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Use of bottom ash from olive pomace combustion in the production of eco-friendly fired clay bricks

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ABSTRACT

Olive pomace bottom ash was used to replace different amounts (10–50 wt%) of clay in brick manufacturing. The aim of this study is both studying bricks properties and showing a new way of olive pomace bottom ash recycling. Properties of waste bricks were compared to conventional products following standard procedures in order to determine the maximum waste percentage. The amount of olive pomace bottom ash is limited to 20 wt%, obtaining bricks with superior engineering properties when 10 wt% of waste is added. Adding higher amount of waste (30–50 wt%) resulted in bricks with water absorption and compressive strength values on the edge of meeting those established by standards. Therefore, the addition of 10 and 20 wt% of olive pomace bottom ash produced bricks with a bulk density of 1635 and 1527 kg/m^3 and a compressive strength of 33.9 MPa and 14.2 MPa, respectively. Fired bricks fulfil standards requirements for clay masonry units, offering, at the same time, better thermal insulation of buildings due to a reduction in thermal conductivity of 14.4% and 16.8% respectively, compared to control bricks (only clay).

1. Introduction

The evolution of oil prices and the geographical distribution of energy reserves have conditioned the energy options in developed countries for more than three decades. Securing supply, respecting the environment and economic competitiveness are the cornerstones of the European and Spanish energy policy. Spain now boasts a solid normative framework in support of renewable energy. Energy from biomass for use in thermal and electrical applications is having more growth prospects thanks to the Spanish Development Plan Renewable Energies. In Spain, biomass consumption has been rising in recent years, being in 2010 of 4751 ktep GW h, 8.0% higher than the previous year according to the data from the European Observatory for Renewable Energy, EurObserv'ER. Among the Spanish autonomous communities, Andalusia, Galicia and Castilla-Leon recorded higher consumption. Almost 40% of all the energy from biomass in Spain can be found in Andalusia, Spain's southermost region. Therefore, Andalusia boasts an important wealth of biomass, largely coming from the cultivation of olive and its derived industries. According to the directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources, biomass is defined as: "The biodegradable fraction of products, waste and residues of biological activities from agriculture (including vegetal and animal substances), forestry and related industries, including fishing and aquaculture, as well as the biodegradable fraction of industrial and municipal waste". Using biomass energy allows the replacement of fossil fuels, a greater self-sufficiency and energy diversification, and contributes to the maintenance of activities in rural areas. Biomass potential detected in Andalusia amounts to 3958 ktep. Considering that consumption of primary energy in Andalusia in 2011 was of 19053.3 ktep, the potential of biomass represents 20% of the energy needs in Andalusia.

In Andalusia, during 2011, a total surface of 1,500,000 Ha of olive groves was reached, what in an average campaign produced about 4,650,000 tons of olive. Of these, approximately 4,300,000 tons/year are intended to obtain olive oil and the remaining 350,000 tons/year will be used in dressing table olive industry. The average quantity of oil produced is 900,000 tons/year. For each ton of processed olives yield, 0.73 Tm of pomace (73%) is produced. Once dried and submitted to the oil extraction process, 27% (0.197 Tm) of pomace is transformed into dry olive cake or *orujillo,* which can be used as fuel. *Orujillo* is a by-product with humidity around 10% which has good properties as fuel, with a calorific value of around 4200 kcal/kg on a dry basis, and it can be used for both energy and heat generation in industries. A part of

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Nomenclature list

ktep	kilotonnes equivalent to petroleum
GW h	Gigawatt hour
Ha	hectare or square hectometer
Tm	tonnes
MW	Megawatt
LOI	loss on ignition
OPBA	olive pomace bottom ash

orujillo in the cooker hoods consumes itself in the installation, both during pomace drying process and steam generation in boilers. Olive pomace and dry olive cake are rich in organic matter and potassium (Alburquerque et al., 2004). At present, there are 18 stations of electric biomass and cogeneration with biomass in Andalusia with a total installed capacity of 25,748 MW, and newer plants are planned. Ash produced by combustion process can be classified into bottom and fly ash (cyclone and filter fly ash). Bottom ash is produced on the grate in the first combustion chamber of the boiler and they consist of totally or partially burnt biomass. Fly ash are particles carried outwards the combustion chamber by the flow of gases. Using dry pomace as fuel generates a large amount of ash (between 4% and 8% of the burnt waste). Biomass plays a fundamental role in an energy framework in which sustainability, diversification and a high degree of self-sufficiency prime. Therefore, various administrations, both at regional, national and European level are determinedly betting on this renewable energy. Common disposal of biomass ash is landfilling next to power plants, but this alternative is the least attractive in an environmental management. Consequently, the volume of biomass ash generated will be important and will grow in the upcoming years, ensuring enough biomass ash for recovery is available. Dry olive pomace ash is used mainly as fertilizer due to its high content in potassium (Nogales et al., 2011). Other studies describe potential use of olive pomace ash as soil amendment (Nogales et al., 2006), as adsorbent to remove copper (Cu^{2+}) ions from aqueous solutions (Bouzid et al., 2008), as raw materials for cement based products (Cuenca et al., 2013; Cruz-Yusta et al., 2011) and as building material (De la Casa and Castro, 2014; Fernández-Pereira et al., 2011; García Calvo et al., 2010). So, even though only few studies have assessed olive pomace ashes, many authors have described the recovery of biomass ashes as raw material for building materials (Cabrera et al., 2014; Carrasco-Hurtado et al., 2014; Hinojosa et al., 2014; Kalembkiewicz and Chmielarz, 2012; Maschio et al., 2011; Pavšič et al., 2014; Pérez-Villarejo et al., 2012; Rajamma et al., 2009; Sua-Iam and Makul, 2015; Vassilev et al., 2013b) in recent years. For environmental protection and sustainable development, many authors have studied the utilization of industrial waste materials as additive of clay bricks. Some different inorganic waste materials such as ferrochromium slag, pumice, marble, galvanic sludge, waste glass, and construction and demolition waste have been used (Gencel, 2015; Gencel et al., 2013; Muñoz-Velasco et al., 2014; Neves Monteiro and Fontes Vieira, 2014; Pérez-Villarejo et al., 2015; Phonphuak et al., 2015; Sutcu et al., 2015; Xu et al., 2014; Zhang, 2013). Mineralogical and composition content of industrial inorganic wastes are well-matched with the of brick structure.

This research work tries to deepen the characterization and possible use of olive pomace bottom ash, focusing on determining, by means of laboratory scale tests, the technological properties of raw materials in the preparation of clay bricks, optimizing the quantity of residue to be added, checking physical, mechanical and thermal properties of the new materials, compared to those obtained by using only clay (control bricks).

2. Experimental

2.1. Materials

Clay was supplied by a clay pit located in Bailen, Jaen (Spain). It was obtained by mixing three types of raw clay in equal parts: red, yellow and black clay. Waste used was bottom ash, a by-product of combustion in a steam boiler from the biomass power plant *La Loma* in Villanueva del Arzovispo, Jaen (Spain). The biomass power plant used olive pomace as fuel.

2.2. Experimental method

The moisture content of olive pomace bottom ash (OPBA) and organic content was measured according to ASTM D-2974, Standard Test Method for Moisture, Ash, Organic Matter of Peat and Other Organic Soils (ASTM D-2974, 1987) and their pH using a PCE-PH20S pH-meter.

Particle size distribution was performed using sieve granulometry following EN 933-1:2012 (EN 933-1, 2012).

Carbonate content (expressed as calcium carbonate) was determined by calcimetry in a Bernard calcimeter.

Qualitative determination of major crystalline phases in clay and OPBA was achieved using the Philips X'Pert Pro automated diffractometer equipped with a Ge (1 1 1) primary monochromator. Chemical composition was determined by X-ray fluorescence (XRF) using the Philips Magix Pro (PW-2440). Thermal behaviour was determined by thermogravimetric and differential thermal analysis (TGA–DTA) with a Mettler Toledo 851e device in oxygen. The total content of carbon, hydrogen, nitrogen, and sulphur was determined by combustion of samples in O_2 atmosphere using the CHNS-O Thermo Finnigan Elementary Analyzer Flash EA 1112. The higher heating value (HHV) was determined using a Parr 1341 Plain Oxygen Bomb Calorimeter.

After characterization of the clay and the bottom ash, the appropriate mixtures for samples were designed. To obtain a uniform particle size, clay was crushed and ground to yield a powder with a particle size suitable to pass through a 150 μm sieve. The waste, olive pomace bottom ash, was dried in an oven at 105 °C and milled in a ball mill until homogeneous particle size was obtained. Particles were sieved throught a 150 μm mesh prior to their incorporation into clay bricks in order to reduce agglomeration. The OPBA was added to clay in different amounts (0–50 wt%) and it was mixed to obtain good homogenization. To enable comparative results, ten samples per series were prepared for testing. The necessary amount of water (7–10 wt% moisture) was added to the samples to obtain adequate plasticity and absence of defects, mainly cracks, during the semi-dry compression moulding stage under 54.5 MPa of pressure, using a uniaxial laboratory-type pressing Mega KCK-30 A. Waste-free mixtures were also made as a reference. Solid bricks with 30 × 10 mm cross sections and a length of 60 mm were obtained. Samples were fired in a laboratory furnace at a rate of 3 °C/min up to 950 °C for 4 h. Samples were then cooled to room temperature by natural convection inside the furnace.