in a solution that is kept for 8 to 15days, the amounts of CaO and $OH^-$ are measured. A high consumption of $Ca(OH)_2$ indicates a strong pozzolanic reaction. Results obtained with the glass residue point towards its strong pozzolanic potential.

## 3 MORTAR FORMULATION AND CONDITIONING

Mortars with three different binders: cement, hydraulic lime and air lime were formulated. A comparison mortar, with no glass residue (named C, HL, L), was used for each case. These formulations, in weight, were chosen taking into account mortars of current use. With the addition of glass residue and although it is most probable, due to the characterization that was undertaken, that the glass residue will act almost totally as a binder, a 1:1:4 (air lime: glass residue: sand) proportion was used with air lime. With the other binders, cement (C) and hydraulic lime (HL), two different glass proportions were used taking into account possible performance as binder or aggregate. Formulations are listed in Table 2.

Table 2: Mortars composition

| Mortar | Air Lime (L) | Cement (C) | Hidraulic Lime (HL) | Glass Powder (G) | Sand (S) |
|---|---|---|---|---|---|
| C | - | 1 | - | - | 4 |
| CG1 | - | 1 | - | 0,5 | 4,5 |
| CG2 | - | 1 | - | 1 | 5 |
| HL | - | - | 1 | - | 3,5 |
| HLG1 | - | - | 1 | 0,5 | 4,5 |
| HLG2 | - | - | 1 | 1 | 4 |
| L | 1 | - | - | - | 3 |
| LG | 1 | - | - | 1 | 4 |

Conditioning was performed according to standard (NP EN 1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar) with a temperature of 20±2ºC and a relative humidity of 65±5ºC.

## 4 CHARACTERIZATION TESTS

In order to determine mechanical characteristics of the formulated mortars a testing campaign was undertaken and all samples were submitted to flexural and compressive strength tests following standard NP EN 1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. The dynamic modulus of elasticity was determined following Rel. LNEC 289/95NCCt (Figure 1). Testing was performed at the ages of 7 days, 28 days and 90 days.

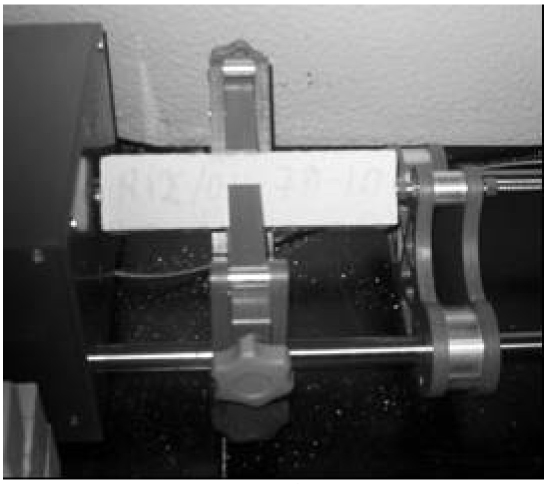

Figure 1 – Measurement of the dynamic modulus of elasticity

## 5 RESULTS AND DISCUSSION

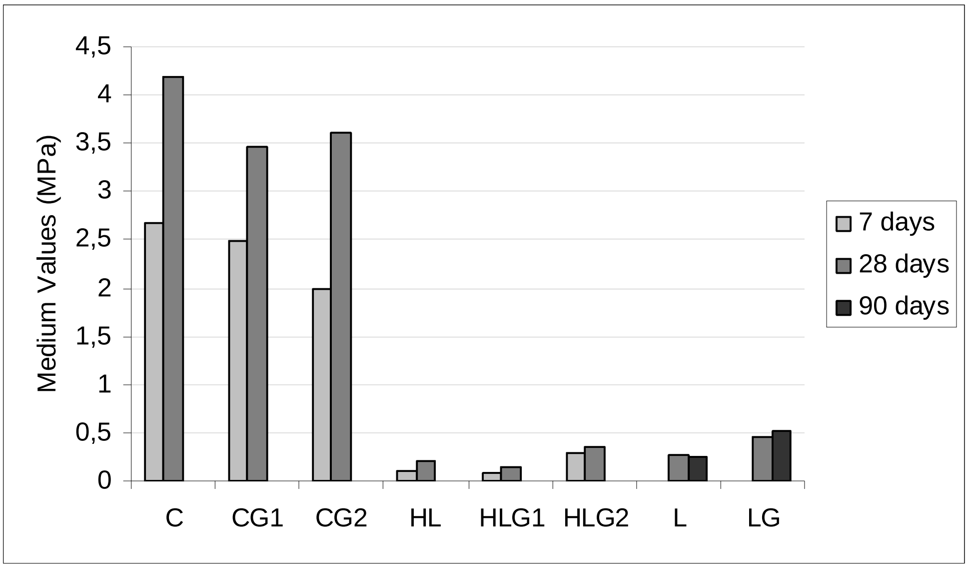


Figure 2 – Flexural strength of mortars at 7, 28 and 90 days

In mortars with cement as binder (C, CG1, CG2) there is a decrease in flexural strength with glass residue addition. However, in both hydraulic lime and air lime mortars, glass residue created an increase this mechanic characteristic.

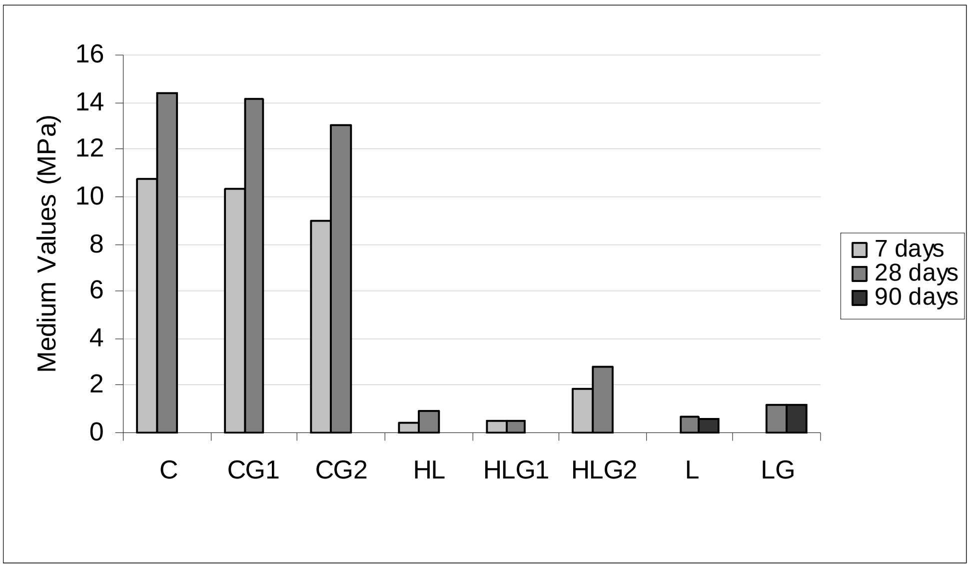


Figure 3 – Compressive strength of mortars at 7, 28 and 90 days

Results show, similarly to those of flexural strength, that incorporation of glass residue reduced mechanical strength in cement mortars, and increased this property in mortars with air lime or hydraulic lime binders.

Pozzolans react with avaliable CH, mainly producing CSH similar to that produced in cement hydration reactions. In the case of cement mortars, not much CH is available, possibly forcing glass residue to act as an aggregate. In these mortars a lower percentage of pozzolan will probably increase mechanical strength.

In lime and hydraulic lime mortars glass residue acts as a pozzolanic addition conferring increased mechanical strength.

## 6 CONCLUSIONS

Glass powder from flat glass waste can be used as a pozolanic material, due to its pozzolanic reactivity. In air lime or hydraulic lime mortars, the addition of glass residue increases mechanical strength. Contrarily, in cement mortars there is a decrease of mechanical strength with the addition of glass residue. A reason for this may be the lack of calcium hydroxide for reaction purposes, inducing the pozzolan to act as an aggregate. The effect of ASR is highly improbable due to the time span and thermal and hygrometric conditions. However, further studies on the chemical reactions developed must be undertaken.

Glass residue is a promising addition for use in mortars, which will are being subject to an enlarged testing campaign, taking into account their behaviour in terms of water absorption, their drying capacity and their cracking susceptibility. These tests will enable a complete characterization and an evaluation of application possibilities.

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