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Mechanical and durability properties of concretes manufactured with biomass bottom ash and recycled coarse aggregates

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HIGHLIGHTS

- We made concrete with 100% recycled concrete and mixed aggregates.
- We manufacture three series with different amount of biomass bottom ashes.
- Mechanical properties were negatively with the addition of recycled aggregates.
- Durability properties declined with increasing recycled aggregates.

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ABSTRACT

Recycled materials of various types have been used as substitutes for coarse recycled aggregates and natural sand in the manufacture of concrete. Generally, the values of mechanical and durability properties decreases when applying different replacements of natural aggregates with recycled aggregates in both fine and coarse granulometries. However, new waste from the combustion of biomass as bottom ash has not been applied as a substitute for fine aggregate in the manufacture of concrete. In this research, concrete consisting of recycled aggregate substitutions was manufactured by applying different replacement rates of natural sand with biomass bottom ash. An efficient dosage method can be applied to obtain an optimal ratio of recycled concretes made with biomass additions. Mechanical properties and durability were evaluated in order to know the possibilities of application of these recycled materials in real concretes. The results showed a worse behaviour in these properties, however these reductions were inferior than it can be expected, due to the appropriate manufacture of the concrete applied.

1. Introduction

In civil constructions, the use of recycled aggregates (RA) in the manufacture of concrete is growing. This increase is a result of the environmental benefits, rather than the advantages in mechanical and durability behaviours presented by recycled waste. Thus, it is partially accepted that there are losses in the mechanical and durability properties for these recycled concretes.

Traditionally, the use of recycled aggregates for their application in construction elements, such as sub-bases for roads or embankments, was focused on a particular type, the recycled concrete aggregate (RCA). Agrela et al. [1] used RA treated with cement in the road sub-base for an access to a highway located in Malaga, Spain.

In recent decades, several studies have been performed on the concrete application substitutions of natural aggregates using RCA to verify their mechanical properties and durability. Kwan et al. [2] studied the mechanical and durability properties in concrete with RCA, and Kou et al. [3] studied the behaviour of concrete with natural aggregate and RCA using mineral admixtures.

Alternatively, International union of laboratories and experts in construction materials, systems and structures (RILEM) in its report containing recommendations for coarse recycled aggregates, included recycled mixed aggregates (RMA) in a mix of crushed masonry and concretes for the manufacture of new concretes [4].

However, the use of recycled mixed aggregates from crushed bricks and masonry is increasingly being investigated for their use in concrete and other construction elements. Mas et al. [5] studied the behaviour of non-structural concretes made with different amounts of RMA, and Martinez-Lage et al. [6] studied the physical–mechanical properties in plain concretes made with RMA.

Generally, many authors concluded that the replacement of NA by RA resulted in lower compressive strength values [7,8], lower flexural strength [9] and a modulus of elasticity [10] than the

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reference concrete. As for the durability properties, many authors have concluded that high RA rates cause significant degradation in certain properties such as penetration of water under pressure and chloride ion penetration, and it is obtained higher shrinkage values [5,11].

Regarding the use of RA as a fine fraction, various investigations have been conducted using these types of concrete aggregates to study their properties [12,13]. Similarly, several studies have incorporated the mineral additions of fly ash, blast furnace slags and metakaolin as an ordinary Portland cement substitution [3,14].

More residues from industrial processes could be applied in the manufacture of concrete for the environmental benefits it affords, if the final concrete did not result in an important reduction in mechanical property values as occurs in recycled concretes with RA.

In Andalusia, a region located in southern Spain, there are a large number of biomass power plants, which primarily use olive residues. These plants produce electrical power and two types of residues are obtained: biomass fly ash (BFA), formed by particles that are washed away by the gas stream to the outside of the combustion chamber and used for agricultural fertiliser, and biomass bottom ash (BBA), formed by particles not combusted [15] which is transported to landfills or dumps because the properties of these residues related to the mechanical behaviour in civil applications are not well known. BBA some studies have characterized physically and chemically the BBA. BBA has low density, high porosity and a high percentage of organic matter content [16–18]. Regarding BBA pozzolanic capacity, other studies have concluded that the presence of CaO in the combustion of biomass, such as olive wood, might limit the use of this type of fly ash because of its low pozzolanicity [18].

Furthermore, BFA has been studied for its possible use in the manufacture of concretes and mortars, replacing cement content. Cuenca et al. [15] concluded that the compressive strength in concretes prepared with substitutions of Ordinary Portland Cement (OPC) by BFA was slightly higher than those in self-compacting concrete. Maschio et al. [19] concluded that similar values of compressive strength and absorption were obtained for mortars that contained 5% BFA and that the properties declined with replacements that contained 10%, 20% and 30%, because of the high porosity.

However, the use of biomass bottom ash (BBA) has not been sufficiently studied. This ash presents different properties than BFA, characterised by a larger grain size and higher humidity, making it suitable for applying in road sub-grades, non-structural concretes, or embankments [16,18].

In this study, the BBA from the combustion of olive tree prunings was studied for its applicability in several substitutions of cement and natural sand in non-structural recycled concretes. The characterisation properties of BBA and RA were determined and then applied in the manufacture of recycled concrete. Additionally, physical (density, porosity and water absorption), mechanical (compressive and flexural strength) and durability properties (chloride and water penetration under pressure, shrinkage) of recycled concretes with different replacement percentages of cement and natural aggregates were studied. This paper presents findings concerning dosages, optimal replacements or modifications of properties in the application of RA and BFA in the manufacture of concrete.

2. Materials and methods

2.1. Materials

2.1.1. Cement

The cement used in the study was Ordinary Portland Cement (OPC), CEM I according to ASTM C150. It has a pure grey clinker, a characteristic strength of 42.5 MPa, and hardens rapidly. This cement is considered sulphate resistant because it has a low content of aluminium. All the chemical properties are summarised in Table 1.

2.1.2. Biomass bottom ash

As a fine fraction substitute, the bottom ash from the combustion of several biomass compounds (BBA) was used, coming from the thermal plant located in the village of Linares, Jaen, (Spain). BBA is a residue generated from the combustion of biomass composed primarily of olive mash and other biomass, such as olive orchard prunings as well as other energy crops. The process begins with the introduction of these products into the biomass-fuelled steam. Inside, the biomass is burned by a boiler at a temperature of 403 °C to naturally circulate heated water for steam. The BBA is obtained from a wet extraction system. The maximum particle size is 6 mm, but the fraction between 2 mm and 6 mm was removed to reduce the content of non-combusted particles.

Fig. 1 shows the BBA samples with the original granulometry and the processed 0–2 mm BBA. The properties of BBA are summarised in Table 2.

2.1.3. Recycled aggregates

Two types of recycled aggregates were used in this research whose particle-size distribution is shown in Fig. 1 and physical and chemical properties are in Table 2:

- Recycled aggregate from the crushing of concrete blocks and mortar (RCA), from plants in El Cabril (Córdoba), whose composition is shown in Table 3.
- Mixed recycled aggregate (RMA) from the crushing of concrete blocks and masonry blocks from the treatment of CDW in Gecorsa (Córdoba), whose composition is shown in Table 3.

2.1.4. Natural aggregates

Three types of natural aggregates were used in the manufacture of concrete: natural coarse gravel (CG), natural medium gravel (MG) and natural sand (NS) with a granitic nature from "La Serena" (Badajoz). The properties of the aggregates are shown in Table 2 and their particle-size distribution is shown in Fig. 1.

2.1.5. Comparison of aggregate properties

All of the aggregates present continuous granulometry. As it can be deduced from the sizes shown for each material, the RCA and RMA will replace the mix of CG and MG called natural gravel (NG) in the manufacture of concrete and BBA will replace NS.

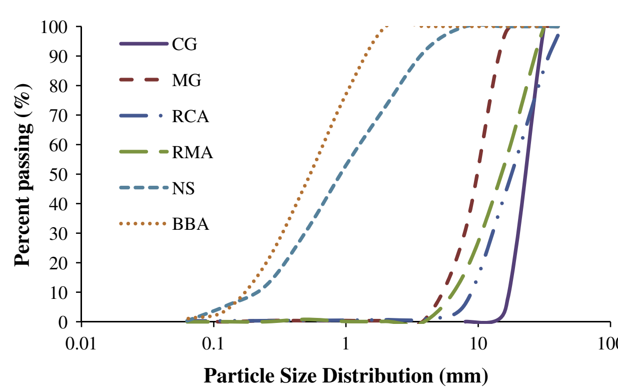

Fig. 1. Particle size distribution.

Table 1
Properties of cement.

SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	SO_3 %	K_2O %	Na_2O %	Granul. 45 μm %	Granul. 32 μm %	Blaine E. S. cm^2/g	Loss of ignition %
20.18	4.14	4.51	63.75	0.91	3.24	0.75	0.31	6.2	16.1	3701	1.44