Material Distribution in Treated MSWI Bottom Ash Fractions

P.M.F. van de Wouw[1], M.V.A. Florea[2], H.J.H. Brouwers [3]

[1, 2, 3] *Department of the Built Environment, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, the Netherlands*
P.M.F.v.d.Wouw@tue.nl, +31 40 247 8225

Abstract

Municipal Solid Waste Incineration (MSWI) reduces the mass and volume of the waste by about 70% and 90%, respectively. Next to boiler and fly ash, solid MSWI Bottom Ash (BA) makes up for 80% of the remaining material and contains unburned matter, glass, ceramics, metals, and minerals. At present BA is used in low-grade applications (such as road base) or landfilled. In order to make a higher-end application possible, correlations between physical properties, size fractions, and mineralogical composition have been studied. Within the various BA fractions, the different material components possess inherent properties affecting their suitability as concrete constituent; convenient material assessment procedures are therefore required to assess treatment processes and to guarantee the quality and applicability of the produced material.

Key Words: MSWI bottom ash, size fractions, density, porosity

---***---

1. INTRODUCTION

1.1. MSWI bottom ash

Municipal solid waste incineration (MSWI) is preferred as an alternative to landfilling. In this way, a significant reduction of both mass and volume, by approximately 70% and respectively 90% [1] is achieved. After collection of the municipal solid waste, incineration takes place in a waste-to-energy plant. Next to energy, the incineration process generates a variety of solid residual materials. 20% of these are carried from the incinerator by flue gasses, e.g. air pollution control residues, fly ash, and boiler ash. The remaining 80% of the total volume of by-products is accounted for by MWSI bottom ash (BA) [2]. This non-airborne material comprises ceramics, glass, minerals (feldspars, quartz, lime, calcite), ferrous and non-ferrous metals, and unburned organic matter [1]. Even though mass and volume are reduced significantly, alternative applications are needed due to vast production quantities, a limited application as a road base material (in the Netherlands), landfilling taxes, and stricter legislation [3–5]. Since BA possesses comparable properties to those of raw materials applied in building materials, it has the potential to be modified to fit this application [3, 6–8]. Not only does this application minimise the need to landfill these materials, additionally it reduces the need for raw materials, essentially making this a sustainable approach. Nevertheless, due to the leaching of contaminants, a well-advised and thoughtful treatment of the material is needed in order to comply with legislation.

1.2. Treatment towards BA application in concrete

Of all materials produced worldwide, with an annual global production of about 3.8 billion cubic meters, concrete is applied twice as much as all other produced materials combined, including steel, aluminium, wood, and plastic [9].

In recent years, both the raw material consumption and the reduction of the overall environmental impact of concrete has attracted attention [10, 11]. By applying BA in concrete, the CO_2 production footprint, and landfilling can be reduced [1–3, 6].

Due to the fact that BA contains leachable salts and heavy metals, environmental legislation is leading when replacing traditional concrete constituents by treated industrial by-products [4, 5].

Towards complying with legislation, the BA quality needs to be upgraded. To this aim, a number of treatments have proven to be effective, such as washing, weathering, physical separation, etc. [12]. The efficiency and effectiveness of upgrading through solidification/stabilization, carbonation [13, 14], weathering [15], washing [16–18] to comply with legislation has been proven. Additionally, binders used in concrete production have the ability to enclose and therefore immobilize part of the leachable elements found in BA [19, 20].

In order to apply BA as concrete constituent, the material either needs to complement or replace a material in the mix design. Multiple studies have investigated replacing concrete aggregates with BA [21–27]. Towards upgrading and improving applicability, several treatment options have been investigated, for instance cement-BA interaction properties have been investigated by Pecqueur et al. [28], how quenching conditions influence the properties of blended cement mortar have been studied by Cheng [29], artificial aggregates applying BA have been created [30] and swelling due to metallic aluminium content has been investigated by Cioffi et al. [21].

Concrete, being the most produced material in the world, is able to cope with the vast quantities of BA produced. Next

to that, application of BA in concrete has the potential to comply with legislation when treated correctly [31].

Instead of applying BA as an inert aggregate or filler, application as raw material for cement production or pozzolanic material was studied [32, 33]. By useing a 1400 °C heat treatment, Lin et al. [34] produced a pozzolanic slag. Li et al. [22], Al-Rawas et al. [3], and Juric et al. [34] suggest a cement replacement of 30%, 20%, and 15% respectively. Additional to an increased reactivity as a result of heat treatment, reduced leaching from the BA has also been shown in several studies [35–38].

Due to the heterogeneous character of BA, where the ratio of constituents vary (e.g. organic matter, ceramics, glass, minerals, and non-ferrous and ferrous metals), the final properties of the concrete are affected. Specific treatments could therefore be targeted to minimise variations (e.g. crushing [39]). Hence this study is aimed at determining the underlying properties of the BA in order to be able to evaluate and quantify the effectiveness of further treatment steps.

2. METHODOLOGY

2.1. Materials

The BA fraction considered in this study is one of several fractions produced after a prior treatment process [40] :

1. Weathering for 3-6 months, reducing the materials heavy metals leaching and reactivity
2. Dry separation: extracting large metal fractions by overhead magnet, impact crushing reducing the particle size to < 40 mm, and ballistic separation into a 0-2 mm and 2-40 mm fraction.
3. Dry separation and recovery of metals from the 2-40 mm fraction: secondary treatment with overhead magnets and non-ferrous metals recovery through triple eddy current magnet systems. Additionally, organics and plastics are mostly recovered creating a mineral granulate fraction.
4. Washing and wet separation, creating a sludge (0-63 μm), a fine granulate fraction (63 μm-2 mm), a coarse granulate fraction (2-40 mm), and a floating organic fraction which is refed to the incineration process.
5. Finally, a last ferrous and non-ferrous metals extraction.

The material under investigation has been sampled according to DIN EN 932-1 [41] from a 1 m^3 flexible intermediate bulk container.

Prior to further analysis, the material was dried at 105 °C to an oven-dry state where a constant mass was reached [42]. By doing so, not only a correct particle size distribution (PSD) is obtainable, also the effect of agglomeration during the sieve analysis is minimised.

2.2. Methods

Based on EN 933-1 and EN 933-2 [43, 44], the PSD of the BA is determined. Consequently, the material is split in fractions. Additional sieve sizes were added to the mesh sizes described in EN 933-2 [44], increasing the detail of the

study (22.4 mm, 11.2 mm, 5.6 mm, 2.8 mm, 1.4 mm, 710 μm, 355 μm, 180 μm, and 91 μm).

Furthermore, with the naked eye, the 4.0-5.6 mm, 5.6-8.0 mm, 8.0-11.2 mm, 11.2-16.0 mm, 16.0-22.4 mm, and 22.4-31.5 mm are hand-sorted based on visual appearance (Fig. 1) into ceramic and stone, glass, mineral (slag), metals, and unburned (plastic, paper, organic) fractions. In the case that more than one material is identified in a particle (e.g. glass with minerals attached) this is classified by the material predominantly present.
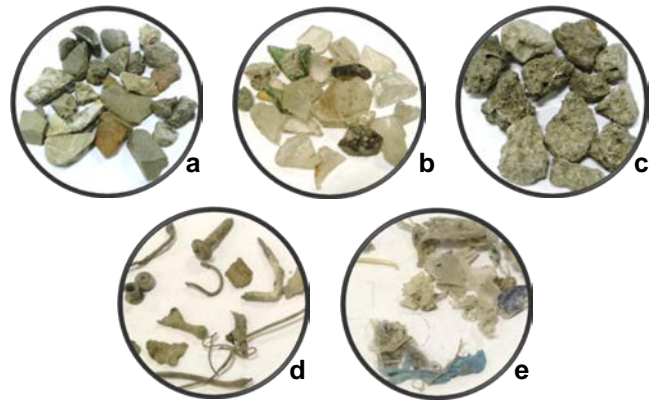

Fig. 1 Hand sorted fractions: (a) ceramic and stone, (b) glass, (c) mineral, (d) metals, (e) unburned

Despite several prior metal extraction steps using overhead magnets, both clean metals and metals embedded in mineral fractions can be found. These ferrous metal particles can be extracted by running the material over a magnetic drum separator. In the laboratory process of magnetic extraction, the momentum of particles is avoided by loading a small amount of particles on the surface of a permanent magnet prior to slowly rotating it upside down. By doing so, an optimal and constant extraction is achieved.

A certain amount of mineral particles have been found to be extractable by magnet. This fraction will hereinafter be referred to as "mineral - extractable". The remainder is referred to as "mineral - non-extractable".

The specific density of every material fraction is determined using a He pycnometer (Micrometrics Accupyc 1340). Finally, the water permeable porosity of these fractions is determined through hydrostatic weighing according to NT Build 492, ASTM C1202, and EN 1097-6 [45–47] after vacuum filling the samples with distilled water using:

$$\varphi_{v,water} = \frac{m_s + m_d}{m_s + m_w} \; x \; 100$$

where:

$\varphi_{v,water}$ water permeable porosity (%),
m_s surface dried mass of water-saturated sample in air (g),
m_w mass of water-saturated sample in water (g),
m_d mass of oven dried sample (g).

3. RESULTS AND DISCUSSION

3.1. Particle size distribution

The particle size distribution (PSD) of the BA is displayed on a logarithmic scale in Fig. 2. The solid lines depict the PSD of the initial material (4-31.5 mm).

For completeness, the dotted lines show the remaining PSD of the initial 0-40 mm BA. This material is excluded from this particular study.
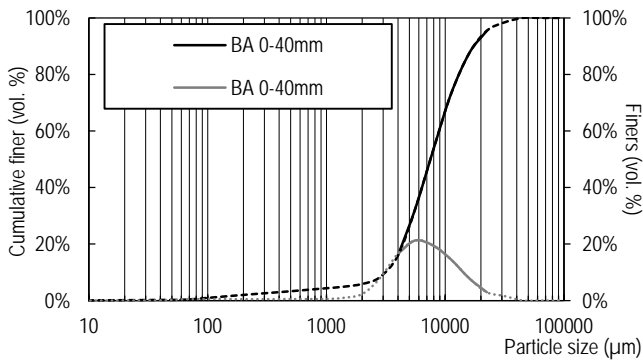

Fig. 2 Particle size distribution MSWI BA 2-40 mm

The material has a PSD comprising the complete concrete gravel range (4-32 mm). Therefore, replacement of this virgin aggregate is easily suggested. However, physical and chemical properties (e.g. fracture resistance, porosity, leaching, alkali silica reaction, etc.) can conflict with the ability to apply the BA directly into concrete, making additional treatment steps necessary.

3.2. Material distribution

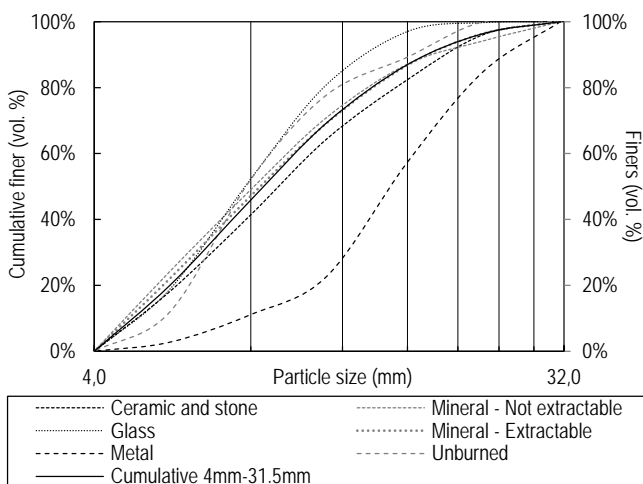Fig. 3 depicts the PSDs of the various materials found in the 4-31.5 mm BA on a logarithmic scale.

Fig. 3 PSD of sorted material fractions

Except for the metal fraction and the glass fraction, with respectively comparatively few small and large particles, all materials show a similar PSD. Additionally, the extractable mineral fraction relates to a very large extent with the average PSD of the entire material (Fig. 2).

When every size fraction of the BA is considered individually, the distribution of the materials throughout the various fractions can be determined (Fig. 4).
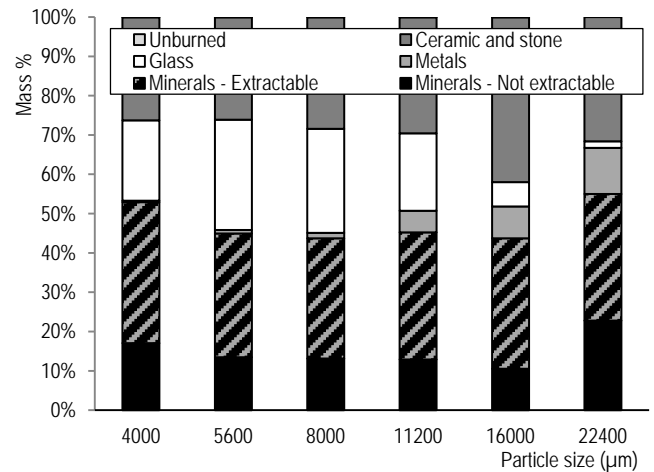

Fig. 4 Material distribution in MSWI BA fractions > 4 mm

In addition to the PSDs, this graph shows how the content of materials change throughout the size fractions. With increasing particle size, the increasing metal, and decreasing glass content can be perceived. Additionally, an overall increasing ceramic and stone content can be observed, while the mineral content decreases until a large increase in the largest fraction is perceived. On average, 70% by mass of the dry mineral fraction contains enough ferrous metals to be extractable by use of a strong magnet. This accounts for 32.5% by mass of the total material.

In this study, the material is pre-dried. Due to the high porosity of this material, the particle weight is greatly increased when the material is moist or wet. In the case of a high moisture content, the increased particle mass combined with a constant magnetic force can potentially reduce the extraction ratio. Additionally, in a full scale treatment setup, the particles will have a momentum while moving across the magnetic separation device (e.g. a rotating drum magnet). Therefore, with an equal magnetic force, a decreased amount of particles is expected to be extracted. Drying the material is costly and reduces the throughput of material. In order to overcome this in practice while achieving a similar extraction ratio, the magnetic force could be increased.

3.3. Porosity

Fig. 5 depicts both the absolute volume (calculated using specific density) of the non-organic, non-metallic materials and their porosity. Due to the fact that the specific densities

of these materials are relatively close to each other, the material distribution based on volume is closely related to the material distribution based on mass.
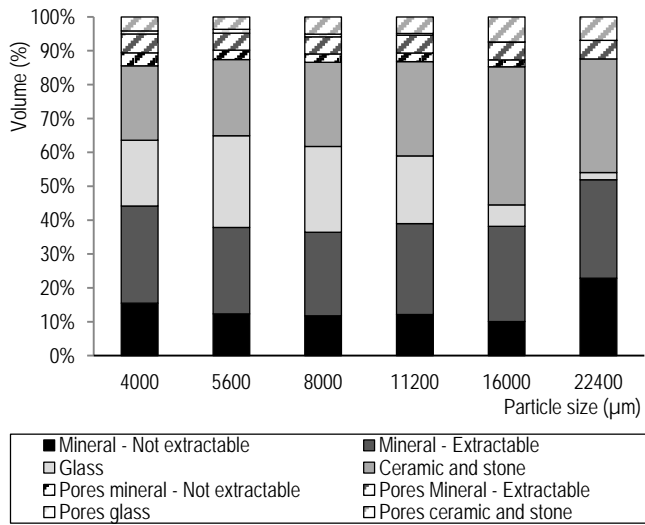

Fig. 5 Material volume and porosity

Together, extractable minerals and ceramics and stones account for the majority of the porosity (5.8% and 5.3% respectively). The remaining non-extractable minerals and glass fraction show a porosity of 3.1% and 0.9%, respectively.

In contrast to prior expectations, the glass fraction has been found to show a porosity. This can be explained by the fact that the BA glass fraction is not purely glass. A number of glass particles show a mineral slag layer on their surface. Additionally, particles can be scratched or etched creating an increased surface area able to retain water. Furthermore, with an increase in particle size, the surface to volume ratio decreases. Because of this, the influence of this layer is reduced.

Since the extractable mineral fraction has the highest porosity of all materials, magnetic separation has the potential to decrease the overall porosity of the BA and to provide a cleaner mineral stream of glass or ceramics and stones. This can potentially increase the applicability for both material streams generated.

4. CONCLUSIONS

Based on the data presented, the following can be concluded:

- The PSD of the BA lies predominantly in the gravel size range An application of coarse aggregates replacement is hereby possible when taking legislation into account;
- 70% of the mineral fraction is extractable by magnet, accounting for 32.5% of the overall material;

- Extractable minerals and ceramics and stones account for the majority of the porosity (5.8% and 5.3% respectively);
- Magnetic separation has the potential to provide a cleaner mineral stream of glass, ceramics and stones;
- Through magnetic separation, the overall porosity of the remaining BA is reduced.

Additional studies determining both the chemical and mineralogical composition of all fractions involved are required in order to establish a correlation between physical properties of individual size fractions and their mineralogical composition related to their density and PSD.

ACKNOWLEDGEMENT

REFERENCES

1. Chimenos, J.., Segarra, M., Fernández, M.., Espiell, F.: Characterization of the bottom ash in municipal solid waste incinerator. J. Hazard. Mater. 64, 211–222 (1999).
2. Wiles, C.C.: Municipal solid waste combustion ash: State-of-the-knowledge. J. Hazard. Mater. 47, 325–344 (1996).
3. Al-Rawas, A.A., Wahid Hago, A., Taha, R., Al-Kharousi, K.: Use of incinerator ash as a replacement for cement and sand in cement mortars. Build. Environ. 40, 1261–1266 (2005).
4. Yang, R., Liao, W.-P., Wu, P.-H.: Basic characteristics of leachate produced by various washing processes for MSWI ashes in Taiwan. J. Environ. Manage. 104, 67–76 (2012).
5. Su, L., Guo, G., Shi, X., Zuo, M., Niu, D., Zhao, A., Zhao, Y.: Copper leaching of MSWI bottom ash co-disposed with refuse: effect of short-term accelerated weathering. Waste Manag. 33, 1411–7 (2013).
6. del Valle-Zermeño, R., Formosa, J., Chimenos, J.M., Martínez, M., Fernández, A.I.: Aggregate material formulated with MSWI bottom ash and

APC fly ash for use as secondary building material. Waste Manag. 33, 621–7 (2013).

7. Saikia, N., Cornelis, G., Mertens, G., Elsen, J., Van Balen, K., Van Gerven, T., Vandecasteele, C.: Assessment of Pb-slag, MSWI bottom ash and boiler and fly ash for using as a fine aggregate in cement mortar. J. Hazard. Mater. 154, 766–77 (2008).

8. Bertolini, L., Carsana, M., Cassago, D., Quadrio Curzio, A., Collepardi, M.: MSWI ashes as mineral additions in concrete. Cem. Concr. Res. 34, 1899–1906 (2004).

9. Cement Association of Canada: No Title, http://ecosmartconcrete.com/?page_id=208.

10. Xu, T., Galama, T., Sathaye, J.: Reducing carbon footprint in cement material making: Characterizing costs of conserved energy and reduced carbon emissions. Sustain. Cities Soc. 9, 54–61 (2013).

11. Tkaczewska, E., Mróz, R., Łój, G.: Coal–biomass fly ashes for cement production of CEM II/A-V 42.5R. Constr. Build. Mater. 28, 633–639 (2012).

12. Grosso, M., Biganzoli, L., Rigamonti, L.: A quantitative estimate of potential aluminium recovery from incineration bottom ashes. Resour. Conserv. Recycl. 55, 1178–1184 (2011).

13. Arickx, S., Van Gerven, T., Vandecasteele, C.: Accelerated carbonation for treatment of MSWI bottom ash. J. Hazard. Mater. 137, 235–243 (2006).

14. Meima, J.A., van der Weijden, R.D., Eighmy, T.T., Comans, R.N..: Carbonation processes in municipal solid waste incinerator bottom ash and their effect on the leaching of copper and molybdenum. Appl. Geochemistry. 17, 1503–1513 (2002).

15. Meima, J.A., Comans, R.N..: The leaching of trace elements from municipal solid waste incinerator bottom ash at different stages of weathering. Appl. Geochemistry. 14, 159–171 (1999).

16. Cossu, R., Lai, T., Pivnenko, K.: Waste washing pre-treatment of municipal and special waste. J. Hazard. Mater. 207-208, 65–72 (2012).

17. Lin, Y.-C., Panchangam, S.C., Wu, C.-H., Hong, P.-K.A., Lin, C.-F.: Effects of water washing on removing organic residues in bottom ashes of municipal solid waste incinerators. Chemosphere. 82, 502–6 (2011).

18. Steketee, J.J., Duzijn, R.F., Born, J.G.P.: Waste Materials in Construction - Putting Theory into Practice, Proceedings of the International Conference on the Environment and Technical Implications of Construction with Alternative Materials. Elsevier (1997).

19. van Eijk, R, J.: Hydration of cement mixtures containing contaminants. Ipskamp BV, Enschede, The Netherlands (2001).

20. Florea, M.V.A. Quaas, L.C. Brouwers, H.J.H.: MSWI by-products and immobilisates as concrete constituents. Int. Conf. Adv. Cem. Concr. Technol. Africa,Dar es Salaam, Tanzania (2016).

21. Cioffi, R., Colangelo, F., Montagnaro, F., Santoro, L.: Manufacture of artificial aggregate using MSWI bottom ash. Waste Manag. 31, 281–8 (2011).

22. Li, X.-G., Lv, Y., Ma, B.-G., Chen, Q.-B., Yin, X.-B., Jian, S.-W.: Utilization of municipal solid waste incineration bottom ash in blended cement. J. Clean. Prod. 32, 96–100 (2012).

23. Müller, U., Rübner, K.: The microstructure of concrete made with municipal waste incinerator bottom ash as an aggregate component. Cem. Concr. Res. 36, 1434–1443 (2006).

24. Quenee, B., Li, G., Siwak, J.M., Basuyau, V.: Waste Materials in Construction Wascon 2000 - Proceedings of the International Conference on the Science and Engineering of Recycling for Environmental Protection, Harrogate, England 31 May, 1–2 June 2000. Elsevier (2000).

25. Siddique, R.: Use of municipal solid waste ash in concrete. Resour. Conserv. Recycl. 55, 83–91 (2010).

26. Sorlini, S., Abbà, A., Collivignarelli, C.: Recovery of MSWI and soil washing residues as concrete aggregates. Waste Manag. 31, 289–297 (2011).

27. Juric, B., Hanzic, L., Ilić, R., Samec, N.: Utilization of municipal solid waste bottom ash and recycled aggregate in concrete. Waste Manag. 26, 1436–42 (2006).

28. Pecqueur, G., Crignon, C., Quénée, B.: Behaviour of cement-treated MSWI bottom ash. Waste Manag. 21, 229–233 (2001).

29. Cheng, A.: Effect of incinerator bottom ash properties on mechanical and pore size of blended cement mortars. Mater. Des. 36, 859–864 (2012).

30. Tang, P., Florea, M.V.A., Brouwers, H.J.H.: Recycling Of Waste Materials As Lightweigth Aggregate By Cold Bonding Pelletizing Technique. In: Proceedings of the thirty-eighth international conference on cement microscopy. pp. 181–188 (2016).

31. Florea, M.V.A.: Environmental Interactions of Cement-Based Products. Int. Conf. Adv. Cem. Concr. Technol. Africa, Dar es Salaam, Tanzania,. accepted in October 2015 (2016).

32. Ferraris, M., Salvo, M., Ventrella, A., Buzzi, L., Veglia, M.: Use of vitrified MSWI bottom ashes for concrete production. Waste Manag. 29, 1041–1047 (2009).

33. Pan, J.R., Huang, C., Kuo, J.-J., Lin, S.-H.: Recycling MSWI bottom and fly ash as raw materials for Portland cement. Waste Manag. 28, 1113–8 (2008).

34. Lin, K.L., Lin, D.F.: Hydration characteristics of municipal solid waste incinerator bottom ash slag as a pozzolanic material for use in cement. Cem. Concr. Compos. 28, 817–823 (2006).

35. Arickx, S., Van Gerven, T., Knaepkens, T., Hindrix, K., Evens, R., Vandecasteele, C.: Influence of treatment techniques on Cu leaching and different organic fractions in MSWI bottom ash leachate. Waste Manag. 27, 1422–7 (2007).

36. Hyks, J., Nesterov, I., Mogensen, E., Jensen, P. a., Astrup, T.: Leaching from waste incineration bottom

ashes treated in a rotary kiln. Waste Manag. Res. 29, 995–1007 (2011).

37. Qiao, X.C., Tyrer, M., Poon, C.S., Cheeseman, C.R.: Novel cementitious materials produced from incinerator bottom ash. Resour. Conserv. Recycl. 52, 496–510 (2008).

38. Tang, P., Florea, M.V.A., Spiesz, P., Brouwers, H.J.H.: Application of thermally activated municipal solid waste incineration (MSWI) bottom ash fines as binder substitute. Cem. Concr. Compos. 70, 194–205 (2016).

39. van de Wouw, P.M.F., Florea, M.V.A., Brouwers, H.J.H.: Crushing of MSWI bottom ash towards material purification. In: AInternational Conference on Advances in Cement and Concrete Technology in Africa, Dar es Salaam, Tanzania,. p. accepted in October 2015 (2016).

40. Florea, M.V.A.: Secondary materials in cement-based products, Treatment, modelling and environmental interaction, Thesis, Eindhoven University of Technology, (2014).

41. DIN EN 932-1: Prüfverfahren für allgemeine Eigenschaften von Gesteinskörnungen - Teil 1: Probenahmeverfahren. (1996).

42. S., Mindness, Young J F, Darwin D.: Concrete. Prentice Hall, Pearson Education, Inc. Upper Saddle River, NJ 07458 (2003).

43. DIN EN 933-1: Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen - Teil 1: Bestimmung der Korngrößenverteilung - Siebverfahren, (1997).

44. DIN EN 933-2: Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen - Teil 2: Bestimmung der Korngrößenverteilung; Analysensiebe, Nennmaße der Sieböffnungen, (1995).

45. NT Build 492: Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments. (1999).

46. ASTM C1202: Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration. , Philadelphia, USA (2005).

47. EN 1097-6. (2000).