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Addition of bottom ash from biomass in calcium silicate masonry units for use as construction material with thermal insulating properties

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HIGHLIGHTS

- Bottom ash from biomass as a source of added value for building application.
- The samples were prepared with bottom ash, lime and Portland cement.
- The properties of silico-calcareous samples were studied following EN standards.
- Bottom ash and cement show the best compressive strength.

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ABSTRACT

This paper studies the effect of adding bottom ash from the combustion process of biomass plants to calcium-silicate samples for use as construction material with thermal insulating properties.

After a process of physical, chemical and mineralogical characterization of the raw materials, calcium-silicate samples were manufactured by mixing bottom ash (CF) with different sources of lime (calcium oxide-OC and calcium hydroxide-HC) and Portland cement (CM). The amount of bottom ash added ranged from 10% to 90% of the dry weight of the mixtures.

The experimental program included a wide range of testing methods of the developed material such as water absorption, mechanical strength, porosity, microstructure, freeze–thaw and thermal conductivity.

The optimal values are those containing a 1:1 ratio of SiO_2/CaO, with compressive strength ranging from 25.21 MPa (CF/HC) to 61.11 MPa (CF/CM) and thermal conductivity from 0.564 W/m K (CF/OC) to 0.773 W/m K (CF/HC). The initial results obtained make it possible in principle to obtain calcium-silicate samples with low thermal conductivity according EN standard 771-2:2011.

1. Introduction

The increase in the global population and advances in technology oriented to new habits of consumption have brought rapid growth in large quantities of solid wastes. As a result, there is growing interest in finding ways to minimize these wastes or even to use them as a resource with added value.

One of the basic goals proposed in Directive 2008/98/CE on Waste [1] and Spain's Integrated National Waste Plan (PNIR 2008–2015) [2], is to foster the reuse, recycling and extraction of value from waste. Developing an alternative market for waste provides an excellent opportunity to develop new initiatives and to foster new sites for employing waste, while also permitting their use, for example, as raw materials or unconventional fuels. Putting these measures into practice encourages prevention and reduction of the environmental impact of their production and management, fostering efficient, sensible and sustainable energy technologies. The PNIR foresees that, by 2015, Spain will gain value from 65% of the non-hazardous industrial waste generated.

One sector that has experienced a sharp increase in waste production, especially of ash, is the generation of electricity from biomass.

Biomass ash is the solid waste that results from the combustion, complete or incomplete, of biomass and it shows a heterogeneous mix of variable composition with both organic and inorganic components [3]. The quantity and quality of the ash produced in biomass plants is strongly influenced by the characteristics of the biomass used [4]. Although it is included in the European Community's legislation on non-hazardous industrial waste [5], the ash generated in the biomass combustion process is becoming an increasing economic and environmental burden. The related goal of using 20% renewable energy by 2020, according to Directive 2009/28/CE to foster the use of energy from renewable sources

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[6], will lead to the production of approximately 15.5 million tons of biomass ash in the EU-27 [7].

The lack of legislation and regulations in many countries, logistical problems and variation in the quality of the ash, among other factors, lead most countries to prefer depositing the ash in dumps [8].

As an alternative to dumping, there are various possibilities for using biomass ash, based on both the physical and the chemical properties of the ash [7,9–15]. The current scarcity of natural resources and the demands of regulations in construction sector encourage the search for new materials from which to derive value from industrial waste capable of satisfying the technical needs of construction within the framework of sustainable development. It is in this context that biomass ash has great potential for incorporation, whether as a raw material, an addition, or filler [16–30]. It also has application in producing component in the $CaO–SiO_2–H_2O$ system. Obtained by mixing sources of lime and silica and used mainly as construction material with thermal, acoustic and fire insulating properties, these components are classified under the general term C–S–H [31–39].

The aim of the present work is to study the effect of adding bottom ash from the process of biomass plant combustion to obtain calcium silicate samples by partial replacement of the sources of lime and Portland cement with bottom ash in increments from 10% to 90% of the dry weight of the mixtures for use as masonry units with low thermal conductivity.

The experimental program included a wide range of methods for the characterization of this by-product including physical, chemical and mineralogical properties as well as some testing methods of the developed material such as mechanical strength, porosity, microstructure, freeze–thaw and thermal conductivity.

The use of bottom ash from biomass power plants as masonry units can be evaluated as an alternative to its use as fertilizer or disposal in landfills.

2. Experimental methodology

2.1. Materials

The materials used were boiler bottom ash (as a source of silica), obtained from the combustion process of a vibrating grate boiler from the biomass electric plant of Linares, located in the province of Jaén (Andalusia, Spain) and different sources of lime, such as calcium oxide (quicklime CL90Q) and commercial calcium hydroxide (hydrated lime) and Portland cement CEMII/B-L 32.5R. The biomass plant of 15 MW of power uses the following mix of biomass as fuel: olive oil waste "orujillo" (40%) and energy crops, cleared underbrush and pruning from olive and fruit trees (60%).

2.2. Characterization of the raw materials

Physical, chemical, mineralogical and microstructural characterization of the raw materials was performed to achieve research goal.

The moisture content of the materials was determined using the EN 772-10:1999 standard [40], their pH using a pH-meter and the carbonate content (CaCO3, %) using Bernard's calcimetry.

The distribution of the particle size was performed using sieve granulometry following EN standard 933-1:2012 [41] for bottom ash and laser for the different sources of lime and Portland cement.

Real density was measured using helium gas pycnometer and the specific surface area (BET) by obtaining the adsorption–desorption of N_2 at 77 K.

The thermal behavior was obtained by TGA/DTA analysis subjecting the samples to a heating process at a speed of 20 °C/min from room temperature to 1000 °C.

The carbon, hydrogen, nitrogen and sulfur content were determined using elemental analysis CHNS-O. The chemical composition was obtained using sequential wavelength-dispersive X-ray fluorescence spectrometer (WDXRF).

In order to evaluate the leaching behavior of bottom ash and its potential impact on the environment, the batch leaching test was carried out according to EPA method 1311 (TCLP) [42]. As, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn were determined by Inductive Coupled Plasma Mass Spectrometry (ICP-MS) equipment.

The crystalline phases present in the samples were determined using X-ray diffraction (XRD) in diffractometer with radiation CuK1,2 (1.5406 Å) using High Score Plus software. The microstructural analysis was performed with scanning electron microscopy (SEM).

2.3. Design of the calcium silicate samples

After obtaining results for the phase characterizing the bottom ash and the different sources of lime and Portland cement design mixes were developed to obtain the different calcium silicate samples (see Fig. 1).

After drying in an oven at 105 °C for 24 h, the bottom ash was milled in a ball mill until a homogeneous particle size was obtained. It was then sieved to obtain a particle size of 100 μm.

The next step was to mix the raw materials in solid state, using a mixer. The addition of water to the mixtures in proportions ranging from 5% to 30% of their weight was optimized to obtain consistency of the mixture for the subsequent compression process.

Nine sample series were prepared (numbered 1–9), with 16 samples (size 60 × 30 × 10 mm) weighing 50 g for each homogenized mix (for a total size of 432 samples) shaped in hydraulic press. The samples were formed in a cylindrical mold with a rectangular opening by applying uniaxial loads of 20 MPa for 30 s. The dimensions of the samples conformed were measured according EN standard 772-16:2011 [43]. The blends contained proportions of SiO_2/CaO mass ratio from 1:9 to 9:1.

The names used to identify the different series of mixtures prepared in the laboratory were CF/OC for bottom ash (CF) and calcium oxide (OC), CF/HC for bottom ash (CF) and calcium hydroxide (HC) and CF/CM for bottom ash (CF) and Portland cement (CM).

Two additional control series were prepared using the base materials with bottom ash and Portland cement constituting 100% of the dry mass, respectively.

The specimens in each series were subjected to a curing process in water for 28 days (at 20 °C), in accordance with EN standard 12390-2:2009 [44].

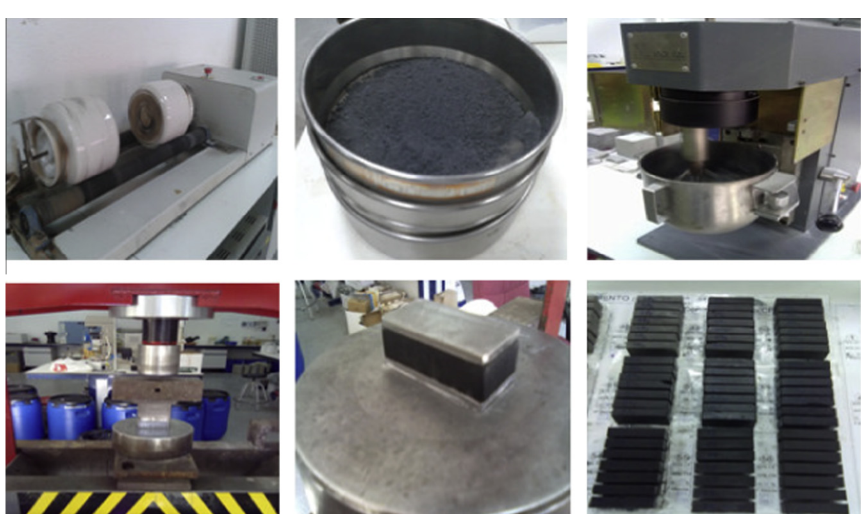

Fig. 1. Processes to obtain calcium silicate samples: (a) homogenization of particles in ball mill, (b) sieving of bottom ash to 100 microns, (c) mixing of sources of silica and lime, (d and e) obtaining press-formed samples, and (f) series of finished samples.