2012 IACSIT Coimbatore Conferences
IPCSIT vol. 28 (2012) © (2012) IACSIT Press, Singapore

Durability of Mortar with High Content of Municipal Solid Waste Incineration Bottom Ash

Martin Keppert [+], Zbyšek Pavlík, Jaromír Žumár and Robert Černý

Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic

Abstract. The utilization of wastes as raw materials for building materials production is established for many decades. It is beneficial for economical, technical and environmental reasons. On the other hand similar applications of Municipal Solid Waste Incineration (MSWI) ashes are still in a research phase. The paper deals with influence of untreated MSWI bottom ash on durability of cement mortar. The mortars were subjected to frost resistance test and also to thermal load. It was found that partial replacement of natural sand by MSWI bottom ash increases the ability of material to withstand both frost and high temperature load.

Keywords: municipal solid waste incineration; bottom ash; durability; thermal load; frost resistance

1. Introduction

Natural and man-made pozzolanic and hydraulic materials are essential for civil engineering for several millennia. Volcanic ash, tuff or crushed ceramics are the ancient examples, modern age brought utilization of industrial wastes – coal fly ash, blast furnace slag, microsilica etc. Before the Portland cement invention pozzolans were the solely way to increase strength and durability of lime based materials. Nowadays there is a wide range of reasons for utilization of mineral (pozzolanic and hydraulic) admixtures in cementitious materials. The most valuable admixture is microsilica used for higher strength and durability of High Performance Concrete. Similar positive effects on durability can be reached also by burnt kaolin clay – metakaolin [1]. The environmental motivation of using mineral admixtures consists in lower energy consumption (and CO_2 emissions) when part of the clinker is replaced by pozzolana or blast furnace slag.

The resistance of concrete towards freezing/thawing action is usually related to its porosity and can be increased by air entraining [2]. Yüksel et al. [3] studied influence of non-ground blast furnace slag and coal bottom ash on concrete durability. Poon et al. [4] compared elevated temperature performance of several concretes with mineral admixtures. Thermally induced changes in cementitious composites are attributed to several processes; generally thermally loaded cementitious materials loss its strength and its microstructure changes – gel pores are diminishing due to CSH dehydration and consequent shrinkage [5] while the larger capillary pores volume is increasing.

Fly and bottom ashes generated in process of Municipal Solid Waste Incineration (MSWI) represent a relatively new group of potential concrete admixtures. Its utilization in this field is limited by its unfavorable chemical composition where especially high content of chlorides and sulfates limits the practical applications [6]. Nevertheless the amount of generated MSWI ashes is high and a reasonable ways of its utilization should be searched. The published papers deal mostly with treatments procedures (washing, vitrification etc.) aiming to improve the ash composition and properties and with optimum composition of concrete mixture but there is a lack of information about influence of MSWI ashes on durability of cementitious materials.

[+] Corresponding author. Tel.: + 420224354563; fax: + 420224354446
E-mail address: martin.keppert@fsv.cvut.cz

The goal of this paper is to evaluate effect of untreated MSWI bottom ash on frost and high temperature resistance of cement mortars where the bottom ash was used as (up to 40 %) replacement of aggregates.

2. Experimental Methods

The pore size distribution of cementitious mortars was determined by mercury intrusion porosimetry. The water sorption isotherm was measured by gravimetric method by DVS Advantage. The bending and compressive strength of mortars were determined by help of 160 x 40 x 40 standard prisms. Resistance of mortars to freezing and thawing action was determined according [7] by means of temperature cycling. The thermal load of specimens was realized in laboratory electrical furnace; the holding time at given temperature was 4 hours, the heating rate 5 °C/min. The (residual) matrix density was measured by helium pycnometry; the bulk density was calculated based on mass and size of specimens. The total porosity was calculated from matrix and bulk density.

3. Materials

The bottom ash (BA) was collected in the winter 2009 in a modern incineration facility in Czech Republic. The BA has been quenched in water after leaving the grate. The generated BA from incinerator involves wide range of particles size but only the separated fraction 0-4 mm was used in the present work. 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. The BA does not fulfill the standard requirements on sulfate and chloride content in aggregates for concrete [8].

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 cement mortar – was tested in this paper. Mortar samples were prepared according Tab. 2.; the digit in symbol corresponds to level of sand replacement by BA. Ordinary Portland cement CEM I 42.5 R was used as the binder; siliceous sand 0-4 mm and bottom ash as aggregates. The fresh mortar was casted into standard prisms 160 x 40 x 40 mm and stored in 100 % relative humidity for 28 days.

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

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

		M 0	MBA 10	MBA 40
Cement CEM I 42.5 R	kg/m^3	480	480	480
Bottom ash	kg/m^3	0	144	576
Sand 0/4 mm	kg/m^3	1440	1296	864
Water	kg/m^3	250	250	250

4. Results and Discussion

The pore size distribution of mortars in initial state acquired by MIP (mercury intrusion porosimetry) is presented in Fig. 1. Unfortunately only the pores with diameter smaller than 100 μm are indicated by MIP but the comparison of MIP results with total pore volume calculated by help of matrix and bulk density revealed that just negligible part of total pore volume falls on pores larger than 100 μm. Generally it can be concluded that admixing of BA increased the porosity. The character of pore system remained unchanged, only large pores (above 100 μm) were present in MBA 40 in higher amount than in the other mortars.

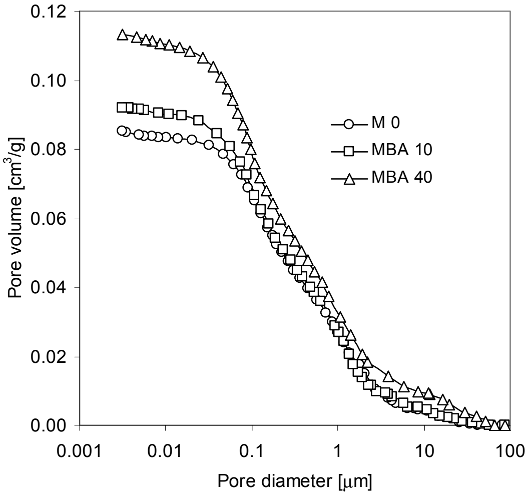

Fig. 1: Mercury intrusion porosimetry of mortars.

The amount of adsorbed water vapor is clearly linked to the pore size distribution. The sorption isotherm's maximum was increasing in the same was as porosity. Very high adsorption/desorption hysteresis was observed; it indicated high extent of capillary condensation in mortars. Such behavior can be expected in cementitious materials, the presence of BA in mortars did not influence significantly the shape of adsorption/desorption curves.

The compressive strength of all tested mortars measured after 28 days of curing was roughly about the same (Fig. 2). It means that even 40 % replacement of aggregates by bottom ash did not cause the strength decrease. The bending strength of all samples was about equal as well. The exposure of mortars to 50 freezing/thawing cycles did not cause any considerable change in its compressive strength. 75 freezing cycles already brought along certain decrease of MBA 10 strength and especially the reference mortar's strength dropped nearly to the half. The specimen MBA 40 preserved its compressive strength unaffected. The frost resistance coefficient (in reference to compressive strength) after 75 cycles was decreasing with increasing bottom ash content (for M 0 0.528, MBA 10 0.766, MBA 40 0.959). The values in reference to bending strength were similar (0.485, 0.984 and 0.914 respectively). There is not any clear and generally accepted parameter which would enable to determine frost resistance of concrete [2]. Some technical standards recommend the air entraining to increase the frost resistance of concrete but the reached frost resistance probably depends on a complex character of particular material; possibly MBA 40 was somewhat favored by its higher porosity in pore size range above 100 μm.

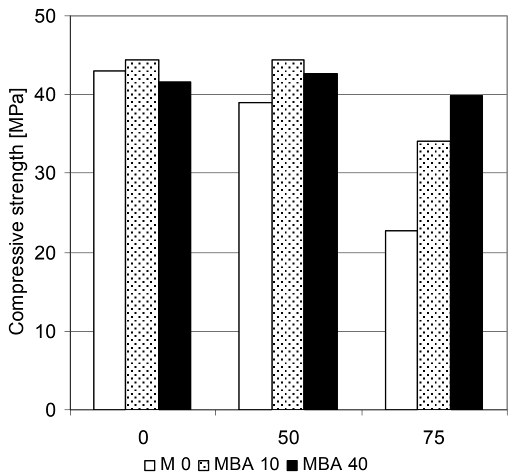

Fig. 2: Compressive strength of mortars before and after 50 and 75 freezing cycles.

The behavior of mortars subjected to high temperature was tested by means of determination of residual properties after defined thermal load. Fig. 3. shows the evolution of residual compressive strength upon thermal load. The first points correspond to mortars dried at 100 °C. The distinct strength loss of all materials began above 200 °C. The initially somewhat lower strength of MBA 40 decreased slower than reference M 0 but the most surprising was the behavior of mortars loaded at 1000 °C; the M 0 and MBA 10 specimens broke before any strength could be measured while the MBA 40 featured still a measurable compressive strength. The residual bending strength followed very similar evolution as the compressive but obviously the lowest measurable values for MBA 40 were acquired already at 800 °C and for other materials at 600 °C.

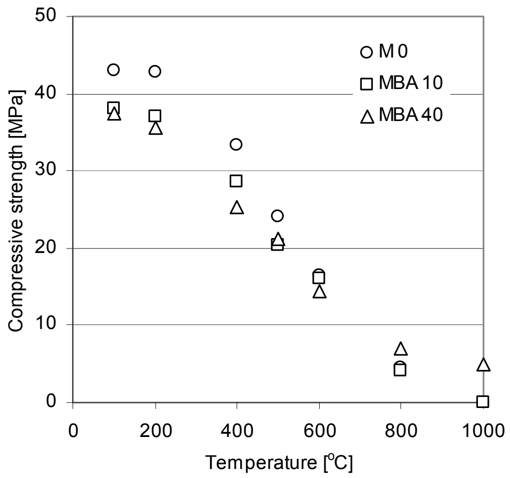

Fig. 3: Residual compressive strength of thermally loaded mortars.

The thermally induced structure changes were observed by measurement of matrix and bulk density (Fig. 4). Changes of matrix density correspond to chemical processes while the bulk density evolution reflects mostly the undergoing physical changes. The matrix density of all studied mortars did not differ too much from each other but the thermal load caused dehydration of all materials resulting into gradual increase of matrix density. The dehydration started (as the strength loss) above 200 °C. The decrease of bulk density upon thermal load took place in roughly the same extent in all tested materials; the bulk density decrease was more distinct from 400 °C. Generally the observed decrease of bulk density of cementitious materials is attributed to thermal expansion of material's components which results into internal tension increase and consequent cracking. Thermal expansion solely should be reversible but the rising cracks are obviously irreversible and thus the bulk density increase can be indicated even after the specimen was cooled down. Another possible source of cracking in thermally loaded cementitious materials are phase changes in aggregates. Any significant bulk density (neither strength) jump was not observed at this temperature in any studied material; the used natural aggregates and especially the bottom ash had complex mineralogical composition and possible cracking due to phase changes was overlapped by cracks due to gradual thermal expansion. The matrix density increase and bulk density decrease resulted into significant linear increase of total porosity. The differences of M 0, MBA 10 and 40 porosities at a given temperature were nearly constant; it indicates that there is not any large difference in thermally induced physical degradation between materials without and with bottom ash. The above summarized results showed that the studied untreated MSWI bottom ash – even though it did not fulfill the standard requirements – can be used as admixture in cement based mortar. Nevertheless the presence of chlorides and sulfates excludes its utilization in steel reinforced concrete. The positive effect of bottom ash higher dosage on frost resistance was probably caused by higher total porosity of MBA 40 when compared to reference material. The better performance of MBA 40 towards the thermal load can not be explained by a less distinct thermal expansion; all materials changed its porosity under thermal load in an identical way. The explanation must be searched in different chemical composition of MBA 40; even though the bottom ash was used as aggregates it took part in the hydration process which resulted to presence of different hydration products than in reference M 0 [9].

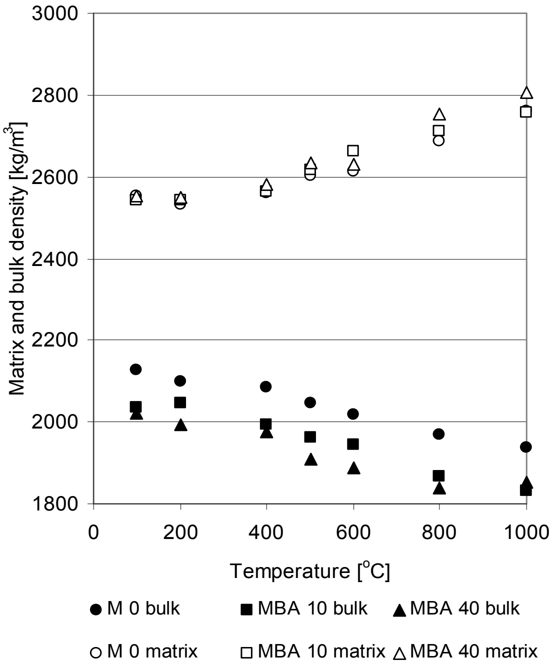

Fig. 4: Evolution of residual bulk and matrix density of mortars upon thermal load temperature.

5. Conclusions

The MSWI bottom ash (fraction 0-4 mm) in state “as received” was used as partial aggregates replacement in cement mortars. The BA admixing caused higher porosity of mortars when compared to reference mixture but the strength was almost unaffected. The maximum replacement level was 40 %; this mortar had significantly better frost resistance and also the residual strength after the thermal load was better. While the higher frost resistance was probably caused by higher total porosity, the better performance of bottom ash containing mortar under thermal load has to be attributed to different chemical/phase composition of binder which resulted from cement + bottom ash hydration.

6. Acknowledgement

This research has been supported by the Czech Science Foundation, under grant No. P104/11/0438.

7. References

[1] E. Vejmelková, M. Pavlíková, M. Keppert, Z. Keršner, P. Rovnaníková, M. Ondráček, M. Sedlmajer and R. Černý, “High performance concrete with Czech metakaolin: Experimental analysis of strength, toughness and durability characteristics”, Construction and Building Materials, vol. 24, 2010, pp. 1404 – 1411.

[2] J. Szwabowski and B. Lazniewska – Piekarczyk, „The importance of porosity structure parameters of freeze-thaw resistant self-compacting concrete”, Cement Wapno Beton, vol. 13, 2008, 155 – 165.

[3] I. Yüksel, T. Bilir and Ö. Özkan, ”Durability of concrete incorporating non-ground blast furnace slag and bottom ash as fine aggregate”, Building and environment, vol. 42, 2007, pp. 2651 – 2659.

[4] C.-S. Poon, S. Azhar, M. Anson and Y.-L. Wong, “Performance of metakaolin concrete at elevated temperatures”, Cement and Concrete Composites, vol. 25, 2003, pp. 83 – 89.

[5] M. J. DeJong and F.-J. Ulm, “The nanogranular behavior of C-S-H at elevated temperatures (up to 700 °C)”, Cement and Concrete Research, vol. 37, 2007, pp. 1 – 12.

[6] C. H. K. Lam, A. W. M. Ip, J. P. Barford and G. McKay, “Use of Incineration MSW ash: A review”, Sustainability, vol. 2, 2010, pp. 1943-1968.

[7] ČSN 73 1322, Determination of concrete frost resistance, 1968, change Z1 (2003).

[8] ČSN EN 12620, Aggregates for concrete, 2006.

[9] P. Ubbriaco and D. Calabrese, “Hydration behaviour of mixtures of cement and fly ash with high sulfate and chloride content”, Journal of Thermal Analysis and Calorimetry, vol. 61, 2000, pp. 615-623.