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Physico-mechanical and performance characterization of mortars incorporating fine glass waste aggregate

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ABSTRACT

The effective management of construction and demolition waste (CDW) is a major challenge for the construction sector. To address such needs, this research work focuses on a specific type of CDW – annealed plate glass – to be incorporated into cementitious renderings.

Studies on glass waste are very recent, scarce, and usually limited to the alkali-silica reaction (ASR), but they tend to involve other types of glass. This work characterizes the physical–mechanical and performance of these modified mortars, something that has not yet been done. A main reason for this lack of knowledge is the serious concern that there is an ASR potential. However, a recent study [1] concluded that the approach set out in ASTM C 1260 (accelerated mortar bar test) [2] may be overly conservative for renderings because it significantly increases the cement content. That study concluded that the use of mortars containing waste glass is technically viable in terms of ASR-related durability as long as the cement type and content are controlled, as well as the size of the aggregates, which proved to be the most decisive parameter [1].

In our study, mortars with a cement-to-sand volumetric ratio of 1:4 were produced with a fraction of the sand replaced by fine glass aggregates (0%, 20%, 50% and 100% by volume), while the aggregate's size distribution in the replacement remained constant so that the material itself was the single factor under analysis.

The study reveals significantly improved results, especially at the level of the mechanical performance and physical compatibility with the substrate, when these mortars are compared with similar ones containing other waste types and a conventional mortar (with only natural sand as aggregate).

1. Introduction

The building industry is a major contributor to the total waste produced in the European Union, where overall construction and demolition waste (CDW) production is estimated at 100 million tonnes. Part of that CDW waste ends up dumped in landfills, along roads or out in the open [3–5].

In this context, CDW must be regarded as a resource or by-product whose reuse and recycling would minimize both its dumping in landfills and the consumption of natural resources. This is the setting for the research work we report here, where a particular type of CDW glass (annealed plate glass) is considered by studying its incorporation in cement-based coating mortars. This work follows other experimental projects related to the technology of mortar incorporating CDW, made at Instituto Superior Técnico (IST,) of the University of Lisbon, and at the National Laboratory of Civil Engineering (LNEC), in Portugal.

The drawbacks of cementitious materials (particularly in coating mortars) include high stiffness, shrinkage and cracking susceptibility, yet they are the materials most widely used in the construction industry because of their advantages of short setting time and high durability. Characteristics such as stiffness are paramount for rehabilitation mortars since they may provoke anomalies involving micro-cracking and consequent loss of adhesion (detachment of the rendering) [6].

The incorporation of other materials, in particular CDW, is not only better for the environment but may also lead to improvements in certain properties. Studies have been published that show the potential of various types of waste: brick [7], concrete [8], rubber [9,10] and glass [1,11–19].

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However, when glass is an ingredient of cementitious mortars there is an additional concern: alkali-silica reaction (ASR). This is an expansive reaction that occurs between (soluble) silica and the cement alkalis in the presence of water. However, the reaction only occurs when these three elements occur simultaneously, which suggests that, on first analysis, it is technically feasible to use mortars such as these in the interior of buildings in terms of ASR related durability. Even though they should with greater caution be used on external surfaces, a recent study [1] developed in parallel with ours concluded that mortars with the composition described, and specifically for this type of glass, have very acceptable results for ASR expansion. It was therefore considered worthwhile to perform an exhaustive analysis to characterize this mortar type at the physical–mechanical and performance levels. The findings are summarized here.

The study reveals that, besides the environmental gains conferred by these mortars, their mechanical strength, physical compatibility with the substrate and low shrinkage (for replacement ratios that may reach 50%) can be exploited, thus significantly improving the general performance of this wall coating solution.

2. Literature review

Major studies have recently been developed on the performance of mortars containing waste materials, namely brick, concrete and rubber. However, there is relatively little literature on glass waste and therefore this study serves as a substantial contribution. Previous studies have analysed a very small number of properties and most of them only deal with alkali-silica reaction (ASR).

According to the literature, glass waste [11–19] requires less water than such wastes as brick [7], concrete [8] or rubber [9] (Table 1). These differences are mostly linked to the differing water absorptions of the waste types.

Concerning the bulk density of fresh mortar, studies are quite consistent, reporting a decrease as incorporation of waste increases. In fact the particle density of the waste is lower than that of sand, so justifying the same trend for fresh mortar's density. Incorporating waste materials in mortars while retaining the aggregates' size distribution causes a significant change of the internal structure of the mortar, associated with the different particle shape of the waste (crushed) *versus* sand (rolled). The different shape and superficial texture of the aggregates (waste and sand) determine different arrangements of the particles and influence the rheological characteristics, implying a change on the mixing water needed for adequate workability. Both different arrangements and different water contents have as a consequence, variations in porosity and pores size, especially those formed in the interface aggregate–matrix. This is reflected in the hardened mortar, since dry bulk density also decreases as the waste incorporation increases. The air entrapped during mixing of mortars with waste crushed aggregate also contributes to the decrease of the bulk density.

This change in internal structure also leads to an increment in water retentivity and incorporated air content when sand is replaced by waste materials. The increase in water retentivity is a very positive aspect in coating mortars since there will be more water available for the efficient hydration of cement, thereby preventing desiccation by suction of the substrate when the latter's water absorption is very high [20]. On the other hand, an increase in incorporated air content would be an added-value to accommodate gel associated with ASR as it is formed. The literature provides no results of this property for this specific waste, and therefore this is one of the most important aspects dealt with here.

The waste materials tested (brick, concrete, rubber and glass) have a wide range of stiffness. In fact the modulus of elasticity of mortar incorporating waste aggregates depends on the waste/sand relative stiffness.

The mechanical performance (flexural and compressive strengths) is a function of the stiffness/strength of the incorporated waste relative to that of the natural aggregates (sand). For aggregates derived from waste brick and concrete the results are satisfactory and maximum and minimum strength values have been identified as a function of the replacement ratio. For rubber waste the literature shows a reasonable performance, notwithstanding the loss of strength with its incorporation, and this is justified by the small replacement ratios tested [9]. For glass waste incorporation, even though it has high stiffness and strength compared with the others, the literature reveals a significant strength loss in cementitious mortars [11–15]. This is because in most studies involving this waste [12–15] the curing conditions for specimens tested under flexion and compression tended to accelerate ASR (immersion in a sodium hydroxide solution at 1 M, at 80 °C, in compliance with the ASTM C 1260 standard [2]), in addition to other factors related to the various properties of the glass types analysed. Since all the conditions favouring the occurrence of this reaction are in place, i.e. sufficient amounts of soluble silica, alkalis and water, together with the thermodynamic and kinetic conditions, ASR will occur, causing cracking of the specimens and consequent strength loss. However, when the three basic conditions for ASR to occur (sufficient amounts of soluble silica, alkalis and water) do not occur on site, there is a good possibility that ASR will either not occur (2) or be efficiently mitigated (2–4), namely if:

(1) The humidity level are below 75–90% (e.g. inside buildings), according to [21–24], cited by [25].
(2) The cement type and content is controlled [1].
(3) The size of the aggregate is controlled [1].
(4) The composition contains additions.

The mechanical potential of these mortars in the absence of ASR or when their tendency to expand is controlled is another important result presented here.

In previous studies [1] the water absorption was determined for mortars without waste and mortars with partial substitution of the sand by glass waste and it was found that this parameter goes down as the glass incorporation ratio goes up. As for the drying of mortars incorporating glass waste, there are no significant changes in the mixes, even compared with a conventional mortar (100% sand).

Concerning susceptibility to cracking (after application on a brick) previous studies [7–9] concluded that this was low for the mortars with brick, concrete and rubber waste. However, the test method used is qualitative and does not allow great precision. Therefore some images, acquired from a microscope magnifying glass and a scanning electron microscope (SEM), are presented in this study to detect any development of micro-cracking. Furthermore, the ultrasonic pulse velocity was determined in mini-wall sections (2 half-bricks on top of another brick) before and after ageing so as to evaluate the natural heterogeneity of the mixes, the level of micro-cracking, and the performance after accelerated ageing.

In terms of dimensional stability linked to drying shrinkage glass waste has been found to perform better than brick or concrete, in that shrinkage is high only for high replacement ratios and depends on the size of the aggregate, as seen in other studies [11,12].

For brick [7] and rubber [9] waste it is found that liquid water permeability falls after accelerated ageing as incorporation ratio of the waste materials increases. In the present study the analysis