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Upgrading MSWI Bottom Ash as Building Material for Concrete Mixes

Introduction

Municipal solid waste incineration (MSWI) plants generate several types of solid residual materials. Typical residues of MSWI by grate combustion are bottom ash, boiler ash, fly ash and air pollution control (APC) residues, among others. Boiler ash represents the coarse fraction of the particles carried over by the flue gases from the combustion chamber, while fly ashes are made up of the fine particles in the flue gases downstream of the heat recovery units. APC residues include the fine material captured prior to effluent gas discharge into the atmosphere.

In the Netherlands, bottom ash is mainly used as road base material. However, this type of material can also be treated and upgraded into a granulate fraction. Considering the fact that the Netherlands mostly import aggregates for concrete, MSWI bottom ash can be one of the solutions for the aggregate shortage. Upgrading this type of waste to new building materials is a sustainable approach which leads to lower land filled quantities of the material as well as reducing the demand for natural aggregates in concrete. In order to obtain a suitable building material from the bottom ash, a complex treatment is necessary. The treatment includes fractionation, metal recovery (both ferrous and non-ferrous), screening and wet cleaning of the bottom ash into a clean granulate fraction.

This study investigates the suitability of bottom ash granulates as natural aggregate replacement in concrete mixes. Bottom ash is a heterogeneous material, consisting of glass particles, synthetic ceramics fragments, minerals (quartz, calcite, lime, feldspars), paramagnetic and diamagnetic metals and unburned organic matter [1]. The proportion of these constituents can vary with the particle size and will affect the properties of the final concrete mix. The separation and washing techniques also influence both the particle size and constituent proportions of the MSWI bottom ash.

Treatment

Freshly produced MSWI bottom ash from the incinerator AVR-Van Gansewinkel Duiven, the Netherlands, is treated by Van Gansewinkel Minerals to produce a new building material. The initial fresh bottom ash consists of 80% mineral material (sintered ash, stone, glass and ceramics), 5-13% ferrous metals, 2-5% non-ferrous metals (Cu, Al, Zn, Pb) and 1-3% unburned organic material (paper, textiles, plastic). The final fraction is a 2-20 mm heterogeneous aggregate, which is called FORZ composite granulate (FCG). The treatment process is a combination of dry and wet separation techniques [2, 3, 4], which can be divided into five separate phases.

Phase 1- Weathering of fresh MSWI bottom ash

Freshly produced bottom ash (a batch of 1000 ton) is transported from the MSWI incineration (AVR-Van Gansewinkel Duiven) towards a depot. The fresh material is weathered for around 3 months. Longer weathering will strongly influence the further oxidation of ferrous and non-ferrous metals. Weathering reduces the quantitative leaching of heavy metals e.g. copper and further stabilises the reactivity of the material.

Phase 2- Dry separation MSWI bottom ash

Bottom ash from the depot is first treated by extracting the large fraction of ferrous metals < 400 mm (overhead magnet). The generated bottom ash fraction is separated with a drum sieve (60 mm mesh) in two fractions, particles under 31.5 mm and above 31.5 mm. Both fractions are treated by extracting the large fraction of ferrous metals (2 overhead magnets). Fraction 0-31.5 mm is the input material for the 3rd phase. The fraction smaller than 31.5 mm is further treated, extracting large non-ferrous metals, large minerals e.g. stones and slag and the large unburned organic fraction.

Phase 3- Wet separation and washing treatment

The mineral bottom ash fraction 0-31.5 mm is treated with a mobile wet separation-washing plant. The input fraction is firstly separated from ferrous parts with a overhead magnet and then split into four fractions: an organic floating fraction, 0-63 µm sludge, fine granulate 63 µm -2 mm and coarse granulate 2-31.5 mm. The organic fraction is reused in the incineration process. The sludge fraction contains the largest amount of heavy metals and salts. The wet cleaning technique is based on concentrating the potential contaminants from the input fraction into the sludge fraction. The fine granulate fraction is more or less a sandy fraction and the coarse fraction is a stony/glassy granulate fraction. The washing water from the washing plant is treated and filtered and reused within the process. No process water discharge is needed.

Phase 4- Dry separation and metals recovery washed granulate

The washed granulate fraction 2-31.5 mm is treated with an overhead magnet and separated in two fractions: 2-16 mm and 16-31.5 mm. Both fractions are treated with a overhead magnet and additionally with a cascade double sequenced eddy current magnet system for optimal recovery of non-ferrous metals. A separation into two divided partial fractions is needed, creating more favourable particle size fractions and particle densities, which is needed for a optimal non-ferrous recovery. The fraction 16-31.5 mm is additionally treated (handpicked) for the recovery of stainless steel. Both fractions are mixed together generating one mineral granulate fraction. Phase 4 is the final phase for introducing the granulate (non-shaped) building material as base material for the road and construction industries.

Phase 5- Final treatment of the bottom ash granulate (for application in concrete)

The final fraction of Phase 4 can be additionally treated in case of concrete application. The total fraction is treated with a drum magnet, reducing the amount of small ferrous particles. Ferrous metals can have a negative influence of the final concrete application. In addition, extra non-ferrous metals are recovered with a double sequenced eddy current system. The total fraction is finally sieved (mesh 22 mm) into a final granulate fraction 2-20 mm. This fraction will be investigated further in this study, and referred to as FCG.

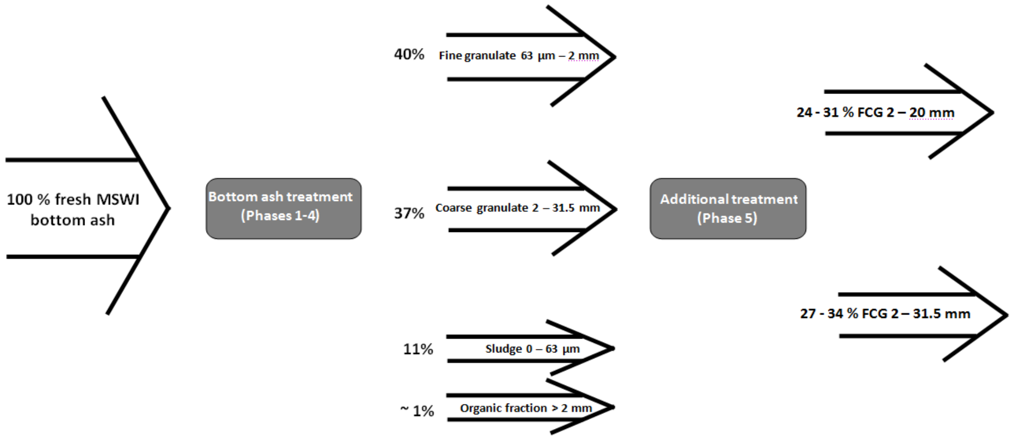

Figure 1. Overview of bottom ash treatment steps

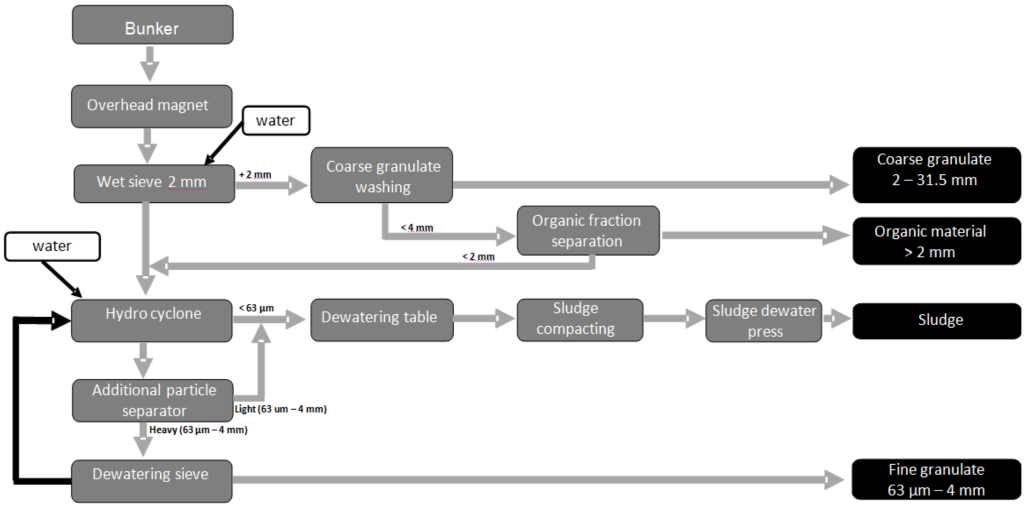

Figure 2. Detailed scheme of the washing treatment (Phase 3)

The final FCG fraction contains 55-60% SiO_2, ~10% CaO and ~6%Al_2O_3, which is close to other secondary building materials used in concrete.

Materials

The bottom ash granulates obtained at the end of the treatment were used in a concrete recipe to replace 20% of the aggregates. The initial reference mix was composed of 13% cement (a CEM II 42.5) and three types of aggregates: a 0-4 mm sand (termed S1) and two gravel types, a 2-8 mm (termed G1) and an 8-16 mm (termed G2). The ratio of the aggregates S1:G1:G2 by mass in the reference sample is 1:2:3. Out of the total volume of the aggregates, 20% was replaced by FCG, and the recipe adjusted to keep the same cement/aggregates and water/cement ratios. Figure 3 shows the particle size distributions of all four aggregate types.

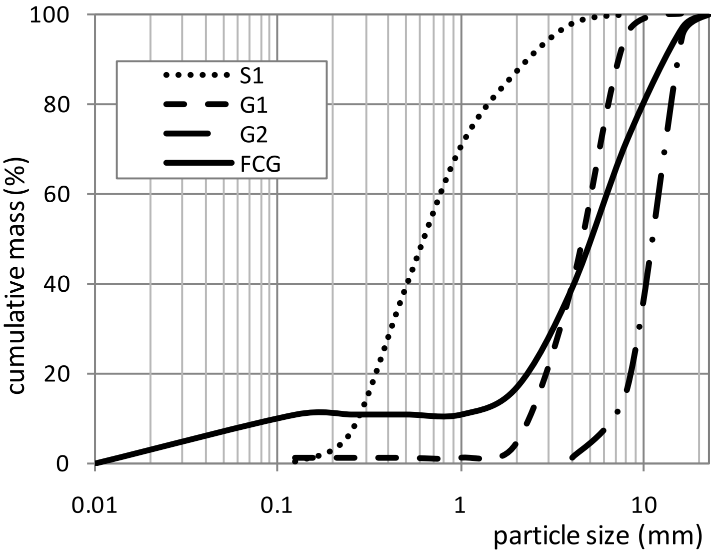

Figure 3. Particle size distributions of all used aggregates

The logarithmic scale was used in order to illustrate the smaller particle sizes more clearly. Table 1 lists the minimum and maximum determined particle sizes for all used aggregates, as well as $d_{0.1}$ and $d_{0.9}$ and their density. The characteristic dimensions of $d_{0.1}$ and $d_{0.9}$ correspond to the mesh size for the passing of 10% and respectively 90% of the material. According to these values, all three natural aggregates are in line with the standard requirement; however, the FCG has a larger than acceptable content of particles under 4 mm, following NEN EN 12620 [5].

Table 1. Physical properties of all used aggregates

	Density (g/cm^3)	**d_{min} (mm)**	**$d_{0.1}$ (mm)**	**$d_{0.9}$ (mm)**	**d_{max} (mm)**
S1	2.64	0.125	0.125	4	8
G1	2.57	0.125	2	8	16
G2	2.57	2	8	16	22.4
FCG	2.41	0.063	0.063	16	22.4

Besides these physical properties, another important analysis for building materials is the leaching of contaminants. In the Netherlands, there are two legislative documents that regulate the use of materials: Building Material Decree [6] and the Landfill Ban

Decree. Both decrees specify acceptable emission levels of both inorganic and organic compounds.

According to the Building Materials Decree (BMD), building materials are classified into three categories: shape retaining, non-shape retaining and IBC materials. IBC materials are also non-shape retaining, but their use is limited to insulated and controlled (“insulation and control”) activities, therefore their emissions would have a very low impact level.

Table 2. Leaching of bottom ash treated in different steps (based on the column test, L/S=10) and comparison with the requirements of the Building Materials Decree

Element	**Phases 1+2+4** (mg/kg)	**Phases 1÷4** (mg/kg)	**Phases 1÷5** (mg/kg)	**Shaped materials** (mg/m^2)	**Non-shaped materials** (mg/kg)	**Isolation IBC materials** (mg/kg)
pH	8	8.4	8.3	-	-	-
Antimony (Sb)	0.86	0.3	0.41	8.7	0.16	0.7
Arsenic (As)	0.1	0.2	0.1	260	0.9	2
Barium (Ba)	0.37	0.6	0.28	1500	22	100
Cadmium (Cd)	0.007	0.007	0.01	3.8	0.04	0.06
Chromium (Cr)	0.05	0.07	0.1	120	0.63	7
Cobalt (Co)	0.05	0.1	0.1	60	0.54	2.4
Copper (Cu)	0.76	0.163	0.13	98	0.9	10
Mercury (Hg)	0.002	0.005	0.005	1.5	0.02	0.08
Nickel (Ni)	0.1	0.3	0.1	81	0.44	2.1
Molybdenum (Mo)	0.3	0.309	0.36	144	1	15
Lead (Pb)	0.1	0.2	0.1	400	2.3	8.3
Selenium (Se)	0.0094	0.009	0.039	4.8	0.15	3
Tin (Sn)	0.02	0.02	0.1	50	0.4	2.3
Vanadium (V)	0.1	0.3	0.1	320	1.8	20
Zinc (Zn)	0.2	0.7	0.2	800	4.5	14
Bromide (Br^-)	15	5.35	4.1	670	20	34
Chloride (Cl^-)	2000	910	690	110000	616	8800
Fluoride (F^-)	7	5.85	72	2500	55	1500
Sulfate (SO_4^{2-})	3800	2400	2300	165000	1730	20000

The aim of the treatment of the bottom ash was to achieve either the acceptable emissions of non-shaped building materials for FCG, or the requirements of shaped materials for prefab concrete containing FCG.

Table 2 presents the required limits by the BMD for all three categories, as well as the leaching of FCG from different treatment phases. The leaching of the material after Phase 4 and after Phase 5 is presented, to show the efficiency of Phase 5. Beside these, the leaching of FCG which followed Phases 1, 2 and 4 (not going through the washing step- Phase 3) is also shown for illustrating the role of Phase 3.

Most of the contaminants were under the BMD limit from the first treatment onwards, but still continued to decrease as phases were added. Some contaminants show a light increase in leaching, which can be just a consequence of changing the redox conditions or composition of the granulates by removing unwanted components. The elements that had leaching values close to the limit (mainly Cu and Br) have shown a clear decrease after both Phase 3 and Phase 5 of the treatment. Chlorides and sulphates, as well as Sb, have decreased by a considerable percentage, but are still above the legal limit. The leaching of these elements makes the use of FCG possible as concrete aggregates when used in prefab concrete elements, because the contaminants will be bound by the cementitious matrix and the "shaped materials" limits will apply.

Pilot test

The FORZ granulate fraction 2-20 mm (Phase 5) were used to replace 20% by volume of aggregates in a concrete mix designed for kerb stones. The recipes and material properties have been detailed in the previous sections. The stones produced had the dimensions of 1000 x 200 x 100 mm. The total production o this pilot test was of 5.5 m^3 of concrete- about 275 kerb stones. From these elements, cilinders of 100x100 were drilled and tested for compressive strength. The flexural strength was tested according to EN 1340 [7], except for the curing requirements. The stones were kept in storage under usual factory conditions (15-18 degrees Celsius, 47-67% relative humidity) until the test date. Figure 4 shows the strength development of the reference sample (termed "reference") and the FCG-containing stones (termed "sample").

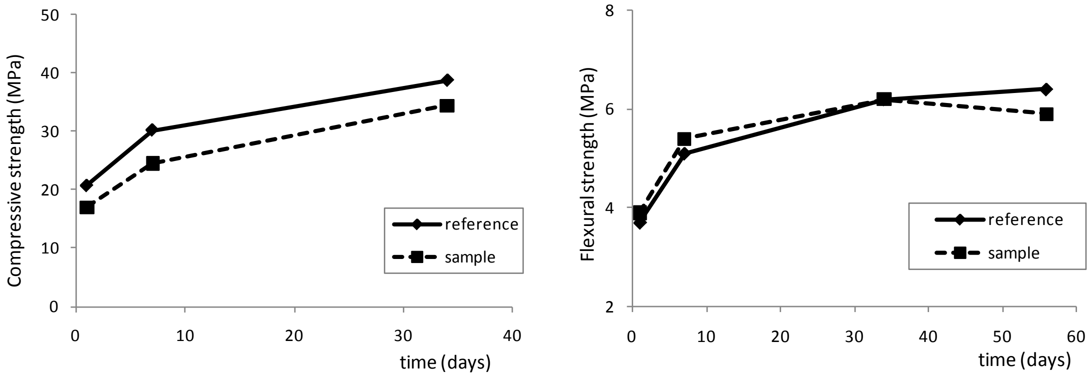

Figure 4. Compressive strength (left) and and flexural strength (right) of the hardened samples

At early ages (1 and 7 days) , the compressive strength loss of the sample containing 20% vol. FCG when compared to the reference concrete was 17-18%. However, after 35 days, this difference was of only 11%. The flexural strength, which is the most important parameter in the case of kerb stones, had an even more promising behaviour. At early ages, the loss of flexural strength was of only 5.1-5.5%, and after 35 days the FCG-containing kerbs reached the same flexural strength values as the reference concrete. After 56 days, the FCG-sample reached a flexural strength higher with ~10% than the reference sample.

Conclusions

Bottom ash from a Dutch incinerator has been treated in order to obtain a suitable building material for concrete mixes or prefab elements. Five separate treatment steps were used in order to achieve this, consisting, among others, of particle size separations, washing procedures and the removal of ferrous and non-ferrous metals. The resulting fraction is termed FORZ composite granulates 2-20 (FCG) and contains less than 0.3% non-ferrous metals and less than 0.1% metallic iron. The efficiency of the various treatment phases was investigated through the leaching analysis of the obtained material. Almost all the contaminant leaching values were under the legal limits after the whole treatment process. However, because chlorides and sulphates still had a slightly raised leaching value, the material was used in the production of shaped building blocks.

Kerb stones were produced using a 20% by volume replacement of the aggregates with FCG. The final aspect of the kerb units did not differ from the reference samples. The compressive strength was slightly lower than expected, which can be explained by the non-standard curing conditions. The low relative humidity during curing has affected the strength of the samples, since at low w/c ratios as employed in this study, the porous samples can easily dry out. Also, the cement used has a slow hydration rate, which will further delay the development of strength. The strength results were extremely positive, with a flexural strength after 35 days of the same level as the reference recipe. After 56 days the flexural strength of the FCG-containing sample reached a flexural strength 10% higher than the reference. This is an indication that the cement content of the recipe can be lowered when using FCG instead of natural aggregates, while keeping the flexural strength of the sample to the same level. The 20% replacement of aggregates is a sustainable option, by reducing the amount of natural sand and gravel and by decreasing the need for cement (and therefore the CO_2 footprint).

All in all, the FORZ composite granulates produced from upgradede and treated MSWI bottom ash have proven to be suitable for the use in prefab concrete such as kerb units.

The authors wish to express their gratitude to Van Gansewinkel Minerals for the support in this project, as well as to the following sponsors of the Building Materials research group at TU Eindhoven: Rijkswaterstaat Centre for Infrastructure, Graniet-Import Benelux, Kijlstra Betonmortel, Struyk Verwo, Attero, Enci, Provincie Overijssel, Rijkswaterstaat Directie Zeeland, Van Gansewinkel Maasvlakte, BTE, Alvon Bouwsystemen, V.d. Bosch Beton, Selor, Twee "R" Recycling, GMB, Schenk Concrete Consultancy, Intron, Geochem Research, Icopal, BN International, APP All Remove, Consensor, Eltomation, Knauf Gips, Hess ACC Systems and Kronos (chronological order of joining).

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