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Reduction of the cement content in rendering mortars with fine glass aggregates

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The viability of the reduction of the cement content of coating mortars with simultaneous incorporation of very fine glass aggregates, without jeopardizing their functional performance, is discussed here. The use of these modified mortars has both environmental and economic potential advantages. In fact less energy is needed to produce cement and the direct cost of mortar production is lower. To evaluate the eventual pozzolanic properties of glass fines an experimental programme was followed comprising a series of tests to characterize the behaviour of these mortars in terms of mechanical strength, water-related behaviour, durability and other properties. The results were extremely positive, well above initial expectations. As a matter of fact, it was clearly demonstrated that the mortar with 1:5 cement:aggregate (considering aggregate as sand + glass fines) ratio instead of 1:4 and 20% incorporation of fine glass aggregates complies with all the requirements to be used as a coating mortar. Since screening of construction and demolition waste and solid urban waste is presently established, it is possible to crush glass waste and upscale the production of pre-mixed mortars with glass incorporation. This will allow a reduction of the cement content of these modified mortars and result in environmental benefits, both in terms of energy needed to produce cement and corresponding emissions to the atmosphere, and reduction of dumped waste.

1. Introduction

Undoubtedly the most expensive and energy-consuming component in conventional mortar is cement. According to Miranda and Selmo (2006), cement promotes the aggregates' cohesion in the fresh mix and the initial adherence of the mortar to the substrate, provides mechanical strength and reduces water permeability.

When used in mortars, pozzolans allow the cement content to be reduced by generating the formation of hydraulic compounds, thus contributing to a considerable increase in mechanical strength. However, because it is made mostly of amorphous silica plus smaller percentages of sodium and calcium, glass has a composition that favours the development of pozzolanic reactions (Fragata et al., 2007a, b). Therefore this study evaluates the possibility of reducing the cement content in coating mortars by incorporating fines from annealed float glass (the most common in construction and demolition waste – CDW) grain size below 0.149 mm with expected pozzolanic properties.

According to the European Flat Glass Industry, 2%–5% of the overall weight of a building is accounted for by float glass (Coelho and de Brito, 2011). However, as architecture has developed so the surface of glass has tended to increase, leading to façades totally made of glass and so buildings contained higher percentages of glass. Besides being one of the components of CDW, glass also represents a considerable portion of urban solid waste (USW), and in 2006 it comprised 5% of such waste (Russo, 2009). Glass waste is also generated by other economic sectors: the car industry, through the end-of-life vehicles, and the glass industry itself.

Whenever glass is used, the potential development of alkali–silica reactions (ASR) is considered. However, as found by Terro (2006) and Penacho et al., 2015, these are not significant for glass particles as small as those used in this study, since the pozzolanic reaction develops so swiftly that it inhibits ASR. Serpa et al. (2013), using the same glass waste aggregates as in this study, reached similar conclusions.

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With this study, it will be possible to reduce energy consumption and the production cost of coating mortars, whilst finding an alternative to dumping of glass waste.

A parallel study was carried out aiming at finding the optimal incorporation ratio of fine glass aggregates, maintaining or even improving the main characteristics to be expected of renderings through a filler effect (Oliveira et al., 2013). Therefore, the optimal incorporation ratio found in that study was used in the mortars produced here.

2. Literature review

According to Fragata et al. (2007a, b), pozzolanic reactivity is generally defined as the capacity to produce hydraulic compounds through the reaction with calcium hydroxide, in the presence of water. They state that a typical pozzolanic material may have two essential characteristics: a high content of amorphous silica and a high specific surface. According to Shi et al. (2005), the composition of glass favours the development of pozzolanic reactions since it essentially consists of amorphous silica (SiO_2 − 72.5%) and less significant percentages of sodium (Na_2O − 13.2%) and calcium (CaO − 9.18%). In the Fragata et al. study (2007a, b), the pozzolanic reactivity of glass was evaluated through a chemical test based on the standard NP EN 196-5. The results obtained in this test indicate the capacity of the material under analysis to react with calcium hydroxide, in the presence of water, thus forming hydraulic compounds. Therefore, it is concluded that glass can be considered a reactive pozzolan since it possesses a high specific surface, is an amorphous material and has high silica content.

Shao et al. (2000), cited by Özkan and Yüksel (2008) and Ling et al. (2011), using glass fines as partial replacement of cement, also found that particles smaller than 38 μm showed pozzolanic behaviour, reacting with calcium hydroxide during cement hydration. The same behaviour was found by Shi et al. (2005), who stated that the pozzolanic reactivity increases as the glass powder gets finer. According to Corinaldesi et al. (2005), cited by Özkan and Yüksel (2008), the positive contribution of glass powder to the microstructural properties of a mortar is that it improves its mechanical behaviour.

According to Corinaldesi et al. (2005), cited by Fragata et al. (2008) and Shayan and Xu (2004), the use of glass waste may cause cracking problems in mortars. However, these authors report that if this waste is used finely ground (<75 μm), the effect does not occur, thus suppressing the tendency for the development of ASR. Terro (2006) notes that glass may produce ASR, which is a major drawback of its use, but if the glass is finely ground the pozzolanic reaction is swift (the rather higher specific surface explains the increased pozzolanic reactivity) and so ASR is inhibited.

Braga et al. (2014), studied the reduction of the cement content and simultaneous incorporation of fine concrete waste and found there was a decrease in the adherence capacity of the mortar without waste incorporation when the volumetric proportion (cement:aggregate) changed from 1:4 to 1:5, in agreement with Carasek and Djanikian (1997), who concluded the adherence capacity improved as the cement content in the mortar increased. On the other hand, they found that when 15% of sand was replaced by fine concrete waste at a volumetric ratio of 1:5 (cement:aggregate) the adherence capacity increased such that it was even greater than that of the reference mortar (ratio 1:4 with no waste incorporation).

Silva et al. (2008) determined that the adherence strength of a reference mortar (ratio 1:4 with no fines incorporation) was 0.338 MPa but for a mortar with 1:6 volumetric ratio and 10% mass replacement of sand by brick fines it was 0.375 MPa. Therefore, they concluded that the reduction of the cement content was not sufficient to offset the positive effect on the adherence to the substrate provided by the amount and quality of the brick powder incorporated.

Both Braga et al. (2014) and Silva et al. (2008) concluded that all the mortars analysed (with reduced cement content and simultaneous incorporation of fines, composed of concrete or ceramics) were hardly susceptible to cracking at all, since after application to brick faces and after several months' observation no sign of cracking was detected.

In terms of mechanical strength, Fragata et al. (2007a, b) replaced part of the cement with glass powder and found a reduction in both flexural and compressive strength. Pereira and Santos (2007) partially replaced cement (in amounts of 10%, 20%, 25%, 30% and 40%) with glass powder from bottles of three grading sizes (0–45 μm, 45–75 μm and 75–150 μm) and found that generally the compressive strength decreases as the replacement percentage increases, for all size ranges analysed. For the same replacement ratio they also found that the compressive strength increases for smaller sized incorporated particles. Therefore, for 10% replacement of cement with particles smaller than 45 μm, the compressive strength was even higher than that of the reference mortar. In terms of flexural strength Pereira and Santos (2007) found that this increased as the replacement percentage decreased and also as the size of the incorporated particles decreased.

Shi et al. (2005) replaced 20% of cement with four types of glass of various sizes and found that the finer glass types reacted quite strongly with the $Ca(OH)_2$ from cement after 7 days of curing, having reached, at 28 days, higher compressive strength than the mortar produced without any cement replacement.

In terms of shrinkage Silva et al. (2008) concluded that the mortar with 1:6 ratio and 10% replacement of sand with red brick ceramic fines had very similar behaviour to that of the reference mortar, with 1:4 ratio and no brick fines incorporation.

Silva et al. (2008) also evaluated the compatibility with the substrate of the reference mortar, with 1:4 ratio and no incorporation of brick powder, and of a mortar with 10% replacement of sand with brick powder and 1:6 ratio. They used an accelerated ageing test on specimens of mortar applied to small brick masonry walls, followed by water permeability under pressure and adherence to the substrate tests, in order to evaluate the effect of ageing. They found lower water permeability for the modified mortar than for the reference mortar, i.e. a performance improvement. The modified mortar also has slightly better adherence results than the reference mortar.

Braga et al. (2014) further found that the reduction of cement content simultaneously with the incorporation of concrete fines did not have a significant influence on the drying time of the mortars.

3. Material and methods

In this section the materials studied and the standards used in each of the tests performed are described.

3.1. Materials

To evaluate the effect of the use of glass powder as pozzolanic material, several mortars were designed and subjected to various tests, using several traditional cement:aggregate ratios (1:4, 1:5 and 1:6) either with any incorporated waste materials and with an incorporation of 20% of glass fines in substitution of sand (the optimal incorporation ratio according to a previous study (Oliveira et al., 2013)). The reference mortar has 1:4 ratio and no glass fines, since it is the composition most commonly used in wall renderings

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