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Crushing of MSWI bottom ash towards material purification

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Abstract
Municipal Solid Waste Incineration (MSWI) reduces mass and volume of the waste by about 70% and 90%, respectively. Next to boiler and fly ash, solid MSWI Bottom Ash (hereinafter referred to as bottom ash; BA) makes up for 80% of the remaining material containing unburned matter, glass, ceramics, metals, and minerals. Despite its similar composition to concrete constituents, which suggests their applicability in this field, at present BA is landfilled or used in low-grade applications (e.g. road base material). In order to make a higher end application possible, correlations between physical properties, size fractions and mineralogical composition have been studied. This study looks into the crushing of the materials within BA and how certain fractions are enriched with specific types of material, therefore depleting and purifying other fractions making them better suitable for implementation in concrete.

Keywords: MSWI bottom ash, crushing, size fractions, density

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Introduction

MSWI bottom ash
Municipal solid waste incineration (MSWI) is preferable to landfiling of the solid waste due to the fact that both volume and mass are significantly reduced, by approximately 90% and respectively 70% [1]. After collection, the municipal solid waste is incinerated in a waste-to-energy plant. Various types of solid residual materials are produced in the process, e.g. bottom ash, boiler ash, fly ash and air pollution control (APC) residues. 80% of the total volume of by-products is accounted for by MSWI bottom ash (hereinafter referred to as bottom ash; BA) [2], a non-airborne fraction consisting of minerals (quartz, calcite, lime, feldspars), ceramics, glass, ferrous and non-ferrous metals, and unburned organic matter [1]. The remaining 20% is carried from the incinerator by flue gases (e.g. boiler ash, fly ash, and APC residues).

Despite the volume and mass reduction, vast production quantities, landfilling taxes, limited application as road base material (in the Netherlands), and stricter legislation stimulates alternative applications [3–5]. Possessing similar properties to raw materials used in building materials, BA potentially can be made to fit this application [3, 6–8]. Use of this industrial by-product in new building materials is aimed at minimising the need to landfill and to reduce the need for raw materials, making this in essence a sustainable approach. However, towards this end, a thoughtful and well-advised treatment of the material is needed since leachable contaminants levels are to comply with legislation.

Treatment towards application of MSWI bottom ash in concrete
Consumption of raw materials and the reduction of environmental impact of concrete in general has attracted attention in recent years [9, 10]. MSWI BA has the potential to be implemented in building materials, to lower the CO₂ production footprint, and to reduce landfilling [1–3, 6].

Since BA contains leachable heavy metals and salts, replacing traditional concrete constituents with treated industrial by-products should be done according to the environmental legislation [4, 5]. For this, the quality of the MSWI BA should be upgraded through a number of treatments to comply with legislation, such as physical separation, washing, weathering, etc. [11]. Even though washing [12–14], weathering [15], carbonation [16, 17], and solidification/stabilization and their efficiency have been shown to be effective in meeting the terms of the legislation.

Replacement of concrete aggregates by BA has been investigated in multiple studies [18–24]. To this end, pre-treatment options towards upgrading and improved applicability have been investigated, for instance quenching conditions on the properties of blended cement mortar have been investigated by Cheng [25], the swelling caused by metallic aluminium content and the properties of the cement-BA interaction have been studied by Pecqueur et al. [26], whereas artificial aggregates implementing MSWI BA were created by Cioffi et al. [18].

In addition to an inert application as aggregate or filler, MSWI BA as pozzolanic material or raw material for cement has been investigated [27, 28]. Lin et al. [29] created a pozzolanic slag by applying a 1400 °C heat treatment. Cement replacements of 15%, 20%, and maximum 30% have been suggested by Juric et al. [29], Al-Rawas et al. [3], and Li et al. [19] respectively. In addition to the increased reactivity, several studies show that the leaching of elements from the BA can be reduced through heat treatment [30–32].

Since BA is heterogeneous, with a varying ratio of constituents (e.g. glass, ceramics, minerals, ferrous and non-ferrous metals, and organic matter), with implementation, final material properties are affected. In order to avoid this, a specific treatment can therefore be targeted at minimising these variations. Hence, this study attempts to enrich certain size
fractions within the BA with specific components through crushing. This results in material depletion and purification of size fractions, enhancing their suitability for any type of implementation in concrete.

In order to quantify the influence of crushing, the particle size distribution (PSD) of the material is determined prior to and after crushing. Since the specific density of materials is independent of particle size, porosity, and particle shape, this property could be used as an initial indicator for changes in the composition of the various size fractions. This approach has been shown to work for other heterogeneous materials such as recycled concrete [33].

**Methodology**

Prior to crushing, the PSDs of the materials are determined according to EN 933-1 and EN 933-2 [34, 35]. Simultaneously, the material is split in fractions. Next to the mesh sizes described in EN 933-2 [35], additional sieve sizes (45 mm, 22.4 mm, 11.2 mm, 5.6 mm, 2.8 mm, 1.4 mm, 710 µm, 355 µm, 180 µm and 91 µm) were added, increasing the detail of the study. The specific density of every fraction is determined using a He pycnometer (Micrometrics Accupyc 1340). Subsequently, all fractions are recombined, restoring the original material and crushed concurrently using a lab-scale jaw crusher fitted with waved jaws and a closed side setting of 8 mm. On the crushed material, the new PSD is determined using identical sieve sizes. Finally, all newly formed individual fractions are analysed for density by means of helium pycnometer once more.

**Results and discussion**

**The effects of crushing on the particle size distribution**

A particle size analysis was performed on the initial bottom ash 0-40 mm prior to crushing. After crushing using a jaw crushe, the resulting material was once more sieved in the same fractions. Figure 1 shows the two particle size distributions, prior to and after crushing, on a logarithmic scale.

![Figure 1: Particle size distributions of 0-40 mm bottom ash, before and after crushing](image-url)

The PSDs of the pre-crushed and crushed BA show, as expected, a decrease in particle top size. Remarkably, the slope of the curve in the gravel size range is the same for both the pre-crushed and crushed materials. In contrast to that, in general for the sand and most fine
fractions, the mass percentage of output material has been increased at a great and constant rate. However, an excessive increase in the < 63 µm fraction is denoted. This great shift towards particles <2.8 mm can be attributed to the either brittle or porous nature of the materials.

**Density of MSWI BA fractions**

In addition to the PSD analysis, the specific density was determined for every individual fraction prior to and after crushing. Figure 2 shows the densities of each initial and crushed bottom ash size fraction. The largest size fraction (crushed, 11200 µm) was not representative, being of a low mass percentage; this is however included since it was solely composed of ceramic pieces, which can be seen to have an evidently large difference in density compared to the other material fractions. This initial result is promising for the correlation of ceramic content and density of size fractions.

Figure 2: Density of initial and crushed bottom ash size fractions

In general, only a tiny number of fractions are lowered in density: 13 of the 17 remaining size fractions increase in density. Specifically looking at the initial material, the overall density of the gravel sizes was high compared to those of the sand and finer fractions. After the crushing, the density of these larger fractions (2800-8000 µm) is increased. One potential explanation could be that particles with a relatively low or intermediate density tend to fracture to a greater extent, depleting these fractions and therefore increasing the overall density for these specific fractions.

Focussing on the sand and finer sized fractions, which are generally the fractions with the lowest density, the overall density is increased through the crushing process. This could be either due to depletion of a low density material in these fractions, or to the intermixing and thereby enriching of these fractions with a medium density material produced by means of breaking larger-sized, intermediate-density particles. Depletion would lead to an increased amount of low density particles in the lowest size fractions, which should be detectable by a decreased density. Even though the < 63 µm fraction has a slightly decreased density, based on the limited information available, this minor change seems to be insufficient to support the hypothesis of an increased fracturing of low density materials, in turn supporting the hypothesis of an increased fracturing of intermediate density materials.

Since this study is aimed at enriching fractions with certain materials, the indication of a distinctively unequal manner of fracturing materials with different densities is encouraging.
Conclusions

Based on the PSD data and all density measurements, the following can be concluded:

- in the gravel size range, the slope of the PSD curve is similar for both the pre-crushed and crushed materials,
- a density-particle size correlation can be identified,
- fraction density is influenced by jaw crushing,
- the hypothesis regarding material dependent fracturing during crushing needs to be validated.

In order to substantiate the influence of crushing, establishing a correlation between physical properties of individual size fractions and their mineralogical composition related to their density and PSD, requires additional studies determining both the chemical and mineralogical composition of all fractions involved. In addition, a variety of crusher settings can be investigated in order to validate and potentially optimise the anticipated influence of crushing.

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