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Incorporation of fine sanitary ware aggregates in coating mortars

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HIGHLIGHTS

- Incorporation of fine sanitary ware aggregates in coating mortars.
- Extensive experimental program on the mechanical, durability and water-related properties of these mortars.
- Almost all properties improved with the incorporation of fine sanitary ware aggregates.
- Prospective applications include brick laying, masonry pointing or masonry repair mortars.

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ABSTRACT

This paper analyses the behaviour of cement mortars with addition of grinded fine sanitary ware (GSWF) aggregates, in percentages of 0%, 10%, 15% and 20% of the natural aggregates' volume, to be used as renderings.

The effect of these recycled materials was studied in an experimental programme through several tests. The performance of these modified mortars was evaluated in terms of strength, water absorption, water retention, dimensional instability and water permeability. Some extra tests were also formulated to understand the microstructure of these mortars such as open porosity and magnifying glass observation.

The research results were very positive since the modified mortars had, in the most tests, better performance than the reference mortar (0% of GSWF addition). The modified mortar with 20% addition of GSWF was the one with the best performance of all the modified mortars, in particular in terms of higher strength and lower water absorption.

1. Introduction

The consumption of natural resources and energy has increased proportionately with the growth of the world population and its economic level. An exponentially growing consumption of relatively scarce resources ensued, with an increase in environmental impacts.

The construction sector is responsible for a very significant portion of the waste produced in Portugal, a situation that is common to most of the other European Union (EU) members, with an estimated global annual production of 100 million tons of construction and demolition waste (CDW) [1].

The ceramic industry is one of the largest contributors to the volume of CDW in Portugal. The ceramic industry can be divided into two sub-groups, according to the materials produced: red ceramic and white ceramic. The white ceramic industry includes sanitary ware [2]. In 2012 in the EU the production of these ceramic materials exceeded 38.1 million pieces [3]. In Portugal there are just over a dozen companies that manufacture and sell sanitary ware. Portugal produces annually an average of 4.5 million pieces, well above the European average, representing about 12% of the parts produced in the EU (while the Portuguese population represents only about 2% of the EU population).

For the production of these millions of pieces it is necessary to use natural resources and a substantial amount of energy. Adding to the consumption of resources and energy, there is also a high percentage of waste in manufacturing, due to the rejection of pieces due to quality control. The Portuguese ceramic industry, in 2012, produced 10,000 tonnes of sanitary ware waste [4]. Thus, about 5–10% of the production of sanitary ware needs to be disposed of. Sanitary ware is classified as a non-biodegradable material, taking over 4000 years to decompose in a natural process [2].

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To help to solve this problem this research analyses the possible incorporation of this non-biodegradable waste material in the construction industry and evaluates its performance in rendering mortars.

There are some recent studies on the incorporation of grinded sanitary ware in construction materials. The performance of incorporation of sanitary ware as aggregates in concrete [2,4–6] was evaluated. However the incorporation as fine aggregate in mortars has not been analysed before.

The components of mortars vary widely in size, physical and chemical characteristics [7] and they are responsible for mortar's performance. The addition of fine waste aggregates leads to an increment in mortar's compactness, in comparison with the mortars with no such addition.

The fine waste aggregates have advantages and disadvantages as mortar's aggregates. The advantages reported in other studies from various authors, relate to: workability, air content, mechanical strength, water retention, water absorption, permeability of water under pressure, and adherence surface.

The workability of mortar is a combination of properties, which determine the ease and effectiveness of use in masonry [7]. The workability improves with the incorporation of fine materials such as red ceramic [8], concrete [9] and glass [10], in maximum percentages of 10%, 15% and 20%, respectively. Thus the water required to maintain the consistency is lower. That is because the fines, due to a filler effect, fill the voids between sand aggregates, decreasing the amount of water required to hydrate and lubricate the aggregates. On the contrary, the incorporation of 25–50% of stone dust has a negative influence on workability [11]. This is probably because the incorporation ratio of stone dust is high and the benefits of this waste material are most important for lesser percentages.

The air content of fresh mortar increased with the incorporation of 10%, 15% and 20% of glass waste [10].

The incorporation of waste materials as aggregate in mortars improved the mechanical strengths: flexural and compressive strengths [8–12], because of the increase of compactness in these mortars. This increase of compactness also causes higher water retention, smaller water absorption and lower permeability to water under pressure.

According to Patural et al. [13] water retention is the property of a mortar that prevents the rapid loss of water to masonry units of high suction and bleeding or water gain when the mortar is in contact with relatively impervious substrates. The higher water retention of mortars with fines incorporation is due to the smaller voids of these mortars. The decrease in the mortar's voids content hinders the release of water from the coating [8–10]. This means that these mortars, when in contact with a porous substrate, have the ability of retaining water and thus the probability of reaching complete cement hydration is higher.

Smaller water absorption was found in modified mortars, with incorporation of waste materials [8–10]. Also, smaller water permeability under pressure was found by some authors [8,10]. Indeed, modified mortars showed better water performance than conventional mortars, with plain sand as aggregate.

The adherence to the surface also increased in modified mortars with fine waste incorporation [8–10]. These positive results are consistent with the improvement of mechanical characteristics and indicate that the fluid (cement + fines + water of the mortar) that penetrates the substrate has higher strength after hydration and promotes a better bond.

Modified mortars have many advantages in comparison with conventional mortars, with only sand as aggregate. Most of the advantages are due to the greater compactness of the modified mortars. However, this increase of compactness is also responsible for some disadvantages such as: higher modulus of elasticity, higher shrinkage and smaller water vapour permeability.

The modulus of elasticity is affected by the volume and number of the voids. Thus, the mortars with incorporation of waste materials have a higher modulus of elasticity in comparison with conventional mortars with greater volume of voids. This was verified by some authors [9,10,12]. The increase of modulus of elasticity is negative because it means that the mortars have more difficulty in coping with deformations. This characteristic can be an indicator of internal and external micro cracking. However a higher modulus of elasticity also suggests better mechanical strength and water behaviour.

According to Itim et al. [14], the shrinkage of an element can be defined as its deformation free of any external mechanical action in a constant thermodynamic environment. Some authors found higher shrinkage in mortars with incorporation of red ceramic [8], concrete [9] and glass [10], in maximum percentages of 10%, 15% and 20%, respectively.

Water vapour permeability decreases in comparison with the one of conventional mortars [8,9]. The permeability of water under pressure and the absorption of water by capillarity were both lower, which is positive because it means that the mortars will have less trapped water. However the low permeability of water vapour, on the contrary, is not beneficial.

Mortars with incorporation of fine aggregates from construction and demolition waste have many advantages over mortars with only sand. This research analyses the incorporation of fine sanitary ware waste in percentages of 0%, 10%, 15% and 20%, in order to have mortars with better performance than the conventional ones and, at the same time, to recycle a waste that does not have a practical application so far.

2. Experimental programme

2.1. General frame

To evaluate the influence of sanitary ware as an addition in cement mortars several mortars were analysed using the most relevant tests for renderings.

The experimental programme was divided in three phases:

- First phase: dedicated to the components of the mortar: cement, sand and sanitary ware.
- Second phase: all the mortars were subjected to the main characterization tests and some performance tests. The best modified mortar went forward to the final experimental phase.
- Third phase: the reference mortar and the modified mortars selected in the previous phase were analysed in the more specialized performance tests.

All the mortars analysed had a volumetric ratio of 1:4 (cement: aggregates) and are identified as:

- 1:4_0% – Reference mortar with 0% of addition of GSWF.
- 1:4_10% – Modified mortar with 10% of addition of GSWF.
- 1:4_15% – Modified mortar with 15% of addition of GSWF.
- 1:4_20% – Modified mortar with 20% of addition of GSWF.

2.2. Materials

The materials used in the experimental programme were: cement, sand and grinded sanitary ware waste.

The binder used in the research was cement type CEM II/B-L 32,5N, from the Portuguese producer *Secil*.

The natural sand used was previously washed and calibrated. The sanitary ware waste used came from crushed toilet rejects. They were first broken manually (Fig. 1) and then crushed with two mechanical devices: a grinding mill (Fig. 2) and a roll mill (Fig. 3). After crushing, the waste material was sieved and only the particles less than 149 μm in diameter were used.

2.3. Methods

The methods used in most of the tests complied with European standards, indicated hereinafter.