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Mechanical behavior of the cement mortar with high amount of Municipal Solid Waste Incineration (MSWI) bottom ash as an alternative aggregate

Kirill Polozhiy[1, 2, a *], Martin Keppert[1, b], Marcel Jogl[3, c], Robert Černý[1, d]

[1] Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Praha 6, Czech Republic
[2]University Centre for Energy Efficient Buildings, Czech Technical University in Prague, Třinecká 1024, 273 43 Buštěhrad, Czech Republic
[3] Experimental Center, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Praha 6, Czech Republic

[a]kirill.polozhiy@fsv.cvut.cz, [b]martin.keppert@fsv.cvut.cz, [c]marcel.jogl@fsv.cvut.cz, [d]cernyr@fsv.cvut.cz

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Abstract

The aim of this study was to find out an application of the municipal waste incineration materials and try to use them as a replacement for the natural ones. MSWI (Municipal Solid Waste Incineration) bottom ash (BA) was used as partial/total replacement of siliceous sand in CEM II based mortar. Three size fractions of BA were used with respect to replace the siliceous sand in corresponding way. There were designed 5 mixtures with increasing replacement of siliceous sand by 25 % each. The water/cement ratio was decided to be taken according to the constant consistence of the mortar. The bulk density, compressive strength and bending strength of the mortars were decreasing with growing content of BA.

Introduction

Nowadays the incineration of the solid wastes have become a usual practice for a great amount of countries – as it reduces the waste mass by 70 % and its volume up to 90 % - producing the two main types of ash that are known as bottom ash (BA) and air pollution control residue (APC). According to the European Waste Catalogue BA is classified as a non-hazardous waste, as it mainly consists of calcium and silica oxides and has a minimum amount of heavy metals in its composition. The major resulting by-product of municipal solid incineration process appears to be the bottom ash (BA). This fracture makes up to 80 % of the all mass and consists of app. 7-15 % ferrous and 1-2 % non-ferrous metals considering an aluminum the most relevant fraction (60 %) [1]. The rest part consists of the non-metals (CaO, SiO_2, SO_3, etc.). So it has become an attractive material for application in civil engineering industry, because using of the waste products leads to the cost reduction.

MSWI BA is produced in huge amounts all over the world. In Czech Republic for example this amount can vary from 100000 tons to 300000 tons [2]. In Denmark the amount of incineration products reaches 70000 tons [3]. In every country the goal is to find an application of this waste material. J.M. Chimenos et al. [4] were studying an aggregate material formulated with MSWI bottom ash and APC fly ash for use as secondary building material. The goal was to obtain the granulated material formulated with MSWI bottom ash and fly ash. Mechanical properties showed that the granular mixture was not suited for application with high amount of BA/APC fly ash and low amount of cement. A.P. Bayuseno and W.W. Schmahl [5] were studying chemical and mineralogical properties of the inorganic portion of MSWI bottom ash. They were investigating the changes of mineral composition of BA in the environment. M. Keppert et al. [6] were studying the durability of mortar with high content of MSWI BA. The prepared mortars were subjected to the frost resistant and thermal loading tests for evaluation of its behavior under the temperature loadings. It was found that partial replacement of the sand by MSWI BA increases the frost resistance and high temperature resistance abilities of material. The present paper deals with a possibility to apply MSWI BA as substitute of natural siliceous sand in significant level.

Studied materials

The applied BA was collected in winter 2013 from an incineration plant situated in the Czech Republic. The metallic particles were removed priory. The rest of incineration product consisted of the particles of wide size range (Fig. 1). In this work just particles 0-4 mm were used. The chemical composition of the studied material was determined with the help of the XRF spectroscopy on the Thermo ARL 9400 XP device, and is shown in the Tables 1 and 2. Bulk densities are shown in the Table 3. Generally the chemical composition is expectable for such kind of material. Dominant are the ash forming oxides (CaO, SiO_2, Al_2O_3, Fe_2O_3), notable is the increase of SiO_2 content with the coarsening of the particles while the content of CaO is decreasing. The same pattern was observed also in case of SO_3 and chlorides. It indicates more salty character of finer fractions compared to the coarser.

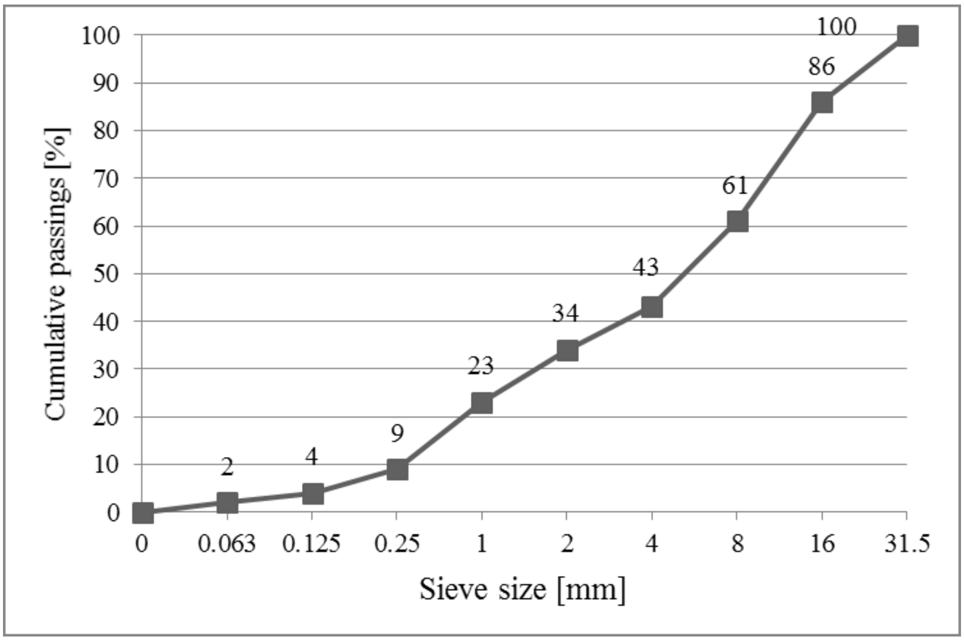

Fig. 1 Grading curve of the BA

Table 1. Major oxides content in the used BA size fractions

% (m/m)	0-1 mm	1-2 mm	2-4 mm
CaO	33.3	29.4	27.2
SiO_2	28.7	32.3	35.8
Al_2O_3	11.9	12.1	12.0
Fe_2O_3	6.6	7.3	6.5
P_2O_5	2.5	2.5	2.5
K_2O	1.8	1.9	1.8
Na_2O	2.8	3.5	3.9
TiO_2	1.3	1.3	1.2
SO_3	5.8	4.8	4.4
Cl	1.9	1.6	1.4

Table 2. Bulk and matrix densities and porosity of the BA

	ρ_v [kg/m^3]	ρ [kg.m^{-3}]	ψ [%]
0-1 mm	2012	2685	25.5
1-2 mm	1786	2128	16.1
2-4 mm	2008	2725	26.6

The bulk and matrix densities and corresponding porosities of particular fractions are summarized in Table 2. All size fractions are relatively porous, especially compared to natural siliceous sand used in Czech Republic which is compact. Composition of the mortar samples is shown in the Table 4. CEM II 32.5 was used as a binder, siliceous sand and BA as aggregates. Replacement was made according to the fraction distribution curves of siliceous sand and BA and bulk densities of the used materials. Fraction distribution of the siliceous sand is shown on the Figure 2. Standard prisms with dimensions 160x40x40 mm were made from mortars and kept in relative humidity 100 % for 28 days.

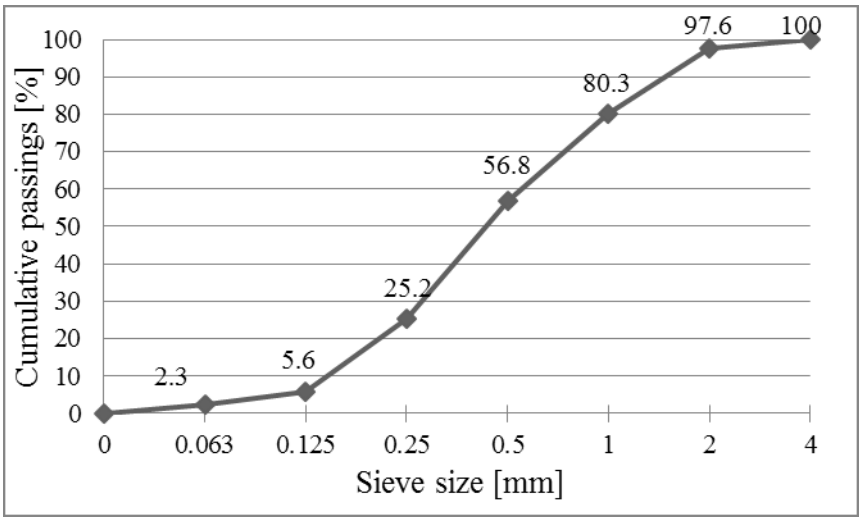

Fig. 2 Grading curve of the siliceous sand

Table 4. Composition of mortars with different percentage of replaced aggregate

kg/m^3	CEM II 32.5	0-1 mm BA	1-2 mm BA	2-4 mm BA	Sand	Water l	w/c
SR	586	0	0	0	1758	293	0.5
S25	586	192	71	67	1318	352	0.6
S50	586	384	142	133	879	393	0.67
S75	586	575	213	200	439	457	0.78
S100	586	767	283	266	0	457	0.78

Experimental methods

The compressive and tensile strengths were determined with the help of the device EU 40 on the beams described above. First those beams were dried in the drying chamber at the temperature 105°. Then the bulk densities of the all corresponding mixtures were measured. Finally they were loaded with the bending stresses up to the strength loss. Then the remaining halves of the beams were loaded with the compressive loadings up to their ultimate strength.

Results and discussion

Mechanical properties of the studied materials are described on the graphs and in the tables below. As we can see the values of mortars bulk densities are decreasing with increasing amount of the MSWI bottom ash replacing the compact siliceous sand. It is obviously related to the higher porosity of aggregates itself but also to necessity to use higher w/c ratio due to expectable high sorptivity of porous BA aggregates. The porous BA is also expected to have lower strength than compact siliceous sand what, together with higher w/c, contributes to the loss of compressive and bending strength of mortars (Fig. 4 and 5). The negative influence of BA aggregates can be reduced to certain level; the workability of the mixture can be improved by a plasticizer instead of higher dosing of water which should result to the better strength. On the other hand, the high porosity of material can be beneficiary with respect to thermal properties and also to durability.

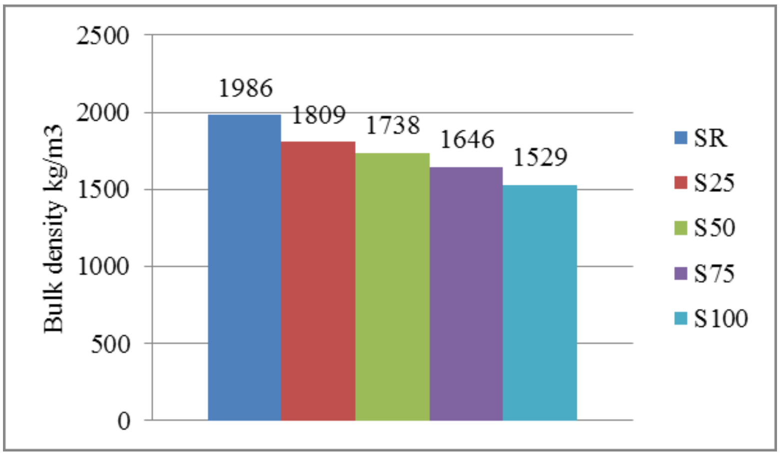

Fig. 3 Bulk densities of the studied materials

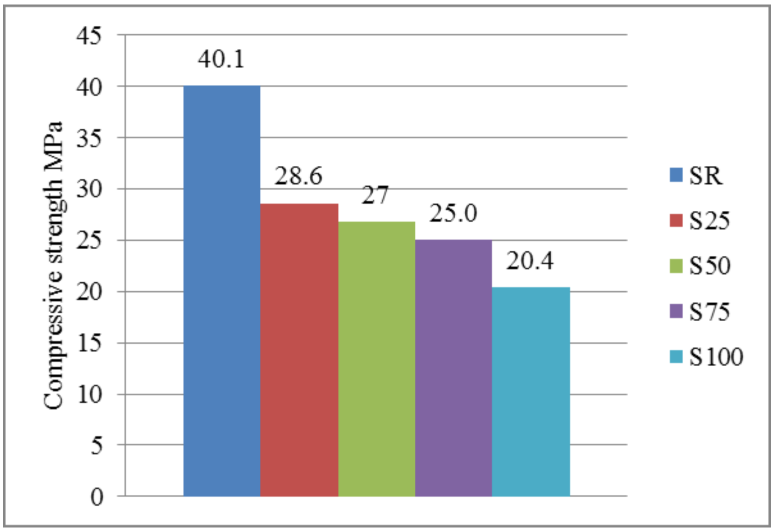

Fig. 4 Compressive strength of the studied materials (28 days)

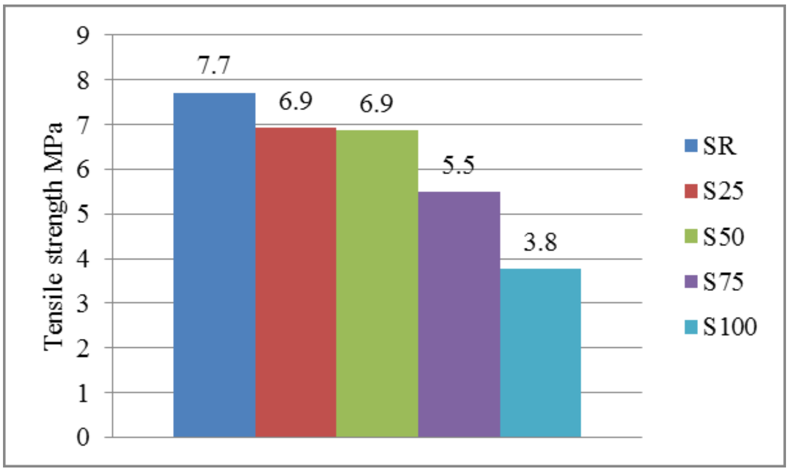

Fig. 5 Tensile strength of the studied materials (28 days)

Conclusion

There were crafted four mortars with increasing replacement level of siliceous sand by the MSWI bottom ash S25, S50, S75, S100 – with 25%, 50%, 75% and 100% of replaced sand. With increasing amount of the MSWI BA was increasing the porosity of the samples which caused decreasing of bulk densities and also compressive and tensile strengths. But still resulting material is acceptable for application in civil engineering industry, because of the ratio of bulk density/compressive strength.

Acknowledgments

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