Use of municipal solid waste incinerator bottom ash as aggregate in concrete

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Background

Modern municipal solid waste incinerator plants produce bottom ashes, which are used in building industry, especially as base course in road constructions. Because of a highly sophisticated reprocessing technique, the ashes show a relatively stable composition, comparatively well defined properties and environmentally relevant parameters below legal limits. Due to its chemical and mineralogical characteristics, the bottom ash can in principle be used as aggregate in the production of normal strength concrete. However, if the ash contains concrete damaging components recycling becomes problematic.

To assess the use of municipal solid waste incinerator bottom ash (MSWI bottom ash) as aggregate in concrete, different additionally treated ashes were chemical and physical characterised. Furthermore, concrete specimens with bottom ash as aggregates were produced and their engineering properties were studied.

Material

2/8 mm 8/16 mm 16/32 mm

Fig. 1
Fractions of municipal solid waste incinerator bottom ash.

The bottom ash is the residue of controlled combustion of domestic waste and municipal solid waste of a modern waste-to-energy plant in Hamburg, Germany. The ash is removed from the boiler by a ram ash expeller using surplus water for wet treatment. Afterwards, comprehensive mechanical treatments as well as an ageing by intermediate storing follow. Lightweight materials, scrap iron, nonferrous metals, unburned residues and oversized particles > 32 mm are separated.

Beside 1.3 MWh steam and electricity, the incineration of 1 ton municipal solid waste yields about 230 kg bottom ash, 24 kg scrap iron, 2 kg nonferrous metals, 11 kg hydrochloric acid and 3 kg gypsum amongst others. [H. Zwahr, NAWTEC 12, Savannah, GA, 2004].

For use as concrete aggregates, the fractions 2/8, 8/16 and 16/32 mm were produced from the treated and aged MSWI bottom ash (Fig.1).

Concrete specimens were produced with 310 kg/m^3 ordinary Portland cement CEM I 32.5 R, an effective water/cement ratio of 0.60 and aggregates according to the grading curve of B32. The aggregates from 2 to 32 mm particle size were replaced by different additionally treated bottom ashes. The fraction 0/2 mm was natural river sand. The control concrete was made up of the same mixture, but exclusively with natural sand and gravel as aggregates.

Results

Characteristics of bottom ash

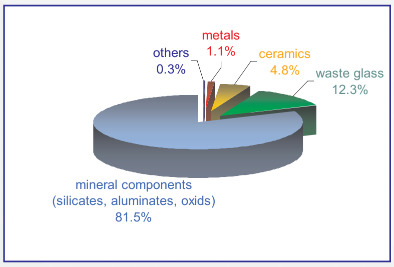

Fig. 2
Average composition of MSWI bottom ash analysed to all appearances according to DIN 4226-100.

Tab. 1
Results of chemical analyses of different fractions of bottom ash determined according to DIN EN 1744-1.

Component in M.-%	Bottom ash		
	2/8 mm	8/16 mm	16/32 mm
Fines	4.4	2.7	1.7
Waste glass	16.2	12.3	4.7
NaOH sensitive components	3.10	4.17	0.94
Floating components	8.73	5.88	4.97
Organic components[1)]	+	-	-
Aluminium (metal)	1.22	1.59	1.06
Chloride	1.59	1.60	1.58
Sulphate	0.80	0.48	0.52
Free lime	3.24	3.24	2.88

[1)] + darker, - lighter relating to a coloured reference solution

Fig. 3
Spalling of a concrete specimen containing MSWI bottom ash as 2/32 mm aggregates caused by an aluminium grain (cross section, scanner, reflected light).

Fig. 4
The aluminium grain with reaction layer, which is up to 2 mm thick (polished cross section, photo-micrograph, reflected light).

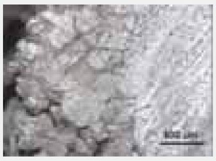

Fig. 5
Details of the reaction layer at the aluminium grain with white $Al(OH)_3$ (polished cross section, photo-micrograph, reflected light).

European Geosciences Union General Assembly 2007
Wien, 15 - 20 April 2007

Fig. 6
Crack into a concrete bar containing MSWI bottom ash as 2/32 mm aggregates caused by an waste glass fragment (polished cross section, scanner, reflected light, EDX).

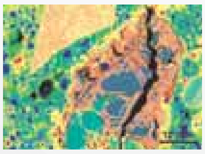

Fig. 7
The glass fragment with ASR products. Overlay of elemental distribution of Ca (green), K (red) and Si (blue), which results in salmon red corresponding to alkali silicate gel (polished cross section, EDX map).

Fig. 8
The alkali silicate gel into the glass fragment (thin section, photomicrograph, transmitted light).

Improvement of ash properties by additional treatment

Tab. 2
Change of properties of the MSWI bottom ash by additional treatment.

Treatment	Upstream sieving/washing	Opto-mechanical glass separation	Lye treatment with NaOH solution
Name of treated bottom ash	BA(S)	BA(G)	BA(L)
Fines	++	++	++
Density, porosity, water absorption	●	●	●
Waste glass	●	+	●
Aluminium (metal)	●	●	++
NaOH sensitive components	●	+	++
Floating components	+	+	++
Organic components	++	++	++
Chloride	+	+	++
Sulphate	●	●	++

++ = considerably improved, + = improved, ● = unchanged

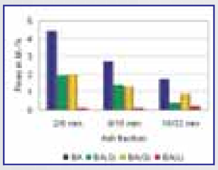

Fig. 9
Content of fines in the additionally treated MSWI bottom ashes. Upstream sieving/washing and lye treatment remove the fines effectively.

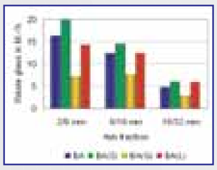

Fig. 10
Content of waste glass in the additionally treated MSWI bottom ashes. The opto-mechanical glass separation reduces the glass fraction to half.

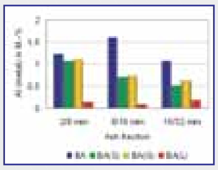

Fig. 11
Content of aluminium in the additionally treated MSWI bottom ashes. The lye treatment with NaOH solution reduces the aluminium content to less than 0.4 %.

Testing of concretes

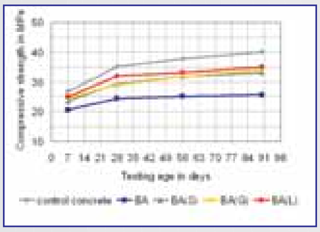

Fig. 12
Development of compressive strength of concretes containing different treated MSWI bottom ashes as 2/32 mm aggregates in comparison to the control concrete with natural aggregates only.

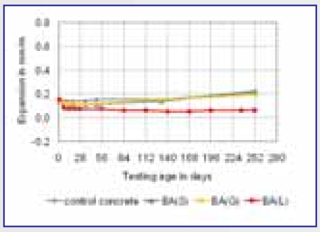

Fig. 13
Expansion of concretes containing different treated MSWI bottom ashes as 2/32 mm aggregates due to ASR. The specimens were stored in a humidity chamber at 40 °C and 99.9 % r.h. over a period of 9 months.

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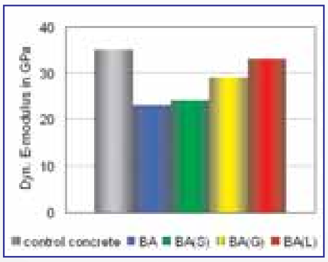

Fig. 14
Dynamic elastic modulus of concretes containing different treated MSWI bottom ashes as 2/32 mm aggregates at the age of 28 days.

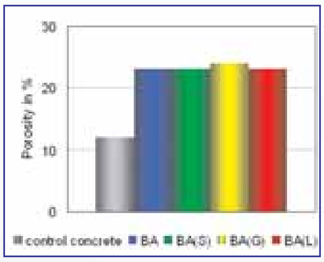

Fig. 15
Porosity of concretes containing different treated MSWI bottom ashes as 2/32 mm aggregates at the age of 28 days.

Conclusions

- The high content of mineral components of about 80 %, such as glassy and crystalline silicates, aluminates, oxides would allow the use of the MSWI bottom ash as aggregate in concrete (Fig. 2). The bulk density of the ash is 2.4 g/cm³ and the porosity is about 18 %.
- But the ash contains concrete damaging components, such as chlorides, sulphates, organic compounds, too large quantities of fines, aluminium and waste glass (Tab. 1).
- Especially, inclusions of aluminium into the ash particles and a glass content of about 15 % cause cracks and spalling in concrete specimens within a very short time. In the alkaline environment of fresh and hardened concrete the aluminium particles react with water to aluminium hydroxide, aluminates and hydrogen (Fig. 3 to 5). Furthermore, glass corrosion yields to alkali silicate gels by alkali silica reaction (ASR) (Fig. 6 to 8). Both reactions form voluminous products, which lead to concrete damages.
- The upgrade of the ash characteristics due to several additional treatments is summarised in Tab. 2. The content of most harmful components of the MSWI bottom ash can be minimised (Fig. 9 to 11).
- Concretes with a good workability and a compressive strength of C20/25 can easily be produced with MSWI bottom ash as 2/32 mm aggregates (Fig. 12).
- The concrete tests confirm that the additional treatments improve the quality of the ash, which results in better (more similar to control specimens) properties of the hardened concretes (Fig. 12 and 14).
- However, the concretes containing additionally treated bottom ashes show a similar behaviour to those made with recycled concrete aggregates. In comparison to the control specimens with natural aggregates only, they exhibit 15 % lower compressive strength and E-modulus but twice the porosity (Fig. 12, 14, 15). These differences arise from the lower strength, higher porosity and reprocessing induced microcracks of the ash aggregates.
- During storing in a humidity chamber at 40 °C and 99.9 % r.h. all concretes show alkali silica reactions, which start at glass fragments or glass inclusions of the ash particles. The alkali silicate gel is well distributed into the pore space because of the relatively high porosity of concretes. Thus, in the testing period of about 9 months the concrete bar do not show considerable expansion (Fig. 13). But individual glass agglomerates cause cracks, which can suddenly result in damages (Fig. 6 to 8).
- Concretes containing the original bottom ash as well as the ashes from the sieving/washing treatment and the glass separation show damages, which are caused by the aluminium reaction (Fig. 3 to 5).
- Only those concretes, which were made with the ash with low aluminium content from the lye treatment with NaOH solution, remain free of damage.

Acknowledgments

This work was supported by
MVR Müllverwertung Rugenberger Damm GmbH & Co. KG.