Properties of Concrete with Municipal Solid Waste Incinerator Bottom Ash

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Abstract. The appropriate utilization of Municipal Solid Waste Incineration (MSWI) residues is a worldwide studied topic over the last decades. One of the possibilities is to use MSWI ashes in concrete production, as it is done with coal combustion products. The bottom ash features the most convenient composition for this purpose, and it is available in highest amounts among the MSWI ashes. Untreated bottom ash was used as partial replacement of sand in concrete; strength was not negatively affected up to 10 % replacement, the prepared concrete had sufficient durability. The longer-time behavior of concrete with bottom ash differed from the control material due to presence of sulfates and chlorides in bottom ash.

Keywords: municipal solid waste incineration; bottom ash; concrete; compressive strength; durability

1. Introduction

Incineration of municipal solid wastes is an effective way (when compared with landfilling) of reduction of the non-recyclable waste amount; the waste weight reduction by incineration is down to 30 % of initial mass, the volume reduction is even more effective (about 10 %). Another positive aspect of the incineration can be energy production (electricity, heat); the caloric content of municipal waste is comparable with lignite. The unwanted – but unavoidable – outcomes from incineration are represented by bottom ash (BA; about 27 wt. % of incinerated waste) and air pollution control (APC) residues (fly ashes; ca 3 wt. %). The generated amount and properties of particular ashes differ from plant to plant in dependence on the applied incineration and air pollution control technology, composition of processed wastes and even on year season. Especially the APC residues bring significant environmental risks due to heavy metals and Persistent Organic Pollutants (POPs) content. The APC management strategies and treatment methods were summarized in [1]. Bottom ash usually does not have to be treated because of its lower heavy metals and POPs content. BA can be dumped or utilized as a material; common is employment of bottom ash as embankment material but even this application is often matter of "green" objections due to possible leach out of heavy metals into surroundings during the long time environmental exposure. Hence it would be attractive to use BA as a raw material for a product where heavy metals would be immobilized and thus such product would be environmental safe. Such requirements are fulfilled well by cementitious composites [2]. The BA can be used either as concrete admixture or as raw material for cement clinker production [3].

Pera et al. [4] used MSWI bottom ash as partial coarse aggregates replacement in concrete; they proposed to treat the BA by NaOH in order to prevent aluminium induced hydrogen evolution which causes loss of strength. Such application of treated BA increased durability of concrete but still reduced its strength. Bertolini et al. [5] compared water washing and dry and wet grinding as MSWI BA treatment; only the latter process to prevent the concrete strength loss. Ferraris et al. [6] proposed melting MSWI BA at 1450 °C and

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grinding the resulting slag to particles smaller than 90 μm which can be used and filler or supplementary cementitious material. Similar approach studied Lee and Rao [7]; they added to MSWI ashes also scrap glass and the resulting slag was ground to particles finer than 38 μm. This material was used for production of blended cement [8]. Rémond et al. [9] studied effect of untreated MSWI fly ash on technological properties of cement mortars. The fly ash caused significant increase of setting time and decrease of workability and strength.

The goal of the present work is to evaluate influence of untreated MSWI bottom ash on technologically important properties – compressive strength, bulk density and durability.

2. Experimental Methods

The granulometry of MSWI bottom ash (BA) was determined by standard sieving analysis [10]. The compressive strength of 7, 28 and 90 days old concrete (cubes 150 mm) was measured using the common test described in [11]. Resistance of concrete to freezing and thawing action was determined according [12] by means of temperature cycling; one cycle consisted in 4 hours at -20° C and 2 hours at 20° C; the compressive strength was measured after given number of cycles.

3. Materials

The subject of study was bottom ash (BA) collected in the winter period of 2009 in a modern incineration facility in Czech Republic. The BA has been quenched in water after leaving the grate, and steel pieces were removed by magnetic separation. The generated BA from incinerator involves wide range of particles size; only the fraction 0-4 mm was used in the present work. The ash was dried before experiments. The content of major components (in form of oxides) is presented in Tab. 1. It was determined by XRF spectroscopy by apparatus Thermo ARL 9400 XP.

Table. 1: Content of major oxides in bottom ash (weight %).

SiO_2	33.5
Al_2O_3	15.8
Fe_2O_3	8.4
CaO	19.4
MgO	2.0
SO_3	9.3
ZnO	0.8
Na_2O	3.6
K_2O	1.9
TiO_2	1.5
Cl	1.1

Nowadays the BA is (in this particular incinerator) mixed with treated fly ashes and used as backfill and embankment material. An alternative use – as fine aggregates in concrete – was tested in this paper. Series of concrete samples was prepared according Tab. 2. Ordinary Portland cement CEM I 42.5 R was used as binder; natural aggregates were siliceous sand and gravel. The fresh concrete mixture was casted into standard cubes of edge 150 mm and stored in water to age 7, 28 or 90 days. The reference specimens (C0) were stored separately in order to prevent possible negative effects of chlorides and sulfates leached out form the C5-C15 specimens.

Table. 2: Composition of concrete mixtures with different level of fine aggregates replacement by BA.

			Natural aggregates			
Material	Cement	BA	0-4	4-8	8-16	w/c
	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	
C0	400	0	607	260	867	0.52
C5	400	30	577	260	867	0.52

| C10 | 400 | 61 | 546 | 260 | 867 | 0.52 |
| C15 | 400 | 91 | 516 | 260 | 867 | 0.52 |

4. Results and Discussion

The chemical composition of BA (Tab. 1) is highly unfavorable in order to be used in cementitious products. The sulfate content is very high when compared with published values; the chloride content is within common range of bottom ashes [2, 4]. Obviously the BA does not fulfill the standard requirements on sulfate and chloride content in aggregates for concrete [13]. On the other hand, the grading curve (Fig. 1) of studied 0-4 mm BA fraction is relatively close to granulometry of natural siliceous 0-4 mm sand. The fines content is higher than in natural sand but the fineness is not sufficient to be considered microfiller.
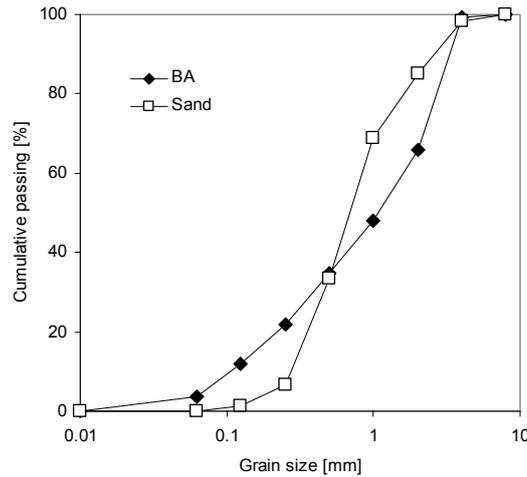

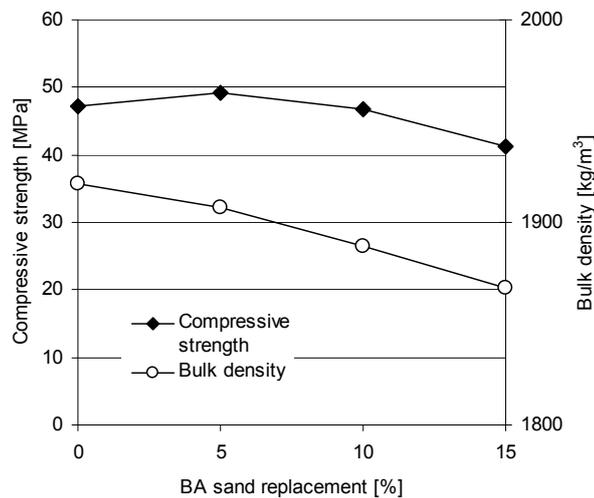Fig. 1: Grading analysis of bottom ash and sand 0-4 mm.

Fig. 2: Compressive strength (28 days) and bulk density of mixtures C0 to C15.

The dependence of concrete compressive strength upon level of sand replacement in plotted in Fig. 2. The replacement up to 10 % does not influence the strength negatively. Bulk density (Fig. 2) is slightly decreasing with the BA content but any visible expansion or spalling caused by aluminium-induced hydrogen evolution [4, 14] has not been observed. It may be explained by fact that studied BA is quenched by water after leaving the grate; the quench water is naturally alkaline (due to bottom ash soluble alkaline

components) and present aluminium reacts already during this operation. Another (auxiliary) reason might be relatively low consumption of aluminium wrappage in Czech Republic.
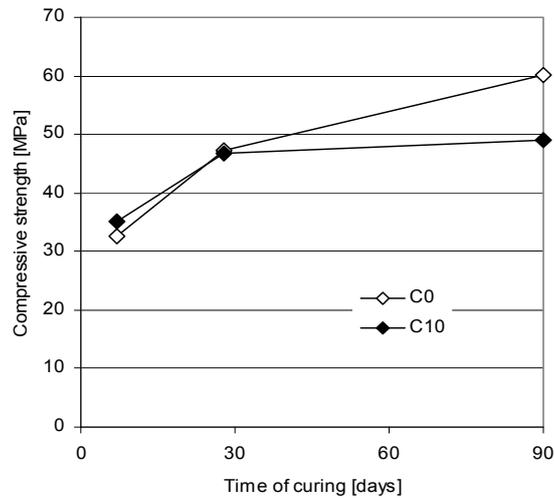

Fig. 3: Evolution of compressive strength upon time of water curing of reference mixture C0 and BA containing C10.

Since the strength of C10 has been about the same as in case of reference C0, this material has been chosen for more detailed characterization. The evolution of compressive strength upon time (Fig. 3) reveals that up to 28 days the rate of strength increase of the reference mixture and C10 has been comparable but later the hydration of reference concrete has continued while the strength of BA containing material has increased only moderately. The frost resistance tests results (Fig. 4) showed a very good durability of BA containing concrete which has sustained 125 freezing cycles without decrease of strength and integrity. Beyond this, the frost resistance experiment has demonstrated again the difference of hardening course which was already observed – C10 specimen reached its maximum strength earlier than reference C0 which hydrated significantly also during the freezing/thawing cycles.
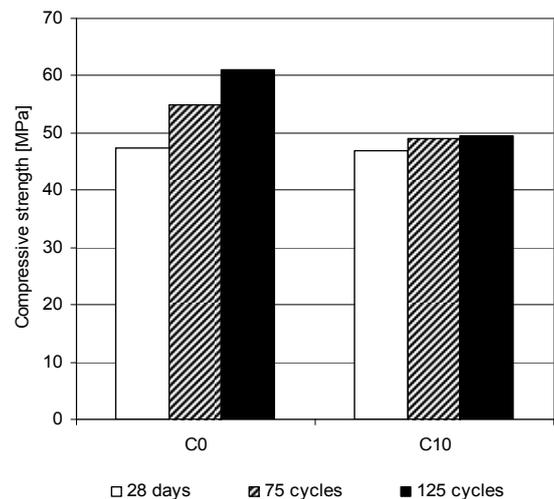

Fig. 4: Compressive strength after 75 and 125 freezing – thawing cycles.

It can be explained by different hydration mechanism of cement clinker minerals in presence of chlorides and sulfates from bottom ash [15]; they cause hydration retardation on the beginning of hydration (ettringite and its chloride analogues – hydrated chloroaluminates). Later the hydration proceeds faster but the final composition of hydrated cement binder is different from the standard cement with only low content of sulfates and almost none chlorides. Material C10 hydrated and reached its final strength faster but this "final"

strength is lower than in case of reference C0. Such behavior was observed also by authors [9] who used untreated MSWI fly ash with high content of chlorides and sulfates while in other papers dealing with treated ashes the strengthening rate was similar for reference and ash-containing mixtures [5, 6]. Obviously concrete made from untreated ashes is excluded from reinforced structures.

5. Conclusions

The untreated MSWI bottom ash (fraction 0-4 mm) was used as partial sand replacement in concrete. This ash, by its chemical composition, does not fulfill the standard requirements on concrete admixtures but the prepared concrete had acceptable properties. The 28-days compressive strength of material with 10 % sand replacement was comparable with the reference concrete; the 90-days strength was lower which can be explained by different hydration process. The frost resistance of bottom ash containing concrete was very good. The prepared concrete contained relatively low content of MSWI ash; this approach represents a compromise between the ecological request on a practical utilization of MSWI ashes and properties of the acquired product. Higher ash dosage – without any accompanied loss of concrete properties – would be possible only when the ash would be treated in some way (e.g. by vitrification) but in such case there would arise additional costs suppressing the MSWI ashes utilization attractiveness for building industry.

6. Acknowledgement

7. References

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