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Potential use of biomass bottom ash as alternative construction material: Conflictive chemical parameters according to technical regulations

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HIGHLIGHTS

- The most conflictive chemical parameters were evaluated in BBA samples.
- A high variety of samples from different combustion power plants were analysed.
- The limiting chemical values of Spanish technical regulations were used as reference.
- The results prove the feasible application of BBA as a filler in road embankments.
- Furthermore, its use as cement treatment material under certain conditions was proven.

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ABSTRACT

The production of energy from renewable resources, such as biomass, is increasing rapidly. Therefore, environmentally friendly and economic solutions to recycle the resulting by-products are essential. The present study was performed to search for possible applications of the biomass bottom ashes that result from biomass combustion at three biomass combustion plants located in the Andalusia region of southern Spain. The analysis of chemical parameters indicated the applicability of biomass bottom ashes as an alternative material in civil construction. Thus, the limiting chemical parameters were analysed according to Spanish regulations. According to the results, biomass bottom ashes could be used as filler in road embankments, cement-treated materials or non-structural concrete, depending on the replacement percentage. This study determined that a review of the chemical parameters specified by the limiting regulations is recommended to promote the use of biomass bottom ashes as a building material in applications that do not require high structural strength.

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1. Introduction

The development of energy is essential from an economic and social point of view. The use of renewable resources as a source of energy and environmentally sound technologies are necessary to ensure a high quality of life and the well-being of future generations [1]. The substitution of coal and petroleum products as energy sources is being studied to reduce costs and decrease the emissions of harmful gases into the environment. Therefore, the study of various new and alternative sources of energy has intensified [2].

In the coming years, biomass will play a fundamental role as a natural resource for renewable energy due to the rising costs of fossil fuels, the doubtful safety of nuclear energy and the need to reduce CO_2 emissions [3]. According to the Directive 2009/28/EC (2009) [4] on the promotion of the use of energy from renewable sources, biomass is defined as the biodegradable fraction of products, waste and residues from the biological origin of farming (including plant and animal substances), forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste. Vassilev et al. [5] defined biomass as a complex heterogeneous mixture of organic matter and, to a lesser extent, inorganic matter, containing various intimately associated solid and fluid phases with different contents and origin. Biomass energy can be defined as the solar energy transformed to chemical energy through photosynthesis being stored in plant material [6].

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Andalusia can potentially produce large amounts of biomass, mainly from olive farming and related industries. This region primarily produces olive biomass, followed by eucalyptus and poplar biomass. Biomass can potentially be used to generate electricity and heat buildings and pools. In Spain, Andalusia leads the scope of power generation from biomass, with 18 biomass combustion plants and a total of installed capacity of 257.48 MW [7,8].

Biomass ashes (BA) are the solid by-products that results from the complete or incomplete combustion of the organic matter. The industrial BA consist of biomass bottom ash (BBA) or slag, and biomass fly ash (BFA) produced in industrial combustion and gasification installations at temperatures commonly between 800 and 1600 °C [5].

The amount of BA produced in combustion plants and their chemical composition depend on several factors, mainly biomass available as biomass fuel on the combustion plant, combustion technology, operation conditions, storage and transport system during the process [5,9–11].

BBA and BFA have been extensively studied focusing on several applications. BFA has typically been used in agriculture due to its mineral nutrient content, including calcium, potassium and phosphorus [12]. Because of the increased production of this by-product, BFA has been investigated for its use in building materials. Fly ash (FA) from coal combustion has been extensively studied over the years as an additive to traditional concrete [13]. FA in concrete increases its workability and contributes to its long-term strength [14]. Thus, Cuenca et al. [10] studied the possible use of BFA as a filler in self-compacting concrete, and Gómez-Barea et al. [15] studied the addition of BFA to manufacture lightweight wall board and bricks with special properties. Similarly, Fernández-Pereira et al. [16] have shown that up to 20% BFA by dry weight (d.w.) can be used to manufacture clay bricks. BFA was applicable in all of these cases depending on its properties and chemical composition. While fly ash utilisation has been extensively studied, similar studies on the effective management and utilisation of bottom ash have been scarce. BBA are traditionally disposed of in landfills. Some studies have focused on the reduction of this by-product generated from biomass combustion via technological improvements of the combustion system, as Sandberg et al. [17] that studied systems that operate with fluidised bed boilers. Other studies focused on the potential use of BBA as a building material. BBA have been used as aggregates to providing mortar formulations [18], and mortar pastes were obtained by replacing a commercial cement with the equivalent mass of 5, 10, 20 and 30 wt.% BFA or BBA [19].

Recently, an extensive study of BA was developed by Vassilev et al., which classified BA into 4 types according to their mineral phases and chemical composition [5]. Once the types were established their possible potential applications, technological and ecological advantages that may be associated with these uses were evaluated. Authors observed that due to the enrichment of BA with numerous phases (active, semi-active and pozzolanic) with cementitious behaviour, the aptness of this by-product for being used as construction material was proved [20].

In order to deepen the study of the suitability of use BBA as alternative construction material, the present study analyses BBA to identify the most limiting chemical factors which determine its possible real applications, namely the conflictive chemical parameters. For that, the Spanish technical regulations used are PG-3, *General Technical Specification for Road and Bridge Construction* [21] and *EHE*-08, *Structural Concrete Code* [22].

Due to the high variability factors that affect to the chemical composition of BA [5], several aspects, such as the combustion processes of the different tested plants and the composition of mixtures of the burned biomass, as well as chemical properties, such as the sulphate content, organic matter, chloride content, mass lost in ignition and potential reactivity, were evaluated in the present work.

2. Biomass power plants and biomass burned

In the present work, materials from 3 biomass combustion plants situated in the Andalusia region (see Fig. 1) were studied. The combustion plants belong to the *Sacyr Industrial Group* and the main technical characteristics are summarized in Section 2.1. In Section 2.2. the Biomass Fuel composition (BF) that originates the BBA samples is described, and the combustion processes and the by-products obtained are detailed in Section 2.3.

2.1. Combustion plants

Plants that were close to the areas of biomass production were included in this study. Furthermore, the proximity of the plant to evacuation power lines 66/132 kV, irrigated areas, available natural gas pipeline or communications routes was important [23]. The Andalusia region contains a cultivated area of 8,759,194.93 ha, of which 1,552,392.92 ha are used to grow the biomass crops studied in this work. Consequently, the potential energy from biomass is 3,958 ktoe for this region, approximately 40% of which consists of olive trees (Fig. 1) and products from industries related to the agricultural olive sector [8,24].

Biomass ashes were obtained from three combustion plants, whose characteristics are detailed below. The technical details of the combustion systems in these plants are illustrated in Figs. 2 and 3.

2.1.1. Linares Bioelectrical combustion plant or Biolinares combustion plant (BL)

Linares Bioelectrical or Biolinares is located in the town of Linares, Jaen. It is a combustion plant dedicated to energy recovery

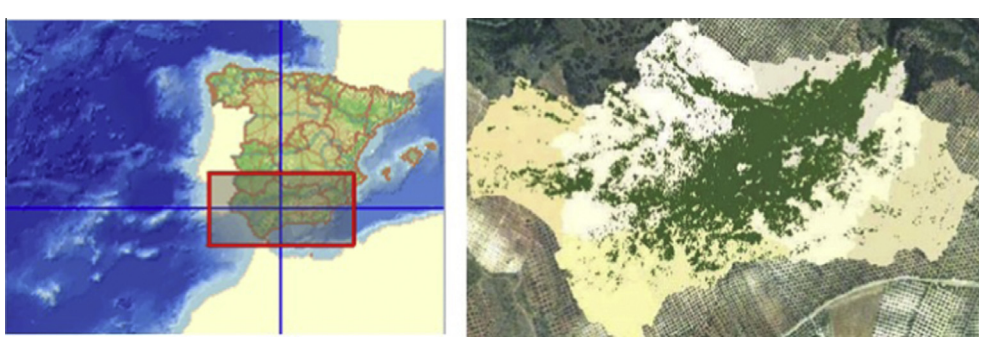

Fig. 1. Location of Andalusia region and olive trees distribution (green zone). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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