



Research paper

Compatibility analysis of municipal solid waste incineration residues and clay for producing lightweight aggregates



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ABSTRACT

This work provides insight into the most important properties of air pollution control (APC) residues from municipal solid waste incineration (MSWI) and clay used at industrial level aiming at producing a ceramic material known as lightweight aggregates (LWA). Both clay and APC residues were characterized to assess the most important chemical, physical, thermal and mineralogical properties to evaluate their compatibility. The maximum percentage of incorporation tested was 10% of APC residues. The results showed that the waste does not own bloating properties and it is not expectable other improvements into the technological properties of LWA, since the fluxing components contribution is high and the amount of silica is low. Although during the thermal analysis of the APC residues the loss on weight is high (about 32% until 1200 °C), they seem not to be suitable as a gas-release additive, once for 10% of incorporation the external shell appears to be significantly broken. The environmental impact due to leaching of pollutants from the LWA incorporating less than or equal to 5% of waste appears not to be relevant. In conclusion, the results showed that synthetic LWA may be considered as a possible approach to recycling of APC residues in case of low amount of waste is used or if a pre-treatment is performed.

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1. Introduction

The municipal solid waste (MSW) incineration has been widely used in most of developed countries, as part of integrated management systems for their destruction and energy recovery. However, one of the important shortcomings of this process is the generation of hazardous air pollution control (APC) residues, which comprise particles captured in the flue gas cleaning system prior to discharge into the atmosphere (Chandler et al., 1997; Sabbas et al., 2003; Quina et al., 2008a). APC residues may represent 2–3% of the MSW incinerated, and thus a huge amount of these wastes have been landfilled in the world. These residues are produced at high-temperature, and therefore they are thermodynamically unstable and highly reactive under ambient conditions (Sabbas et al., 2003). In the literature there are various studies aimed at APC residues characterization, where properties such as moisture, loss on ignition (LOI), size distribution, density, porosity, specific surface area, morphology, total elemental content (TC), total availability (TA) and the leaching behavior, mineralogy and thermal behavior can be found (Chandler et al., 1997; Quina and Quinta-Ferreira, 2002; Quina et al., 2008b, 2009, 2011a, 2011b). The principal characteristics of concern are the high heavy metals content,

soluble salts that leach in quantities that do not comply with the regulatory constraints, as well as the trace organic pollutants. Other studies analyze in particular the thermal behavior of such incinerator residues (Tettamanti et al., 1998; Wang et al., 1998; Sakai and Hiraoka, 2000; Mangialardi, 2001; Wang et al., 2002). A pre-treatment stage involving washing with water can be applied to APC residues in order to remove soluble salts prior to further utilization or chemical stabilization processes (Mangialardi, 2001; Nzihou and Sharrock, 2002; Sabbas et al., 2003). Salts may account for up to 10 to 20% of the material and are responsible for many of the negative effects of such residues. Some studies have indicated that a liquid-to-solid ratio of 10 allows for extraction of more than 90% of the soluble salts (mainly chlorides) (Nzihou and Sharrock, 2002). However, for evaluating the overall benefits of a washing pre-treatment, the shift of the pollutants from solid to liquid streams must be considered (Sabbas et al., 2003). Indeed, to assess the suitability for a specific application, besides the environmental impact, the ability for processing and the technical performance must be also considered (Ferreira et al., 2003).

In this framework, some European countries have devoted efforts to find feasible applications for APC residues rather than just disposed of in environmental acceptable landfills (Sabbas et al., 2003). Although these residues generally have limited applications, thermal treatments can produce a material that is environmentally stable, and may be further used for producing ceramics (Quina et al., 2008a). In this scope,

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the production of lightweight aggregates (LWA) has been considered for many secondary materials (Wainwright and Cresswell, 2001; Ducman et al., 2002; Cheeseman and Viridi, 2005; Cheeseman et al., 2005; Chiou et al., 2006; Quina et al., 2006; Huang et al., 2007; Qiao et al., 2008; Gonzalez-Corrochano et al., 2009, 2012; Chen et al., 2010; Kourtis and Cheeseman, 2010; Latosinska and Zygadlo, 2011; Tan et al., 2012) such as combustion ashes, waste glass, sewage sludge ash, incinerator bottom ash, mining residues, heavy metal sludge, washing aggregate sludge, lignite coal fly ash, and contaminated mine soil. Indeed, LWA can be defined as materials lighter than water and more porous than sand, gravel or ground rock (commonly referred to as “dense” aggregates) and can be produced from natural resources (e.g. volcanic aggregates or pumice), requiring only mechanical treatment, or obtained by thermal processes in kilns (Chandra and Berntsson, 2002; de’ Gennaro et al., 2004, 2005). In a broad sense, synthetic aggregates are ceramic materials obtained by thermal treatment of materials with expansive properties, such as (i) perlite, vermiculite, clay and shale and (ii) industrial by-products (e.g. fly ash, slags, and sludge) (Chandra and Berntsson, 2002). One of the most widespread types of LWA is produced from expanded clay and commercially known as Leca® (Lightweight Expanded Clay Aggregates), or from coal fly ash and referred as Lytag®. Expansion (bloating) occurs by heating materials to fusion temperature, where pyroplasticity and formation of gas must take place simultaneously. The technological applications of LWA are mostly linked to the low density and high compressive strength (de’ Gennaro et al., 2005).

The valorization of fly ash and/or APC residues from MSW incineration in LWA has been analyzed only in few studies (Quina et al., 2006; Huang et al., 2007; Hwang et al., 2012; Tan et al., 2012). However, other sintered or melting materials and ceramic bricks have been considered (Wang et al., 1998; Sakai and Hiraoka, 2000; Mangialardi, 2001; Wang et al., 2002; Dimech et al., 2008; Haiying et al., 2011; Valle-Zermeño et al., 2013). Some studies point out that a washing treatment of APC residues with water to separate soluble salts may be important in the scope of their recycling (Mangialardi, 2001; Sabbas et al., 2003; Quina et al., 2011b), but attention should be given to the mobilization of toxic heavy metals (Nzihou and Sharrock, 2002). The stabilization of most heavy metals can be accomplished with chemical additives (Nzihou and Sharrock, 2002; Quina et al., 2010). It should be noted that an important benefit of recycling polluted wastes into synthetic aggregates is the low leachability usually observed (van der Sloot et al., 2001).

This work focuses on the characterization of APC residues from MSW incineration and natural clay currently used in industry in order to assess the possibility of producing lightweight aggregates.

2. Materials and methods

2.1. Characterization of APC residues and natural clay

In our study, APC residues samples were collected in an incineration plant in the region of Lisbon, comprising gas cleaning residues from economizer, semi-dry scrubbers (with lime and activated carbon) and fabric filters; the sample of natural clay was taken in an industry that produces LWA in the center region of Portugal. APC residues were extensively characterized in our previous study (Quina et al., 2008b), where moisture content, loss on ignition (LOI), particle size distribution, density, porosity, specific surface area, morphology, total elemental content (TC), total availability (TA), leaching behavior with common compliance tests, and the acid neutralization capacity (ANC) can be found. The main mineralogical crystalline phases were identified, and the thermal behavior of the APC residues is also shown. Those parameters were determined for 5 different samples, collected over two years. The specific features of the leaching behavior of these residues may be found in other publications (Quina et al., 2009, 2010, 2011a, 2011b). In the present study, the analysis of the thermal behavior was deepened for one sample (referred as A2), aiming at considering the recycling of

the waste by its incorporation in LWA, and includes simultaneous thermal analysis (STA), X-ray diffraction (XRD) and heating microscopy.

The natural clay was characterized regarding moisture content through weight loss over night in an oven at 105 °C; loss on ignition (LOI) was determined as the weight loss after exposing the clay at 1000 °C using a muffle furnace during 1 h; the real specific density was determined by using helium pycnometry, Micromeritics-AccuPyc 1330, based on the amount of displaced gas (helium); the total dissolved solids (TDS), pH and electrical conductivity were determined in the liquid obtained at liquid-to-solid ratio (L/S) of 10 mL/g, under agitation for 24 h with demineralised water; the particle size distribution was determined by sedimentation, Micromeritics-SediGraph 5100. In addition, the elemental composition of clay was assessed using X-ray fluorescence (XRF), Philips-PW 1480, equipped with an Rh X-ray tube. The samples were dried, finely grinded and mixed with Li₂B₄O₇ (66.5%) and LiBO₂ (33.5%). The major elements were reported as wt.% oxide. Powder XRD, Philips-PW 1710, with Cu K α radiation (40 kV and 30 mA) was also employed and the minerals were recognized according to the data base ICDD (International Centre for Diffraction Data).

The thermal behavior of both clay and APC residues was obtained by using STA, Netzsch – STA 449C, with a heating rate of 10 °C/min in air. This test allowed us to obtain simultaneously the thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) of samples previously milled to less than 75 μ m, using about 20–30 mg of powder. Heating microscopy, Leitz-2A, enabled us to observe with video recording 3 mm sided cubic samples of clay and APC residues by heating them to 1500 °C at a rate of 10 °C/min.

The total content (TC) of previously calcined APC residues at 1100 °C for 1 h was determined by acid digestion with aqua regia, using 3 mL of HNO₃ (65%) and 10 mL of HCl (38%) in a digestion bomb (Parr 4744). The solid sample (0.4 g) and the acid mixture (13 mL) within the bomb were heated in a conventional oven during 6 h at 150 °C. These analyses were carried out in triplicate.

2.2. Washing of APC residues

The washing treatment of APC residues involved extractions with water in one or two stages, at L/S of 10 mL/g, using an open beaker under agitation through a magnetic stirrer at 120 rpm. The separation of both phases was conducted by vacuum filtration through a 0.45 μ m membrane filter. The solid and liquid phases were collected and preserved for further chemical analysis. The times of extractions were 0.5, 1, 5, 10, 30, 60, 480 min and 24 h. In the washing solutions pH, electrical conductivity (EC), total dissolved solids (TDS), concentration of the soluble ions (Cl⁻, Na⁺, K⁺) and toxic heavy metals (Pb, Zn, Cr) were measured. The flame atomic absorption spectrometry (FAAS), Perkin Elmer-3300, and ion chromatography, Waters-Action Analyzer, were used as the main analytical techniques.

Moreover, some experiments were conducted by adding a small amount of phosphoric acid, in order to reduce the mobilization of toxic heavy metals (mainly Pb which is the most critical element). The experimental conditions involved 248.5 mL of water plus 1.5 mL of H₃PO₄ (85%) and 25 g of APC residues, which means a L/S of 10 L/kg for 10 min.

2.3. Preparation and characterization of LWA

The LWA were produced not only using natural raw materials but also incorporating APC residues, according to the formulations shown in Table 1. The LWA were prepared and sintered based on the method used for quality control in the laboratory of the industrial plant that produces commercial LWA. The experimental procedure to obtain LWA followed different phases: homogenisation of clay and APC residues during 30 min; blend the mixture by adding about 20% of water and 1% of oil (as expanding agent) to achieve sound pelletization

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