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A comparative analysis of the properties of recycled and natural aggregate in masonry mortars

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HIGHLIGHTS

- Masonry mortar is one of the most produced and used building materials in Havana, Cuba.
- Different fine mixed recycled aggregates and fillers were used for the masonry mortar production.
- Mortars were made using either 100% natural or recycled aggregates with all types of different fillers.
- The physical, mechanical and durability properties were analyzed.
- The adequate behavior of the recycled aggregate mortar is validated.

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ABSTRACT

Masonry mortar is one of the most manufactured and used building materials in Havana, Cuba. The lack of natural sand and the great quantity of demolition waste that exists in the city makes one realize the potential benefits of the use of this abundant waste material to create recycled fine aggregates for their use in the production of masonry mortars. In this research work three types of fine mixed aggregate were used. These aggregates, which were the result of the crushing of demolition waste proceeding from the three typical types of buildings in Havana, were used as a substitute for 100% of the natural sand used in the production of masonry mortar.

Due to the lack of natural fine aggregates Cuban regulations allow for the use of fillers in the manufacture of masonry mortars, in order to correct this defect. Three different types of filler were evaluated for masonry mortar production; lime hydrate (commonly used in Havana) white slag filler (a by-product of steel manufacturing) and limestone filler (natural). The masonry mortars were made using either 100% natural or recycled aggregates with any of type of filler, they were tested after a 28 days period of curing in a humidity room and their physical, mechanical and durability properties were analyzed. The results obtained from the tests proved that the masonry mortars manufactured with a combination of recycled fine aggregates and any of the three types of filler mentioned not only complied with the requirements established in the Cuban regulation, but in the majority of cases the properties obtained from these mortars were better than those mortars made with natural aggregate.

1. Introduction

The actual requirements of sustainability in construction promote the use of materials which cause a lower environmental impact than those traditionally used [1]. The vast majority of the mortars employed in Havana use natural aggregates in their production. The manufacturing of mortars which replace natural aggregates for those of recycled aggregates obtained from construction and demolition waste is a sustainable alternative. An alternative which can only be considered as beneficial as it reduces the exploitation of the existing quarries, thus conserving natural resources as well as reducing transport costs and minimizing the environmental impact resulting from the irregular dumping of construction and demolition waste (CDW) [2].

Employing the data recorded by the National Statistics Office (ONE) it is estimated that Havana generates about 1000 m^3 of CDW [3] daily. The majority of this CDW is tipped in communal waste dumps, causing them to be contaminated by other materials and consequently unfit for use. This situation is principally due to the lack of adequate technological infrastructures and policy deficiencies with respect to the management of these wastes.

In the absence of a selective demolition process the vast majority of uncontaminated CDW generated in Havana can only be

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classified as a mixed type. This CDW contains materials of differing natures (ceramic, concrete, mortar, lime, gypsum, etc.) which emphasizes the need for the development of treatment applications that will contribute to the sustainable development of the city.

Moreover, there is a steelmaking industry within the city (Antillana steel) that generates high volumes of waste slag. At present there is a large volume of slag accumulated around that industry and it is estimated that it generates in the region of 18,500 tons of slag annually [4], which could possibly be used as recycled aggregates or filler.

Many of the natural aggregate quarries near to the city are beginning to run out of material as a result of over exploitation. The consequence of this lack of materials is significant as the new quarries that supply the capital are increasingly more distant thus resulting in an increase in transportation costs [5].

Masonry mortars, which employ a lot of fine aggregates, are one of the most used building materials within Havana. These mortars are widely employed in a variety of construction uses, such as wall rendering or for brick and block laying. The performance level of these masonry mortars is not required to be very high, consequently allowing for the possibility of producing them with lower grade recycled fine aggregates in order to reserve the higher quality natural aggregates for the construction elements that require them.

The use of recycled aggregates from CDW for mortar production is not as widely studied as its use in concrete manufacture. Corinaldesi [6] analyzed the use of recycled fine aggregates obtained from waste concrete and ceramic bricks to create mortars that would be employed as a bonding material for masonry brickwork. She subjected the mortar to compressive and flexural load tests in order to determine its compressive and bonding strength. The results of her research showed that although the mortar produced from recycled aggregates had less compressive strength than that produced with natural aggregates, its bonding strength and its behavior under tensile stress was better.

Furthermore, with respect to other investigations, Silva et al. [7] concluded that 10% of ceramic fine incorporation improved most of the mortar properties. Braga et al. [8], increased the incorporation of very fine concrete recycled aggregates up to 15%, which resulted in the improvement of the majority of the properties of the reference mortar. The results obtained by Dapena et al. [9], showed that the use of up to 20% of recycled aggregate caused a little drop in the mechanical properties of the mortars. Vegas et al. [10] showed the possibility to replace up to 25% of natural sand by recycled concrete aggregate without decreasing the main properties of the masonry mortar.

Jiménez et al. [11], defined that the density and workability of mortars with a 40% replacement ratio of fine ceramic recycled aggregate decreased with respect to those of natural aggregate mortars, but the other properties such as compressive, tensile or bond strength maintained a similar performance to that obtained by the reference mortar.

Corinaldesi and Moriconi [12], produced mortars with 100% recycled aggregates which achieved lower mechanical properties than those obtained by conventional mortars. There was a noticeable difference when the recycled aggregates were obtained from ceramic bricks. However the mortars which were produced with recycled aggregates achieved higher bonding strength than conventional mortars.

In this research work the use of three types of recycled fine aggregates in the producing of masonry mortars were studied. Mortars were manufactured with 100% replacement of natural aggregate for recycled fine aggregate, also using three types of fillers available in Havana, hydrated lime, limestone and white slag filler (steel industry waste). The physical, mechanical and durability properties of the mortars containing recycled aggregates were determined, and the results obtained were compared with the values required by the Cuban regulations governing their use, the ASTM equivalent and the values obtained from conventional masonry mortars, which were produced with natural aggregates.

Table 1
Chemical composition of cement.

Elements	Results (wt.%)
Fe_2O_3	2.74
MnO	0.05
TiO_2	0.29
CaO	61.11
K_2O	0.79
P_2O_5	0.14
SiO_2	21.34
Al_2O_3	5.89
MgO	1.68
Na_2O	0.50

Table 2
Properties of fillers used in the study.

Physical properties	Lime Hydrate (LH)	Limestone Filler (LF)	Slag (WS)
Density (kg/dm^3)	2.1	2.58	3.2
Compacted volumetric weight (kg/dm^3)	0.57	1.50	1.42
Material finer than 75 μm (%)	88	32	63
Material finer than 45 μm (%)	27	7	37

2. Materials

2.1. Cement

Portland P-350 cement was used, having a density of 3.12 g/cm^3, specific surface of 3089 g/cm^2 and a compressive strength of 35 MPa at 28 days. The cement came from the Mariel plant, located in the province of Artemisa, adjacent to Havana. This plant is the leading supplier of cement in Havana. Table 1 shows the chemical composition of the cement.

2.2. Fillers

Three different fillers were used: lime hydrate (LH), limestone filler (LF) and white slag (WL, waste from steel production). According to Cuban regulations lime hydrate (LH) is the established filler to be employed in the production of masonry mortars. The limestone filler (LF) was obtained by the grinding of limestone and the white slag filler (WS) from the waste generated from the manufacturing of steel at a local steel industry. The white slag (WS) was composed of 47% CaO, 27.5% SiO_2, 9% Al_2O_3 and 13% MgO. Table 2 shows the properties of the three fillers used.

2.3. Fine aggregates

2.3.1. Production and composition of the recycled aggregates

The recycled aggregates used in this work were obtained from three different sources of Construction and Demolition Waste (CDW) originating from the most common types of housing to be found in the municipality of Guanabacoa (Havana). Approximately 80% of the CDW is generated from these three types of housing. The composition of the recycled aggregates depends on the building typology and the materials employed. The representative sampling was carried out according to UNE-EN 932-1:1997 after the crushing of between 3 and 4.5 tones of each of three types of building demolition waste. Table 3 shows the nomenclature used for three types of recycled aggregates, their composition as well as their origin.

The three types of recycled fine aggregates were produced by using the following production process:

First, the total volume of each type of CDW material was passed through a 4.76 mm sieve. The larger retained material was saved for crushing and the finer sieved material was discarded. Second, all the larger retained material was crushed into finer particles using a jaw type crushing machine. Third, all the crushed finer particles were passed through a 4.76 mm sieve. The finer sieved material was saved