



## Research paper

# Technical feasibility of reusing coal combustion by-products from a thermoelectric power plant in the manufacture of fired clay bricks



B. Sena da Fonseca<sup>a,b,\*</sup>, C. Galhano<sup>b,c</sup>, D. Seixas<sup>c</sup>

<sup>a</sup> ICEMS-DEQ, Instituto Superior Técnico, ULisboa, 1049-001 Lisboa, Portugal

<sup>b</sup> CICEGe, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

<sup>c</sup> Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

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## ABSTRACT

This paper intends to study the suitability of reuse a waste produced by thermoelectric power plants in the clay bricks industry. One of the main by-products is bottom ash and currently only half of these residues are reused; therefore a new environmentally-friendly solution is researched.

Besides a chemical and mineralogical characterization of bottom ash, clay bodies were moulded by using clay pastes with 2.5, 5, 10, 15 and 20 wt.% of bottom ash. Then the green bodies were fired at 900, 1000 and 1100 °C and thereafter studied.

This bottom ash shows particular features of a fluxing agent which reduces the melting point of the liquid phase, and so the water absorption and open porosity tend to decrease with the increasing amount of waste, while the bulk density increases. Improvements were found; some regarding the mechanical strength and salt fog resistance due to bottom ash incorporation, especially in the case of samples fired at 900 °C with 20% of bottom ash. Since ceramics made from these mixtures reveal good performance at all levels, the bottom ash shows high potential to be used in the ceramic industry.

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## 1. Introduction

Coal has an important role in the energy consumption in many countries (Liu et al., 2004). In fact, coal power plants supply over 42% of global electricity demand (OECD/IEA, 2010). During the combustion of coal, different types of residues are produced: fly ash, bottom ash, boiler slag and fluidized bed combustion ash and flue gases (Shamshad et al., 2012; Vinai et al., 2013). Currently, more than 600 million tons/year of these residues are generated, of which 60–90% are bottom ash (Carrasco et al., 2014; Vinai et al., 2013). In the past, the final disposal for these residues was landfill (Anderson et al., 1996), but presently the society is making an effort to reuse all the types of waste and landfill is the last alternative in the waste management options list.

After detecting their potentialities, the use of waste is considered an activity that can contribute to material diversification, decreasing the products' final costs and reducing the demand of natural resources (Menezes et al., 2005; Vinai et al., 2013).

The building industry, which usually involves huge amounts of resources, is at the forefront on residue reutilization (Cultrone and Sebastián, 2009). In particular, the concrete and fired clay ceramics are materials that can tolerate high compositional fluctuations. Therefore,

in the last years the partial substitution of clay in bricks by several types of waste is being investigated, e.g. processed waste tea (Demir, 2006), waste bricks (Demir and Orhan, 2003), sewage sludge (Martínez-García et al., 2012), rock sawing waste (Menezes et al., 2005; Sena da Fonseca et al., 2013), red mud (He et al., 2012), oily waste (Monteiro and Vieira, 2005), recycle paper mill waste (Raut et al., 2012), coffee waste (Eliche-Quesada et al., 2011; Sena da Fonseca et al., 2014; Vilão et al., 2012), and ash from biomass incinerator (Pérez-Villarejo et al., 2012).

The use of coal combustion by-products from thermoelectric power plants in cementitious mixtures has also been a focus of research. Regarding the Portland cement substitution by ash, some contradictory results can be found (García-Ubaque et al., 2013). Nevertheless, fly ashes (both, class F and C) from coal combustion are frequently used in concrete production (Andrade et al., 2007; Cultrone and Sebastián, 2009; Naik et al., 1994).

This solution cannot consume all the produced waste; it was estimated that only 55.2% of produced coal combustion residues are reused, mainly by the cement and mining industries (Vinai et al., 2013). Thus, the necessity of environmentally friendly solutions for coal combustion residue disposal is still a concern.

Studies on the use of coal fly ash in fired clay ceramics have also been investigated (Aineto et al., 2006; Lingling et al., 2005; Little et al., 2008; Queralt et al., 1997; Sokolar and Vodova, 2011). However, studies concerning the reuse of other by-products are quite scarce. Furthermore,

\* Corresponding author at: CICEGe, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal. Tel.: +351 925455230.

E-mail address: [senadafonseca@gmail.com](mailto:senadafonseca@gmail.com) (B. Sena da Fonseca).

**Table 1**  
Chemical composition of raw materials.

	Clay	Bottom ash	2.5% mixture	5% mixture	10% mixture	15% mixture	20% mixture
SiO <sub>2</sub>	61.48	54.85	61.31	61.15	60.82	60.49	60.15
TiO <sub>2</sub>	1.61	2.8	1.64	1.67	1.73	1.79	1.85
Al <sub>2</sub> O <sub>3</sub>	21.89	16.12	21.75	21.60	21.31	21.02	20.74
Fe <sub>2</sub> O <sub>3</sub>	3.74	16.45	4.06	4.38	5.01	5.65	6.28
MnO	0.47	1.29	0.49	0.51	0.55	0.59	0.63
MgO	0.06	0.73	0.08	0.09	0.13	0.16	0.19
CaO	8.73	4.95	8.64	8.54	8.35	8.16	7.97
Na <sub>2</sub> O	0.07	0.17	0.07	0.08	0.08	0.09	0.09
K <sub>2</sub> O	1.85	2.44	1.86	1.88	1.91	1.94	1.97
P <sub>2</sub> O <sub>5</sub>	0.08	0.09	0.08	0.08	0.08	0.08	0.08
ZrO <sub>2</sub>	0.01	0.11	0.01	0.02	0.02	0.03	0.03
L.O.I.	6.26	–	–	–	–	–	–

most of the literature is focused on the viability of making bricks from mixtures of clay and coal combustion residues with emphasis on the resulting physical and mechanical proprieties, but further investigations on the material durability are needed. The degradation of building ceramic materials could affect the material's correct performance and cause aesthetical, functional and security problems (Moser, 1999).

The interaction between the salt spray and building materials causes severe damages. Efflorescence resulting from salt deposits has been observed in old clay ceramic facades and harmful types of damaging like exfoliations or spalling were found (Kuchitsu et al., 2000; Lubelli et al., 2004). Due to severe exposure to sea spray, this type of degradation has also been found in ceramic facades from recent buildings (Sena da Fonseca, 2012). By using short-term tests, this type of degradation has been widely studied in other construction materials, namely in dimension stone (Galembeck et al., 2008; Silva and Simão, 2009).

The present work aims at providing further knowledge in the proprieties and behaviour of bricks made of clay and a specific type of coal combustion residue, bottom ash.

For this purpose, clay mixtures with up to 20 wt.% of bottom ash were made and their behaviour was evaluated by plasticity tests. Green samples were fired at 900 °C, 1000 °C and 1100 °C and the effect of sintering temperature and amount of bottom ash were studied through physical and mechanical tests.

To understand the degree of alteration provided by these variables in decay resistance, the samples were submitted to an accelerated salt fog ageing test.

## 2. Experimental

The clay material used in this investigation was obtained from one manufacturing industry in Aveiro region, Portugal. The bottom ash was taken from a coal thermoelectric power plant in Sines, Portugal. The bottom ash, as received, is a coarse material with dimensions spanning from fine sand to gravel. For its analysis, the bottom ash was slightly grinded (1 min in a ring mill) and further experiments were conducted using these particles. The particles to be used have a fraction of 66% larger than 63 µm with a mean grain size of 138 µm, while 34% of material has dimensions below 63 µm.

To determine the chemical and mineralogical composition of both materials, the powders were analysed by a scanning electron microscope and X-ray diffraction, according to Galhano et al. (1999).

Six different mixtures of clay/bottom ash were prepared: clay without residue and with the following additions of bottom ash: 2.5 wt.%, 5 wt.%, 10 wt.%, 15 wt.% and 20 wt.%.

In order to characterize and evaluate the differences in raw material behaviour, plasticity tests were made by the Atterberg consistency limits in accordance with NP-143 (1969).

The green samples (100 × 20 × 20 mm) were made using a hydraulic press, a load sensor (Centor Easy R Andilog) and gypsum moulds. The load applied in moist mixtures was 2.6 kN. The linear shrinkage was measured by a calliper in dry samples.

Afterwards, the samples were fired in an electric kiln under oxidizing conditions at 900, 1000 and 1100 °C. The temperature increased at a rate of 2.7 °C/min and a plateau of 1 h was made at 525 °C.

Despite not being common in brick production the use of firing temperatures above 1000 °C, the temperature of 1100 °C was used mainly to provide more information and a better understanding of ceramics physical behaviour due to the action of salt crystallization.

The determination of bulk density, apparent porosity and water absorption in fired samples were made according to ASTM C373 (1999) standard. The effect of the increasing bottom ash content on the mechanical strength was evaluated by flexural tests made in a Ceramic Instruments Press, according to ASTM C1161-2 (2008) standard. Despite the non-standard dimensions, compression tests were made in samples with the dimensions of 40 × 20 × 20 mm, in a Zwick universal testing machine.

The assessment and quantification of colour changes induced by the different firing temperatures and amount of bottom ash were made by placing the samples directly under the colourimeter (ColorTec-PCM) and recording the colour characteristics according to CIE Lab system, which is the most used in ceramic materials (Società Italiana di Ceramica, 2003). Three different points in each sample were measured and the mean values were used for analysis.

The colour difference between two samples could be obtained according to Eq. 1, where ΔE value is conventionally used to indicate whether a colour is sufficiently close to a reference colour, or a colour to be copied (Società Italiana di Ceramica, 2003).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (1)$$

In terms of ceramic industry it is crucial that the actual difference between elements and the standard colour does not exceed ΔE = 1 (Società Italiana di Ceramica, 2003).

Four samples of each type were submitted to a salt spray ageing test for 15 days, each day comprises 6 h of active spray and 18 h of drying (total of 15 cycles). The test was performed in an ASCOTT S120T chamber containing a solution with 1 part of NaCl to 19 parts of distilled water. The chamber temperature was maintained constant at 55 °C (± 2 °C) during the entire exposure time.

Thereafter, the samples were placed in a container filled with distilled water until constant mass was reached (without salt). The evaluation of sample degradation was made by visual inspection and quantified by mass loss and apparent porosity according to ASTM C373 (1999).

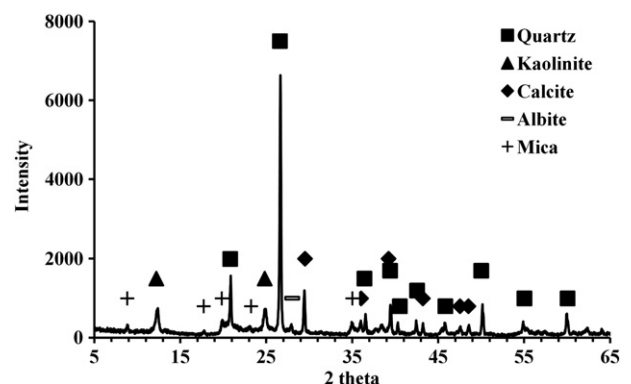


Fig. 1. XRD pattern of clay.

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