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Mechanical performance of bedding mortars made with olive biomass bottom ash

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HIGHLIGHTS

- The use of biomass bottom ash (BBA) significantly increased the porosity of mortars.
- The incorporation of BBA led to the decline of mechanical properties.
- Mortars with CEM-II were more susceptible to incorporation of BBA than those with CEM-I.
- Bedding mortars with BBA can be made according to technical specifications, namely type M and N.

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ABSTRACT

Two waste streams result from biomass combustion for power generation: biomass fly ash (BFA), which is used as fertilizer in agriculture, and biomass bottom ash (BBA) currently with no practical applications and generally deposited in landfills.

This study provides significant information about the mechanical behaviour of mortars made with BBA, and the influence of several variables on such behaviour, namely type of cement, cement content, BBA incorporation ratio, and material type replaced with BBA.

Two mortar families were produced according to the type of cement applied (CEM-I and CEM-II). In each family, three volumetric replacement ratios of natural sand (NS) with BBA (0%, 10% and 20%) and three cement contents (515 g/L, 485 g/L and 450 g/L) were used. Mortars with replacement of cement with BBA (10% and 20% in cement volume) were also produced.

Four mechanical properties were analysed: porosity, density, flexural strength and compressive strength. Strength was analysed at different ages to assess its evolution over time.

There was a declining trend with the application of BBA for all properties analysed. Different behaviours were observed depending on the type of cement used or the material type replaced with BBA. Furthermore, there is an influence of porosity and density on strength due to the high absorption of BBA, allowing establishing meaningful relationships between the properties analysed.

This paper proves the viability of bedding mortars with BBA depending on the cement type and content and the BBA incorporation ratio.

1. Introduction

The generation of renewable energy has significantly increased in recent years, primarily due to the need to reduce gas emissions harmful to the environment. In 2010, the *per capita* emission of CO_2 was 5.8 metric tonnes in Spain, whereas in the Euro area, it was 7.4 metric tonnes [1]. According to the International Agency Energy, the current trend to reduce CO_2 emissions involves increasing the use of renewable energy as a substitute of energy from fossil fuels. Its use favoured the generation of 370 TWh worldwide, corresponding to 1.5% of global electricity generation [2]. According to the European Directive 2009/28/CE [3], it is expected that the amount of renewable energy consumed will become 20% of the total by the year 2020. This has led to an increase of the number of renewable energy power plants in Spain. In the region of Andalusia alone, there are 17 power plants using

Abbreviations: ASR, alkali silica reaction; BFA, biomass fly ash; BBA, biomass bottom ash; EHE-08, Spanish Concrete Code; NS, natural sand; OPC, Ordinary Portland Cement; P, plasticizer; PG-3, Spanish technical specification for road and bridge works; SSD, saturated surface dry.

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biomass combustion. This biomass is mainly composed of pruning from olive trees and other varieties of vegetation, such as poplar and eucalyptus trees.

Generating power from this type of raw material through combustion produces two waste products, biomass fly ash (BFA), formed by light particles agglomerated in the upper combustion furnace, and biomass bottom ash (BBA), consisting of heavier particles deposited at the base of the furnace.

Both waste products are formed by particles that are not combusted during the process [4]. BFA has been widely used in agriculture, mainly as fertilizer [5]. Some investigations on its use in construction have been performed. Rajamma et al. [6] studied the characterisation and use of BFA in cement-based materials by replacing Ordinary Portland Cement (OPC) with BFA at various ratios (10%, 20% and 30% in cement mass). They measured various properties of fresh and hardened mortars and concluded that replacing up to 20% of cement with BFA allows obtaining suitable mechanical strength. Cuenca et al. [7] manufactured self-compacting concrete using BFA from olive tree pruning combustion as filler, obtaining similar compressive strength in mixes with high amounts of superplasticisers relative to a reference concrete.

Wang [8] studied the influence of BFA on the compressive strength and alkali silica reaction (ASR) expansion in mortars. The author concluded that, for up to 25% incorporation by mass of BFA, ASR expansion decreased and compressive strength increased.

In Spain, an average of 43,000 tonnes of olive BBA are generated each year. Despite the high production of BBA [9], few investigations were conducted to study the possibility of using BBA in the construction sector. Cabrera et al. [10] made a physicochemical characterisation of 30 samples of three biomass combustion plants to compare the results with the specifications set by PG-3 for use in roads. Beltrán et al. [11] studied the mechanical and durability properties of concrete manufactured with coarse recycled aggregates (from masonry and concrete) as substitute of coarse natural aggregates and BBA as substitute of natural sand (NS) (volumetric NS/BBA replacement ratios of 0%, 10% and 20%). The results showed the feasibility of incorporating 10% of BBA in non-structural concrete.

Modolo et al. [12] investigated the influence of BBA on adhesive mortars, performing replacements of NS by BBA at rates of 25%, 50% and 100% in mass. The results proved the feasibility of using BBA in adhesive mortars within given limits.

Maschio et al. [13] replaced cement with BFA and BBA at 5%, 10%, 15%, 20% and 30% in mass, to study the rheological behaviour and compressive strength of mortars. It was concluded that up to 5% cement replacement with BBA, compressive strength and absorption were similar to those of the reference mortar.

The scarce literature shows the lack of information on the mechanical behaviour of mortars containing BBA. Therefore, the study of properties of mortars containing BBA provides significant data on the influence of BBA on the physical and mechanical behaviour of bedding mortars. The knowledge of the properties of mortars with BBA allows defining new ways of applying BBA, thereby enabling an environmental-friendly use of this type of by-product in the construction sector.

Based on these premises, this work studies in detail the mechanical behaviour of mortars in function of four main variables: type of cement, cement content, BBA incorporation ratio, and material replaced with BBA, providing interesting and novel results on the implementation of BBA in bedding mortars.

The results showed a reduction of compressive and flexural strength with the incorporation of BBA as replacement of cement and sand, as expected [13,14]. Similarly, due to the high porosity of BBA, mortars with lower density and higher porosity, relative to the control mortar, were obtained in all cases. On the other hand, interesting results were obtained by analysing the influence of given parameters on the mechanical behaviour and defining trends and relationships between various properties.

2. Materials

2.1. Natural sand and biomass bottom ash

Natural sand (NS), with nominal particle sizes of 0–2 mm, was used as reference aggregate in the production of mortars. The characteristics of this type of sand comply with Standard DIN EN 196-1, and its main properties are shown in Table 1.

Biomass bottom ash (BBA) with nominal particle sizes of 0–2 mm from a thermal plant located in Linares, Jaen (Spain) was used to replace cement and NS. This BBA is the result of the combustion of waste from olive pruning and other plant compounds. The plant material is deposited in a chamber and burned at 403 °C to generate steam that flows through a closed-loop system. BBA is the non-combusted waste generated in the process. Its physical and mechanical properties are presented in Table 2.

Table 2 shows that the absorption of BBA (19%) was significantly higher than that of NS (0.5%). Furthermore, the densities of BBA were lower than those of NS due to the high porosity of BBA. Similar values were obtained by Cabrera et al. [10], who obtained an average absorption of 20% and a similar SSD density (1.7 kg/dm^3) for BBA from the same plant.

The abrasion ratio of BBA was higher than that of NS, i.e. BBA is more susceptible to abrasion. However, the value obtained was below the maximum value (40%) indicated by the Spanish Concrete Code (EHE-08) [15]. This value is slightly higher than the average (26%) of the values obtained by Vegas et al. [16] for six fine recycled aggregates.

A chemical analysis of BBA concluded that it contains a high amount of organic matter (5.26%), as expected because the current combustion process does not eliminate this material. For complete removal of the organic matter, a new combustion process would be needed, with negative environmental impacts. This factor may affect the mechanical properties of mortars. Similar values were obtained by Hinojosa et al. [17] for samples of similar BBA.

Regarding size distribution, both NS and BBA were within the limits established by EHE-08 [15]. Furthermore, the analysis showed a continuous distribution of particle size for both fines, one of the steps necessary to ensure the compactness of mortars (Fig. 1).

Table 1
NS properties characterisation.

	Standard	NS	EHE-08 limits
Apparent density (kg/dm^3)	UNE-EN 1097-6	2.18	–
Dry density (kg/dm^3)	UNE-EN 1097-6	1.37	–
SSD density (kg/dm^3)	UNE-EN 1097-6	1.67	–
Absorption (%)	UNE-EN 1097-6	19	5%
Abrasion ratio (%)	UNE-EN 83115	29	40
Acid-soluble sulphates (%SO_3)	UNE-EN 1744-1	0.26	0.8
Water-soluble sulphates (%SO_3)	UNE-EN 1744-1	0.27	0.8%
Organic matter (%)	UNE-EN 1744-1	5.26	1%

Table 2
BBA properties characterisation.

	Standard	BBA		EHE-08 limits
Apparent density (kg/dm^3)	UNE-EN 1097-6	2.18		–
Dry density (kg/dm^3)	UNE-EN 1097-6	1.37		–
SSD density (kg/dm^3)	UNE-EN 1097-6	1.67		–
Absorption (%)	UNE-EN 1097-6	19		5%
Abrasion ratio (%)	UNE-EN 83115	29		40
Acid-soluble sulphates (%SO_3)	UNE-EN 1744-1	0.26		0.8
Water-soluble sulphates (%SO_3)	UNE-EN 1744-1	0.27		0.80%
Organic matter (%)	UNE-EN 1744-1	5.26		1%
Dissolved organic carbon (mg/l)	DIN EN 1484	730		–
Fig. 1. Phenox index (mg/l)	DIN 38409-H16-1	0.34		–
Fig. 2. Elemental content (wt.%)	UNE 80 215:1988	Si	24.52	–
		Ca	14.12	–
		K	13.10	–
		Mg	2.38	–
		Al	0.75	–
		Na	0.38	–
		Ti	0.14	–