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Solidification/stabilization of ash from medical waste incineration into geopolymers

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ABSTRACT

In the present work, bottom and fly ash, generated from incinerated medical waste, was used as a raw material for the production of geopolymers. The stabilization (S/S) process studied in this paper has been evaluated by means of the leaching and mechanical properties of the S/S solids obtained. Hospital waste ash, sodium hydroxide, sodium silicate solution and metakaolin were mixed. Geopolymers were cured at 50 °C for 24 h. After a certain aging time of 7 and 28 days, the strength of the geopolymer specimens, the leachability of heavy metals and the mineralogical phase of the produced geopolymers were studied. The effects of the additions of fly ash and calcium compounds were also investigated. The results showed that hospital waste ash can be utilized as source material for the production of geopolymers. The addition of fly ash and calcium compounds considerably improves the strength of the geopolymer specimens (2–8 MPa). Finally, the solidified matrices indicated that geopolymerization process is able to reduce the amount of the heavy metals found in the leachate of the hospital waste ash.

1. Introduction

Medical waste generation has increased considerably worldwide in the last few decades (Rajor and Kunal, 2011). Among the principal methods available for proper management of medical waste, incineration and disposal of the resultant ash by landfilling is the priority method used (Xie et al., 2009). The main advantages of incineration are the destruction of pathogens and the reduction in the volume and weight of the waste. However, incineration produces residues that are enriched by toxic chemicals, such as heavy metals (Jung et al., 2004). In some densely populated cities, the disposal of the waste ash is becoming increasingly difficult, owing to high cost, diminishing land availability, more stringent regulation, and frequent public opposition to the sifting of new landfills (Anamul et al., 2012). Due to this reasom, the need to manage the produced ash in an environmentally friendly way has major priority.

Stabilization/solidification is a pre-landfill waste treatment process, which has been used for different types of industrial wastes, but is particularly suited to those containing heavy metals (Malviya and Chaudhary, 2006). For stabilization, the objective is to minimize the solubility and toxicity of contaminates while for solidification, usually matrices like cement are used to encapsulate the waste material in order to immobilize contaminates and reduce leachability (Charles et al., 2010). Despite the fact that, the stabilization/solidification of municipal solid waste incineration ash in geopolymers has been already studied by many authors (Komnitsas et al., 2012; Lancellotti et al., 2010; Zheng et al., 2010; Galiano et al., 2011), until today, only few have studied the stabilization/solidification of medical waste incineration ash. Anastasiadou et al. (2011) used medical waste ash in combination with different amounts of Ordinary Portland Cement (OPC) as a binder, in order to reduce the leachability of the heavy metals present in this material and to increase its mechanical characteristics. Sukandar et al. (2009) tried to stabilize the medical waste fly ash using chelating agent and phosphates. In this paper, geopolymerization technology has been proposed to stabilize and solidify medical waste ash. Although this paper focus on the advantages of geopolymers towards heavy metal immobilization, because of their physical properties these specimens can also be utilized in the future as replacements for concrete in most instances.

During the past decade many researchers have started to deal with the performance of one such stabilization agent. Geopolymer

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materials have attracted much more attention due to their excellent mechanical properties, good chemical resistance, low shrinkage, environmentally friendly nature and long-term durability (Duxson et al., 2007). Their final structure and physical properties depend upon several parameters as water content, particle size, thermal history, alkali metal content and degree of amorphicity (Komnitsas, 2011). The properties and uses of geopolymers are being explored in many scientific and industrial disciplines: modern inorganic chemistry, physical chemistry, colloid chemistry, mineralogy, geology, and in all types of engineering process technologies (Davidovits, 2008). Potential products and applications include among others concrete, building components and temperature stable resins, encapsulation of toxic wastes, surface capping and stabilization of tailing dams (Komnitsas et al., 2012). For the production of the geopolymer matrices many kinds of raw materials have been used, such as lignite bottom ash (Sata et al., 2012), blast furnace slag (Zhang et al., 2007; Oh et al., 2010), red mud and metakaolin mixture (Dimas et al., 2009), blends of circulating fluidized bed combustion fly and bottom ash (Li et al., 2012) and metakaolin (Rovnaník, 2010). Due to the interesting findings of these studies, the possibility of using the residual ash of hospital waste in combination with metakaolin as raw materials for the production of geopolymers was investigated.

2. Experimental

2.1. Materials

Bottom and fly ash were sampled from a Medical Waste Incineration Facility (MWIF). Bottom ash was first dried at 105 °C and then was ground in order to reduce its particle size class below 100 μm. The particle size of the fly ash was already below 100 μm so there was no need for such pretreatment.

The chemical composition of the two kinds of ash (Table 1) and the leachability of the heavy metals (Table 2) were measured with the XRF and TCLP method respectively.

According to Table 1, the main elements of the bottom ash are SiO_2 (39.74%), CaO (27.77%) and Na_2O (9.13%), while the major element of the fly ash is CaO (89.20%). The difference between the two kinds of ash is remarkable, as the content of CaO in fly ash is very high due to its pre-treatment with hydrated lime. The concentration of all the heavy metals measured in bottom ash was within permissible limits for the US EPA TCLP test (Method 1311). On the other hand, concentrations of Zn and Pb were found to be high in fly ash, exceeding the limits of the TCLP method. According to Rajor et al., 2012, feeding waste of medical waste incinerator is susceptible to reactive chemicals such as chlorine compound that may be originated from disinfectant and plastics, especially PVC. The presence of large quantities of chlorine available, formation of metal chlorides in the combustion zone appears generally to increase. The results of this study are in agreement with previous studies (Anastasiadou et al., 2011; Kougemitrou et al., 2011; Javied et al., 2008).

Materials used for the production of the geopolymers in constant quantities were sodium hydroxide solution of 10 M and sodium silicate solution with a composition of 8.9 wt.% Na_2O, 28.7 wt.% SiO_2, 62.5 wt.% H_2O, and metakaolin, produced by calcination at 700 °C for 4 h of kaolinite.

2.2. Mix proportions

Four series of experiments were carried out in this study. In the first series, only bottom ash was used as a raw material. In the second series, a quantity of calcium carbonate was added in order to study its effect on the geopolymer paste. In the third and fourth series, fly ash and bottom ash at proportions of 75:25 and 50:50 (FA:BA) were used, respectively. In all series three different proportions of Medical Waste Ash (MWA): Metakaolin (MK) of 20:100, 30:100 and 50:100 were applied.

The production of the geopolymer matrices comprised the following steps: (a) preparation of the alkaline solution by dissolving the quantity of sodium silicate and sodium hydroxide in distilled water, (b) addition of the ash in the solution and stirring for 5 min (c) addition of the quantity of the MK and stirring until a homogeneous and fluid paste was formed. Then, the mixture was poured into 50 mm $*$ 50 mm $*$ 50 mm cubic molds, which was the sample's dimension, and were cured in the oven at 50 °C for 24 h to complete the geopolymerization reaction.

The values of the temperature (Chindaprasirt et al., 2007), of the curing time (Palomo and Fuente, 2003) and of the concentration of the sodium hydroxide solution (Rattanasak and Chindaprasirt, 2009; Chindaprasirt et al., 2009) were chosen based on the literature and after a large number of trials.

2.3. Methods of analysis

X-ray fluorescence (XRF) method provides a qualitative identification and a quantitative analysis of the element. The samples of bottom and fly ash were initially grinded to a particle size class <60 μm and then pressed to a pellet. An S2 Ranger EDS (Bruker Ltd.) was then used for quantitative chemical analysis of both kinds of medical waste ash. X-ray diffraction (XRD) was utilized to determine the mineralogical properties of the fly and bottom ash samples and of the produced geopolymers. The XRD patterns were recorded on a D8 Advance XRD (Bruker Ltd.) with a copper target (λ = 15.406 nm). A diffraction angle (2θ) between 4° and 70° and a scanning rate of 4°/min was applied to analyze the crystal phases of the fly ash and bottom ash samples. Diffraction patterns were manually analyzed using the Joint Committee on Powder Diffraction standards.

Characterization of the effectiveness of s/s treatment should be based on determining the environmental impact of the treated waste after it is disposed or reused (Batchelor, 2006). One method to succeed this is to estimate the amount of contaminant that might be released to the environment, using tests under specific conditions.

The TCLP analysis (Method 1311) simulates landfill conditions. It determines which of the contaminants identified by the United States Environmental Protection Agency are present in the leachate and their concentrations (US EPA, 1992). Manually crushed material (<1 cm) was leached using an extraction buffer of acetic acid and sodium hydroxide (pH 4.93 ± 0.05) at a liquid/solid ratio of 20:1. The extraction (at 25 ± 2 °C) was performed by shaking the material for 18 h. Subsequently, the leachate samples were filtered through a 0.8 μm borosilicate glass fiber filter, and the resultant TCLP extract (filtrate) was analyzed for heavy metals using Inductively Coupled Plasma-Mass Spectrometer (ICPMS) Agilent Technologies, model 7500cx.

Table 1
Chemical composition of medical waste bottom and fly ash.

Chemical composition	SiO_2	CaO	Na_2O	Al_2O_3	Fe_2O_3	MgO	BaO	TiO_5	SO_3	K_2O	Other
Bottom ash	39.74	27.77	9.13	5.16	4.53	2.92	2.25	2.24	1.36	0.49	0.41
Fly ash	6.00	89.2	2.50	–	0.30	1.0	–	–	–	–	0.10