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Characteristics and application potential of municipal solid waste incineration (MSWI) bottom ashes from two waste-to-energy plants

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HIGHLIGHTS

- MSWI bottom ashes properties related to their production time and procedure.
- Environmental impact evaluation of bottom ashes over time.
- MSWI bottom ash application potential in cement clinker production.
- Influence of bottom ash on cement hydration and mortar strengths.

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ABSTRACT

This study focuses on municipal solid waste incineration (MSWI) bottom ash characteristics, its heterogeneity, environmental properties, and their stability in time. The physical and chemical characteristics of bottom ashes from two plants were determined over time; results show that their properties are very stable and similar to each other. As an exploratory study, bottom ash was applied in mortars without further treatment, in order to identify the limit conditions of its use as replacement material. Results show that bottom ash fines have a detrimental effect on cement hydration and strength of the mortars.

1. Introduction

In recent years, the waste-to-energy technology [1] became an efficient method to deal with the increasing amount of municipal solid waste worldwide [2]. The incineration reduces the mass and volume of the solid waste dramatically [3], thus the requirement for landfilling is decreased [4]. Moreover, energy in the form of heat, electricity, etc. can be recovered during incineration [5], together with the recycling of ferrous and non-ferrous metals, paper and plastics from the solid waste [6], which can bring financial benefits. However, there is a considerable amount of solid incineration residues generated after the combustion, typically bottom ash, fly ash, boiler ash, etc., of which bottom ash accounts for about 80% [7].

The bottom ash from municipal solid waste incineration (MSWI) is a stony material that contains stone, brick, ceramic, glass and unburned organic matter (wood, plastic and fibre etc.) [7] and its properties differ from plant to plant, and country to country [8–11]. Many previous studies were focused on the characteristics of the bottom ash, as well as its disposal or reuse. For instance, Forteza et al. [12] studied the physical, chemical and engineering properties of the bottom ash from MSWI and concluded that the bottom ash has similar properties as natural aggregates and is suitable to be used in road-construction. Olsson et al. [13] and Hjelmar et al. [14] addressed the environmental impact of the bottom ash used in road construction considering the leaching of heavy metals. Others investigated the utilisation of MSWI bottom ash in concrete [15–17], the results of which indicate that the incineration bottom ash is usable as a concrete ingredient. It was also reported that the use of bottom ash as concrete aggregate could affect the durability of concrete, because of the metallic aluminium and glass particles which may contribute to cracks and alkali–silica reaction, respectively [18–21]. Hence, a suitable way to recycle the solid residue in waste-to-energy plants could be by applying it in concrete as a secondary material, but appropriate treatments are needed

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Table 1
Maximum leaching of inorganic compounds for building materials (SQD) [30].

Parameter	[a]Shaped [[d]E_{64d} in mg/m^2]	[b]Non-shaped [[e]mg/kg d.m.]	[c]IBC building material [mg/kg d.m.]
Antimony (Sb)	8.7	0.16	0.7
Arsenic (As)	260	0.9	2
Barium (Ba)	1500	22	100
Cadmium (Cd)	3.8	0.04	0.06
Chromium (Cr)	120	0.63	7
Cobalt (Co)	60	0.54	2.4
Copper (Cu)	98	0.9	10
Mercury (Hg)	1.4	0.02	0.08
Lead (Pb)	400	2.3	8.3
Molybdenum (Mo)	144	1	15
Nickel (Ni)	81	0.44	2.1
Selenium (Se)	4.8	0.15	3
Tin (Sn)	50	0.4	2.3
Vanadium (V)	320	1.8	20
Zinc (Zn)	800	4.5	14
Bromide (Br^-)	670	20	34
Chloride (Cl^-)	110,000	616	8800
Fluoride (F^-)	2500	55	1500
Sulphate (SO_4^{2-})	165,000	1730	20,000

[a] Building material with a minimum volume unit of at least 50 cm^3, and has stable shape under normal conditions.
[b] Building material that has not been molded.
[c] Materials can be used only when isolation is applied.
[d] The measured cumulative leaching for a component per unit surface area over 64 days, in mg/m^2.
[e] mg elements per kg of dry material.

before such an application. Nevertheless, as a combustion residue of many types of solid wastes, bottom ash contains heavy metals, such as lead, copper and antimony etc., as well as some soluble salts. The leaching of these substances from the bottom ash to the environment will result in a potentially negative impact on water resources, human health and environment [22–24]. Thus, the environmental impact of the bottom ash should be evaluated before its application. To estimate the influence of bottom ash on the environment, various pieces of legislation are established on the disposal or reuse of municipal solid waste incineration ashes, which is in consideration of environment protection and reuse/recycle resources, and based on the conditions in different countries [25–28].

In the Netherlands, there is a national regulation termed the Soil Quality Decree (SQD) [29,30] with the latest version released in 2007. This legislation defines the utilisation of construction materials, considering the protection of the environment from potential risks posed by the leaching of contaminants from construction materials. The goals of this legislation are soil protection and improvement of recycling and reuse of secondary materials. According to this legislation, the emission of the inorganic compounds from the material should be below the limiting values, as shown in Table 1, based on which the materials are divided into three categories: shaped, non-shaped, and IBC materials. The IBC materials refer to materials which can be applied only when an insulation approach is used.

A very important aspect of the application of MSWI bottom ashes is the stability of their chemical and physical properties [31]. It is also known that the properties of the MSWI bottom ashes from different plants and countries vary due to the source of solid waste and incineration process [32,33]. Moreover, the environmental legislation, management and application of the MSWI bottom ashes differ from country to country in consideration of the local situation [34,35]. In the available literature, studies are seldom focused on the stability of the MSWI bottom ashes properties in relation to the different production period and procedure.

The aim of the present study is to identify the stability of the properties of two MSWI bottom ashes over a long time period and to analyze the MSWI bottom ashes in regard to their environmental impact. Additionally, their application potential as a building materials ingredient, such as clinker, cement and sand replacement, etc. is investigated.

In this study, the bottom ashes were provided by two waste-to-energy plants of Attero, which are located in Wijster and Moerdijk, in the Netherlands. The plant in Wijster started to be in operation in 1996, and includes three parallel processing lines with an annual capacity of around 800,000 tonnes of solid waste. The collected municipal solid waste firstly goes through a separation line to extract the recyclable materials, such as metals and certain plastics. Then, the modern techniques of film separation and NIR technology (near-infrared detection) together with air separation are applied to separate the plastic packaging materials. After the above pre-separations, the remaining waste is sent to the incineration boiler, the grid temperature of which is around 1000–1300 °C. The heat generated during the incineration converts the water into

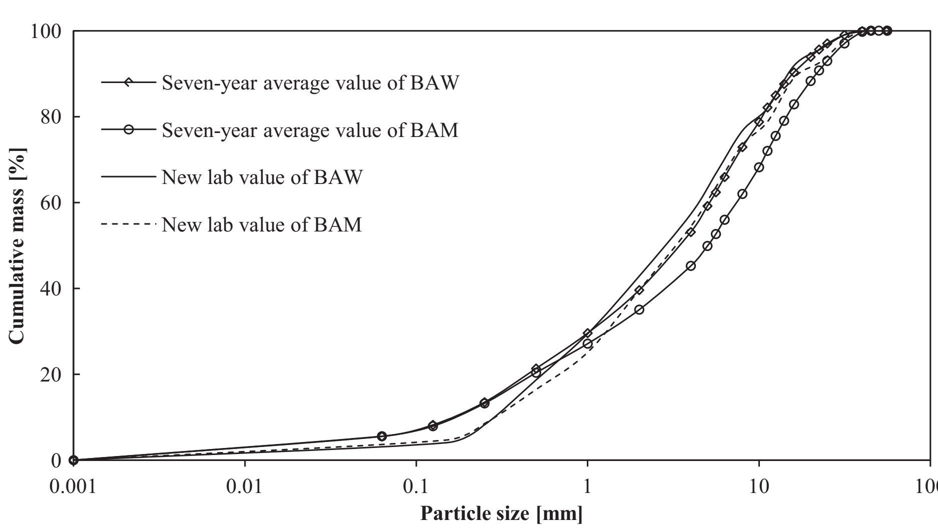

Fig. 1. The particle size distributions of BAW and BAM.