Use of glass residue in air lime mortars

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ABSTRACT: Air lime mortars are nowadays mostly used in conservation practice, but this binder is often substituted by hydraulic lime due to the long time it needs to harden and to its specific application technique. However, hydraulic lime doesn't seem to be the best solution as its behaviour in terms of water intake and drying capacity is inadequate for this kind of application, as is its high elastic modulus. An alternative for this situation is the use of pozzolanic materials that enable an easy application of mortars and, used in the correct proportions, give mortars mechanical and physical characteristics that are compatible with conservation applications. With this background, a decision to incorporate pozzolanic residues in lime mortars was taken, with the double purpose of re-using residues and providing a possible source of pozzolanic materials that give air lime mortars the desired characteristics. Due to the availability of very fine (under 25µm) crushed glass residue from flat glass, this material was tested for its pozzolanic capacity and incorporated in air lime mortars in different proportions. Storage of samples was undertaken in different temperature and humidity conditions in order to verify the influence of external conditions on the final properties of mortars. The obtained results point towards the possibility of the use of air lime /glass residue mortars in the conservation of ancient buildings but also show that climatic conditions have an important influence in the development of mortar properties.

1 INTRODUCTION

In Portugal, there still exist many historical buildings with renders based in air lime. Although, nowadays, these old renders present good general characteristics (in terms of cohesion and adherence to the background), they often need to be submitted to some conservation actions. As they act as sacrificial layers, being exposed to climatic actions and mechanical and environmental impact, they are the first ones to need interventions such as, according to Veiga & Carvalho (2002), local repair or partial substitution and in some cases, if there is a deep generalized degradation, total substitution.

The compatibility of repair mortars with the preexisting mortars is critical to the success of a conservation process. According to Lanas & Alvarez (2003) this compatibility must be assured in terms of: (i) chemical compatibility between the mortar and the preexisting materials (stone or brick and its bedding mortar); (ii) physical compatibility with special reference to water transport; (iii) mechanical compatibility (the strength of repair mortar must be similar to the ancient ones).

Due to the lack of knowledge about these old renders and about the behavior of the old masonries, in the last years, the conservation practice has been directed to the substitution of these old mortars by cement and hydraulic lime based ones which, in the majority of cases, demonstrated to be incompatible with the preexisting materials (leading to non-durable conservation actions).

Despite this, there has been an increasing concern about the use of compatible solutions - lime based substitution mortars – in order to assure the durability of the intervention.

Pozzolanic additions in air lime based mortars can be an interesting way to assure the desired compatibility and improve the physical and mechanical characteristics due to the pozzolanic reaction.

As in recent years the research has been directed toward the finding of alternative uses for waste materials from industries or building demolitions, the construction industry can be an area where this waste materials can have an interesting application.

Flat glass powder was incorporated in air lime based mortars expecting that on one hand it improves mortar characteristics, developing pozzolanic reaction and on the order hand it also provides a way of promoting sustainable materials.

Furthermore, the use industrial by-products such as fly ash, silica fume and granulated blast furnace slag as partial replacement of the binder has proved to improve the mortars characteristics in terms of mechanical and physical behaviour, in order to produce restoration mortars, similar to historic ones (Velosa, A. L. 2006).

One of the major problems of selecting the appropriate pozzolan used as a pozzolanic addition in restoration mortars is its reactivity since the use of highly reactive pozzolans as their addition to lime mortars in reasonable quantities produce durable mortars with sufficient mechanical strength with similar characteristics to historic ones. Various physicochemical characteristics influence pozzolanic reactivity such as: the total and active silica content, the grain size distribution, the specific surface area. However, these factors are only indicators of the pozzolanic reactivity and they could not assure that the lime/pozzolan mortar produced would present the best potential behavior (Moropoulou et al. 2004).

The purpose of this study is to investigate the contribution of glass waste to physical and mechanical characteristics (flexural strength, compressive strength, elastics modulus, capillary water absorption and water vapour permeability) of air lime mortars, taking into account the influence of different curing conditions Thermogravimetric analysis (DTA/TG) was performed in order to analyse the chemical reactions responsible for the large variation of mortars mechanical and physical characteristics with different curing conditions.

2 GLASS POWDER

2.1 Reuse of flat waste glass

The reuse of flat waste glass from building demolition or residual waste of industries, by partially substitution of the air lime binder of the mortars, can be a solution for the actual proportions of these wastes that would otherwise be sent to the landfill.

The use of crushed flat glass residues in mortars can be also a possibility for this purpose. In one hand, abundant glass residue is available and in the other hand, its composition favour pozzolanic reaction.

Due to the great quantity of reactive silica present in glass and its amorphous structure the glass is susceptible to chemical attack, says Shayan & Xu (2004), favouring the formation of ASR gel, which is expansive.

This expansive reaction (ASR), according to Corinaldesi et al. (2005) and Shayan & Xu (2004), can cause problems of craking of mortars, however if this waste is finelly ground (under 75 um) it means in powder form, this effect does not occur, suppressing the ASR tendency.

2.2 *Characterization of the glass residue*

Very fine crushed glass residue (powder glass - under 25µm) from flat glass was used. Due to its high content in amorphous silica (SiO_2 -72.5%) and high specific surface (3060 cm^2/g) this material presents a favourable composition to the potential development of pozzolanic reaction.

In previous work, (Fragata et al. 2007) a pozzolanic reactivity test in glass was performed, following standard EN 196-5 – Methods of testing cement – Part 5: Pozzolanicity test of pozzolanic cement. The results obtained with this test showed a high pozzolanic reactivity of the glass powder.

It is expected that due to the pozzolanic reaction, the glass reacts with the free $Ca(OH)_2$ from the air lime creating silicate hydrates, that contribute towards a more resistant structure and towards the possibility of hardening in high relative humidity conditions.

As abundant glass residue is available and its compositions favour pozzolanic reaction, waste glass is a potential material to be used as a pozzolan in air lime based mortars.

3 EXPERIMENTAL WORK

3.1 *Mortars formulation and curing - mechanical and physical tests*

Due to the characterization of the glass residue that was undertaken, it was expected that glass residues would act essentially as a binder (Fragata et al. 2007). Mortars with hydrated air lime were formulated, with a volumetric dosage of 1:1:4 (air lime: glass residue: siliceous sand). A reference mortar for comparison, with no glass residue, with a volumetric dosage 1:3 (air lime: siliceous sand) was used. The mortars curing conditions are presented in Table 1. All mortars were prepared according to standard procedures EN1015-2.

Table 1. Mortars formulation and conditioning.

Designation	Volumetric Dosage	Curing conditions
CA	1:3	A - In moulds at room temperature of 23 ± 2ºC and relative humidity of 50± 5% during 2 days, following removal of the mould, keeping the same conditions till the day of the tests.
CVAS	1:1:4	A - In moulds at room temperature of 23 ± 2ºC and relative humidity of 50± 5% during 2 days, following removal of the mould, keeping the same conditions till the day of the tests.
CVAH7	1:1:4	B - In moulds at room temperature of 23 ± 2ºC and relative humidity of 95± 5% during 7 days, following removal of the mould, and keeping the same temperature but decaying the relative humidity to 65 ± 5% till the day of the tests.

3.1.1 *Results of mechanical and physical tests*

A testing campaign was undertaken in the formulated mortars in order to determine their main mechanical and physical characteristics. The samples were submitted to flexural and compressive strength tests following standard NP EN 1015-11. The dynamic elastic modulus was determined following NF B10-511F (French Normalization). The determination of the capillarity absorption was performed following EN 1015-18.

The mortars mechanical and physical characteristics, presented in Table 2, were tested at 90 days.

Table 2. Mortars mechanical and physical characteristics (tested at 90 days).

Designation	Flexural strength (MPa)	Compressive strength (MPa)	Elastic modulus (MPa)	Capillarity coefficient* (Kg/m2.min1/2)	Water vapor permeability Sd(m)
CA	0,24	0,62	2715	1,79	0,06
CVAS	0,51	1,20	5126	1,88	0,06
CVASH7	0,09	0,31	1157	3,34	0,05

*Determined between 0 and 10 minutes.

It can be seen that the incorporation of these residues in air lime mortars only promoted the increase of the desired mechanical and physical characteristics in dry conditions (type A), although it was expected that it would happen in wet conditions (type B).

3.2 *Formulation and curing – thermal analysis*

In order to better understand the behaviour of these air lime based mortars, with glass powder as pozzolanic addition, in terms of mechanical and physical characteristics, the mortars were submitted to thermal analysis - thermogravimetry (DTA/TG). Thermogravimetric analysis (DTA/TG) was carried out at a temperature range of 30-1000ºC with a heating rate of 10ºC/min in a nitrogen atmosphere, in order to determine the weight loss of the various compounds in the total sample. The analysed mortars are presented in Table 3.

Volumetric ratios of the components used in pastes were 1:3 and 2:1 of glass powders to hydrated lime, respectively. All mortars were submitted to the same curing conditions as the ones for the mortars formulated for the mechanical and physical tests. The CVS mortars were submitted to dry conditions (type A), while CVH7 1:3 and CVH7 2:1 were submitted to humid conditions (type B).

3.2.1 *Results of thermal analysis*

Bakolas et al. (1998), state that the temperature ranges below 120ºC correspond to the weight loss due to adsorbed water, when there are not particular hydrated salts present. The loss of chemically bound water is in the range temperature 200-600ºC, when there are no other compounds that undergo weight loss in this temperature range. The loss of CO2 due to the decomposition of carbonates at the temperature happens in temperature higher than 600ºC.

From 400ºC to 520ºC there is a loss of weight corresponding to the dehydroxilation of calcium hydroxide (Velosa, A.L. 2006).

The percentage of hydraulic and bound water, calculated in the 125-425ºC range. The 700-900ºC range, indicate the loss of CO2 from recarbonated lime (CaCO3) (Paama, L. 1998).

Table 3. TG-DTG analysis of the total samples and CO_2/H_2O ratio (eight loss % > 600ºC/weight loss % between 200-600ºC).

Sample	Weight loss in each temperature range (ºC)				
	<200ºC	200-400ºC	400-600ºC	>600ºC	CO_2/H_2O
	(%)	(%)	(%)	(%)	
GLASS	0,53	0,27	0,41*	0,11	0,16
CVH7 1:3	0,82	1,42	3,34	25,79	5,42
CVH7 2:1	1,09	1,46	0,69; 1,12**	11,94	3,65

* In the case of glass powders the range of values considered is 450-550ºC.
**Values obtained in the temperature range of 450-530ºC and 530-600ºC, respectively.

The dehydratation of calcium silicates hydrates occurs in the range of values between 200-600ºC.

The high CO2 peaks in the temperature range above 600ºC is due to the decomposition of CaCO3. The content of CaCO3 calculated by the TG curves in weight losses were: 25,79% (CVH7 1:3) and 11,94 (CVH7 2:1).

The TG and DTA curves are shown on Figures 1-3.

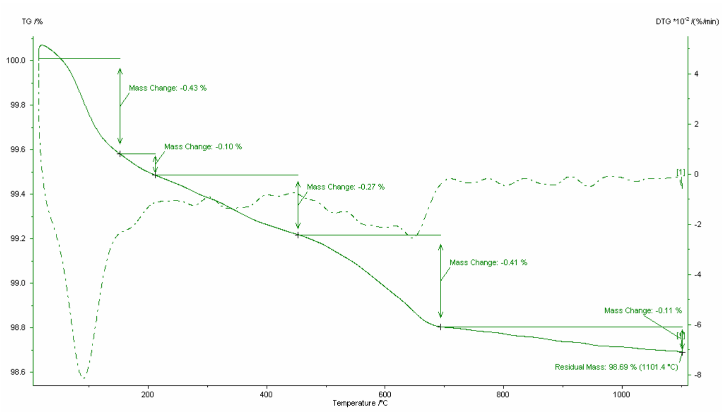

Figure 1. Thermogravimetric Analyses (DTA/TG) of glass powder.

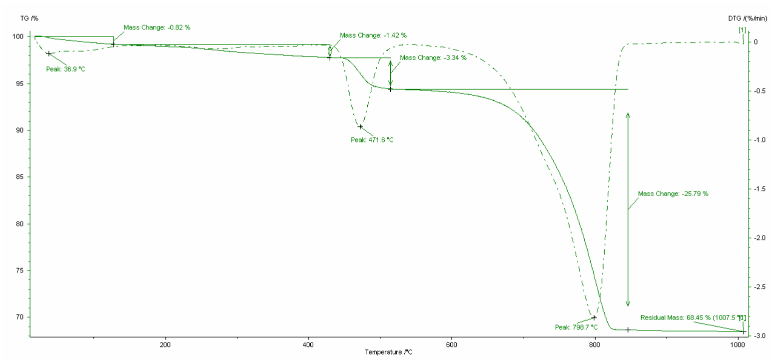

Figure 2. Thermogravimetric Analyses (DTA/TG) at 90 days, of mortars formulated with hydrated air lime and glass powder in volumetric dosage 1:3 and cured under type B.

The Figure 2 above shows that with low dosage of pozzolanic material (1:3) cured in type B conditions, it can be seen that the weight loss below 400°C is 1,42, the loss in the temperature range 400-600°C revealing the percentage of uncarbonated calcium hydroxide is 3,34, over 600°C is 25,79%.

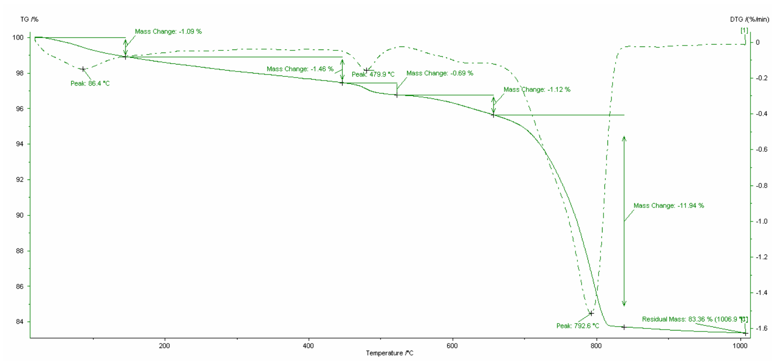

Figure 3. Thermogravimetric Analyses (DTA/TG) at 90 days, of mortars formulated with hydrated air lime and glass powder in volumetric dosage 2:1 and cured under type B conditions.

Figure 3 depicts the DTG/TA curve relative to a high dosage of pozzolanic material (2:1) cured in type B conditions. The initial loss, up to 400ºC is 1,55; from 400ºC to 550ºC there is a loss of 1,81 related to the desidroxilation of calcium hydroxide. However, this diagram reveals a further peak in the temperature range of 450ºC-550ºC related to the loss of adsorbed water from the glass particles. Weight loss above this temperature, of 11,94 is due to the decarbonation of calcium carbonate. The fact that there is a loss in the 2:1 composition related to the adsorbed water linked to the glass particles is a possible explanation for the fact that underwater hardening produced lower mechanical results as these water particles may have interfered with the pozzolanic reaction, delaying or inhibiting its development. However, this fact will be further evaluated by the use of other techniques such as environmental scanning electron microscopy.

4 DISCUSSION OF THE RESULTS

4.1 *Mechanical and physical characteristics*

Mortars based in air lime with powder flat glass have been submitted to different curing conditions (type A and type B). Based on the results obtained in terms of mechanical and physical behavior there can be stated that the mortars formulated with glass powders and submitted to dry conditions (CVAS) obtained higher general mechanical characteristics when compared with the other mortars. These mortars also show similar water behavior to the reference mortars (CA). The mortars formulated with glass powders and submitted to humid conditions (CVAH7) showed lower general mechanical characteristics but higher capillarity coefficient and lower water vapor permeability, in comparison with the other tested mortars.

4.2 *Thermal analysis*

The CVH7 1:3 mortars present low dosage of pozzolanic material. On the first stage between 0 and 200ºC there can be seen a loss of mass of 0,82%, due to the loss of adsorbed water. Between 400-600ºC there is a loss of mass of 3,34 due to the desidroxilation of portlandite and in the last stage, above 600ºC they present the higher lost of weight of the 25,79%, due to the higher presence of calcite ($CaCO_3$).

Samples CVH7 2:1 present an higher dosage of glass. The further peak between 450ºC-550ºC (that also can be seen in the glass DTG/TG analyses, Figure 1) may be due to the loss of adsorbed water from the glass particles, that may be inhibiting the development of the pozolanic reaction. There can be seen a lower percentage of weight loss above 600ºC, due to the lower quantity of lime used in this sample.

The thermal analyses studies show that content of hydration products (range temperature of 200-400ºC) increases as the replacement of pozzolan increases and the air lime decreases. Also for the same formulation (1:3) with humid curing conditions the content in hydration products increases, when compared with dry conditioning.

As the weight loss in the range temperature above 600ºC of CVH7 2:1 is lower when compared with the other studied mortars, the physical characteristics in terms of mechanical strength and elastic modulus are also lower.

5 CONCLUSIONS

Mortars to be used as renders in old buildings must be compatible with the background and the pre-existing materials.

It was expected that the glass residue would act almost as binder, due to the characterization that was undertaken, and showed the higher mechanical characteristics in conditions type B, but the results were the opposite. This may be due to the existence of bound water in CVH7 2:1 mortars. Chemically bound water to glass particles may be responsible for delay or inhibition of pozzolanic reaction, retarding hardening and producing mortars with lower mechanical strength; further analytical methods will be performed in order to validate this hypothesis

The re-use of a waste material in a conservation process provides a double and important input towards sustainability. Glass is a possible material for these applications, however due to differential behaviour in dry or underwater conditions of lime/glass mortars, there is a relationship between application conditions and behaviour, that must be further explored.

These analyses provided a further insight towards the behaviour of this material in lime mortars

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