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Use of Municipal Solid Waste Incineration Waste Materials as Admixtures in Concrete

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ABSTRACT

Waste materials generated by Municipal Solid Waste Incineration (MSWI) facility Termizo in Liberec (Czech Republic) – bottom ash, two types of furnace fly ash and fly ash from Electrostatic Precipitator (ESP) were tested as admixtures in Portland cement based concrete. The effect of ashes on the initial and final setting time of cement paste was determined by the Vicat method. The fly ashes were used as cement replacement in amounts of 2 to 15 %. The quality of the cement replacement was evaluated by measurement of the compressive strength of the prepared concrete. The bottom ash and fly ashes were also tested as partial replacement of fine aggregates. The sand replacement by the bottom ash at levels up to 5 % caused slight increase in compressive strength. The fly ashes used as fine aggregates caused a decrease in strength. The pH of concretes containing ashes was monitored for 2 months, no effect of ashes on pH was observed.

INTRODUCTION

Municipal Solid Waste Incineration (MSWI) ashes possess a chemical composition that is not dissimilar from that of coal fly ashes. While the recycling of ashes from coal power stations is technologically well established and commonly applied in the building practice, fly and bottom ashes from municipal waste incinerators are technologically an open field from this point of view, until now. The main reason of this fact is majority of incineration technologies without utilization of modern Best Available Technologies. It causes high properties variability of ash materials from incineration and also high toxicity of ashes, especially collected on sleeve filters at the absence of electro-filter units. The composition of MSWI ashes suggests possible pozzolanic or hydraulic behavior [Keppert et al. 2010] and its addition to the concrete mixture could have a beneficial role in the development of the microstructure of the hydrated cement paste. Hence a great advantage in the sustainability of the concrete industry would be achieved if MSWI materials, which are available in great quantities throughout the world, could be used to produce quality concretes. The MSWI ashes can be used in cement based materials as filler or active pozzolanic admixture. Besides these applications MSWI bottom ash and fly ash can be used as raw materials for manufacturing of cement and ceramic products [Bertolini et al. 2004], [Beaumont and Meyer

2003]. Pera et al. [1997] studied the possibility to replace coarse aggregates (4 – 20 mm) in concrete by MSWI bottom ash. They observed cracking and swelling when “raw” ash was used. When the bottom ash was treated by sodium hydroxide, the durability of concrete was better but still the strength of such concrete was lower than the strength of the reference one with natural gravel. Lin et al. [2003] performed melting of MSWI fly ash and the solidified ground melt was used as cement replacement in mortar. The 10 % replacement was found to be reasonable. Bertolini et al. [2004] proposed the wet (water) grinding of MSWI ashes to be the effective way of prevention of aluminium alkali corrosion in concrete which causes the hydrogen evolution and consequent loss of the concrete strength. Müller and Rübner [2006] analyzed the reasons of the strength loss of concrete with MSWI ash content. They found that the hydrogen evolution due to aluminium metal had the worse effect on strength than alkali-silica reaction which is taking place in MSWI concretes as well. Gao et al. [2008] studied the treatment of MSWI fly ash by water. It reduced the chloride content in ash which was then used as cement replacement; the water washing was effective enough to prevent the loss of concrete strength up to 10 % of cement replacement. Ferraris et al. [2009] treated the MSWI bottom ash by vitrification at 1450 ˚C without any other agent; this method is probably the best way how to prevent the problems resulting from adding of MSWI materials to concrete. Lee and Rao [2009] obtained positive results after MSWI ashes vitrification with added glass frit and fine grinding of the cooled melt.

The present paper deals with four types of ashes produced by MSWI facility Termizo in Liberec in Czech Republic [Šyc et al. 2010]. The ashes were tested as concrete admixture in roles of cement and aggregates replacement. The ashes were studied in state “as received” from the MSWI plant (i.e. without any treating operation) in order to evaluate the feasibility of their utilization without any additional treatment procedure.

EXPERIMENTAL

Materials

Four types of MSWI ashes from Termizo facility in Liberec (CZ) were studied; the bottom ash (denoted S), the fly ash collected in 2nd and 3rd pass of boiler (A), the fly ash collected in 4th pass of boiler (B) and fly ash from the electrostatic precipitator ESP (C). The chemical composition of the ashes can be found in Tab. 1. More detail information about the ashes can be found in other paper in these proceedings [Keppert et al. 2010]. Two series of concrete specimens (150 mm standard cubes [ČSN EN 12390-1]) containing the ashes were prepared. Firstly all the ashes were tested as the partial replacement of fine aggregates fraction 0–4 mm (sand) (Tab. 2.). The cement was the ordinary Portland cement CEM I 42.5 R, the aggregates were natural siliceous sand and two fractions of siliceous gravel. Water was dosed in amount to maintain w/c 0.52 with no corrections to the ash content. In the second series the fly ashes A, B and C were tested as cement replacement (Tab. 3.); here water amount was given by water/(cement+ash) ratio.

Tab. 1. Results of XRF chemical analysis.

	mass %			
	A	B	C	S
SiO_2	15.9	19.6	9.9	33.5
Al_2O_3	8.0	9.7	4.2	15.8

Fe_2O_3	2.9	3.4	1.9	8.4
CaO	25.7	25.6	13.0	19.4
MgO	2.1	2.4	1.2	2.0
SO_3	28.8	14.9	15.7	9.3
ZnO	2.8	2.5	8.0	0.8
Na_2O	5.4	5.9	17.9	3.6
K_2O	4.4	4.4	8.4	1.9
TiO_2	1.6	1.6	0.8	1.5
Cl	0.7	7.3	15.1	1.1
∑	98.1	97.5	96.0	97.1

Tab. 2. Composition of concrete mixtures containing MSWI ashes as partial fine aggregates replacement.

Agg. 0-4 replacement	Cement	Ash	Aggregates			w/c
			0-4	4-8	8-16	
%	kg m^{-3}	kg m^{-3}	kg m^{-3}	kg m^{-3}	kg m^{-3}	
0	400	0	607	260	867	0.52
5	400	30	577	260	867	0.52
10	400	61	546	260	867	0.52
15	400	91	516	260	867	0.52

Tab. 3. Composition of concrete mixtures containing MSWI ashes as partial cement replacement.

Cement replacement	Cement	Ash	Aggregates			w/(c+a)
			0-4	4-8	8-16	
%	kg m^{-3}	kg m^{-3}	kg m^{-3}	kg m^{-3}	kg m^{-3}	
0	400	0	607	260	867	0.52
2	392	8	607	260	867	0.52
5	380	20	607	260	867	0.52
10	360	40	607	260	867	0.52
15	340	60	607	260	867	0.52

Methods

The effect of MSWI ashes on initial and final setting time of the paste of normal consistency was studied by help of automatic Vicat apparatus (Beton system). The paste of normal consistency was prepared from cement and water (reference mixture) and from cement and ashes (5, 10 and 15 % of the total dry mass) and water. The influence of the ash admixture on the consistency of fresh concrete mixture was studied by help of slump test [ČSN EN 12350-2]. The prepared cubic concrete specimens were matured in water; the compressive strength was measured after 28 days [ČSN EN 12390-3]. The bulk density of matured concrete was determined by measuring and weighing of the cubes before the strength testing. The possible influence of ashes on pH of concrete was monitored on mixtures containing 10 % of ash instead of fine aggregates. The concrete was sampled 2 days after mixing and put into 200 ml of distilled water. The pH of leachate was measured periodically for 2 months.

RESULTS AND DISCUSSION

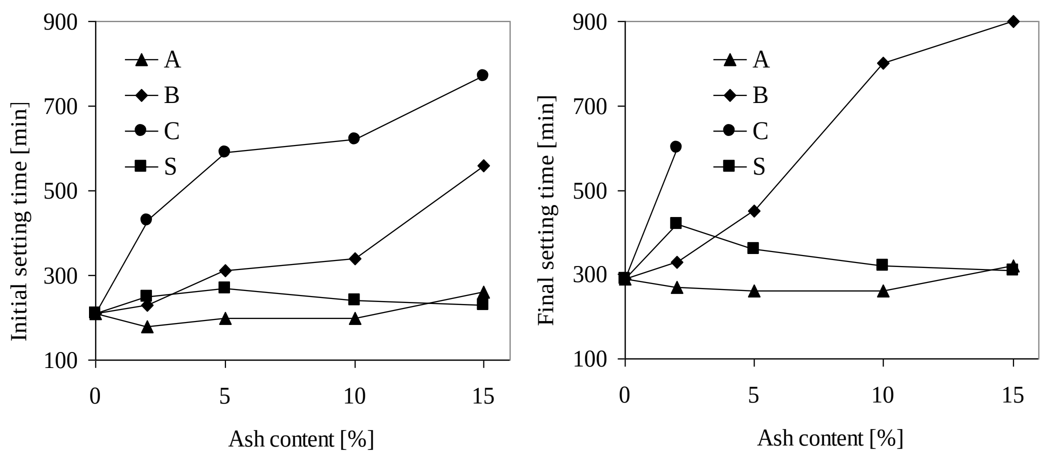

Fig. 1. Influence of MSWI ashes on setting of paste of normal consistency.

Fig. 1. shows the influence of MSWI ashes on initial and final setting time of paste of normal consistency prepared from cement as the reference point and from cement and particular ashes. The initial and final setting time of the reference mixture was 210 and 290 min. The bottom ash S and the boiler fly ash A do not have any significant influence on the paste setting in the whole concentration range. The fly ashes B and C retard the setting; especially the ESP fly ash C has very detrimental effect on the paste setting. The final setting time of mixtures containing more than 5 % of C was longer than 24 hours. It is caused by high content of soluble salts especially in the ESP ash (C). The amount of needed water for the preparation of normal consistency paste was about 5 % higher for the C fly ash containing paste in comparison with the other ashes (122 ml and 116 ml per 400 g of dry mixture). All the tested MSWI ashes reduced the slump of the fresh concrete mixture (Fig. 2.). This effect was observed in all prepared mixtures; the ashes absorbed the mixing water. The constant consistency of mixture could be maintained by using of a plasticizer.

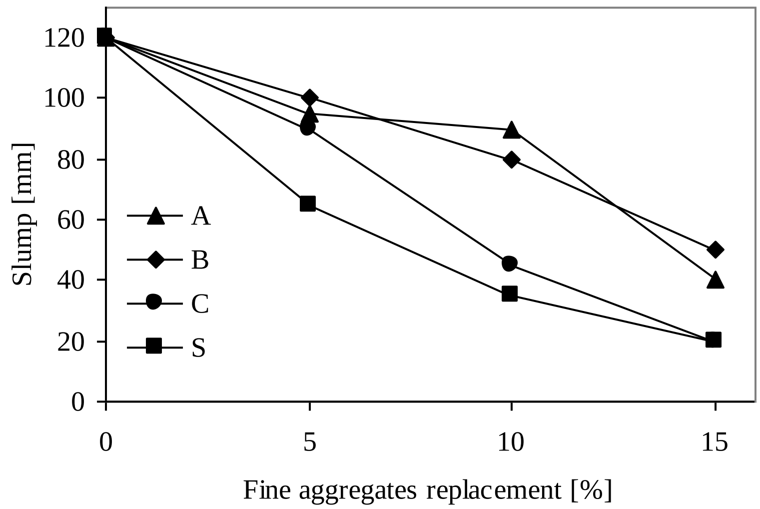

Fig. 2. Slump of the fresh concrete mixtures containing MSWI ashes.

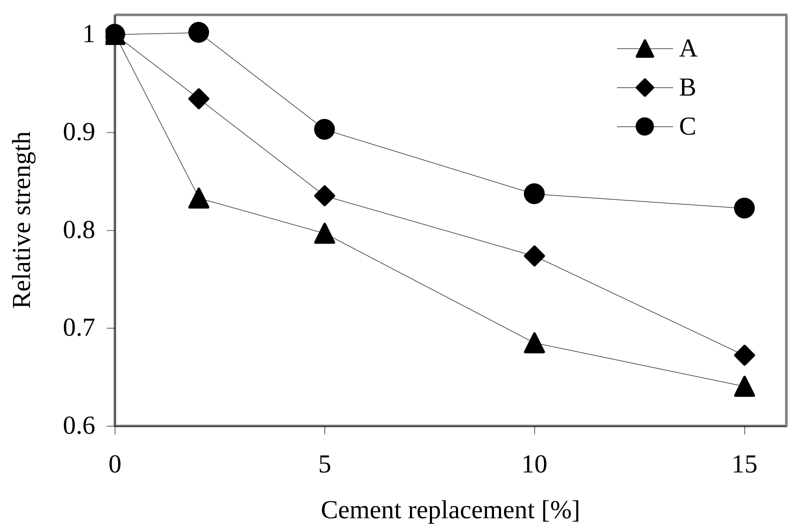

Fig. 3. Effect of MSWI fly ashes as cement substitutes on the relative compressive strength of 28 days old concrete.

The fly ashes were intended to be used as partial cement replacement. The ashes A and B were pozzolanic active [Keppert et al. 2010]. The relative compressive strength of 28-days concrete is presented in Fig. 3. (control strength was 47.1 MPa). Surprisingly the ESP fly ash (C) reduced the strength by "only" 18 % at its highest dose while the boiler ashes A and B had the worse effect. Similar results were obtained when the MSWI ashes were used as the partial replacement of fine aggregates (Fig. 4.). Here the bottom ash was also employed. The bottom ash has the particle size distribution relatively close to the natural fine aggregates (Fig. 5.). The fly ashes are finer than the natural sand and thus can not replace it adequately but they are not fine enough to play a role of filler [ČSN EN 12620].

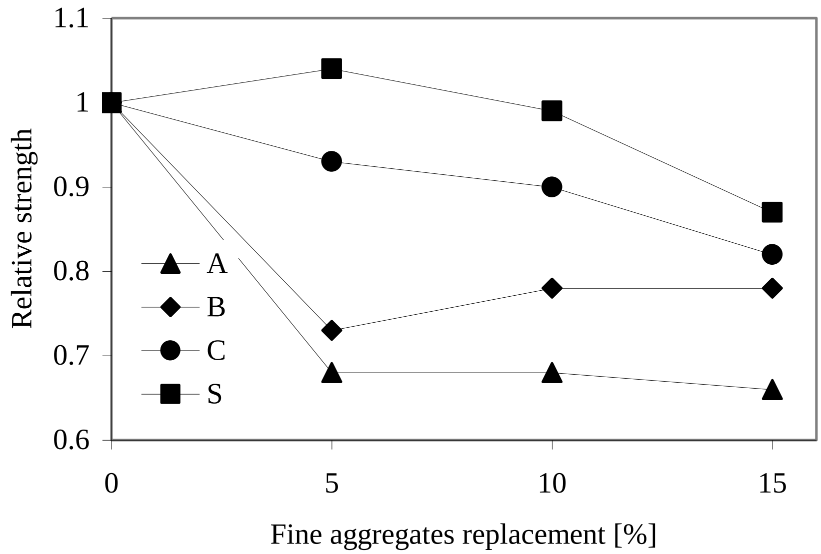

Fig. 4. Effect of MSWI ashes as fine aggregates substitutes on the relative compressive strength of 28 days old concrete.

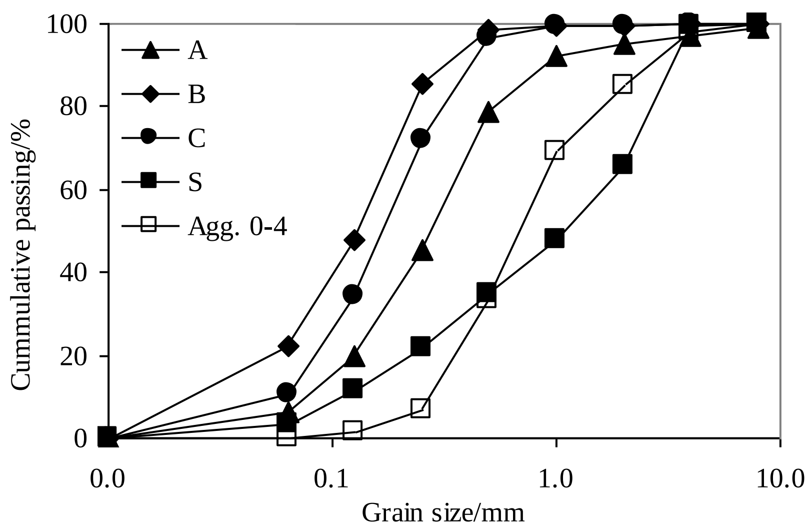

Fig. 5. Grading analysis of MSWI ashes and natural fine aggregates.

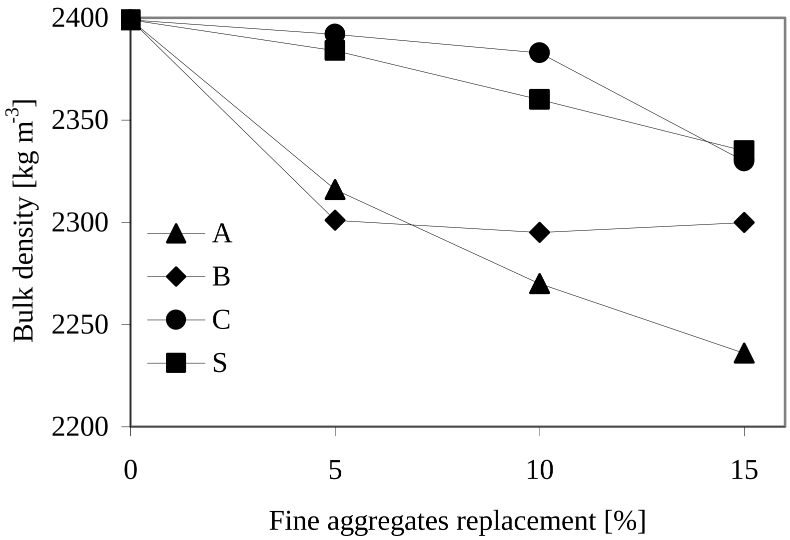

Fig. 6. Effect of MSWI ashes as fine aggregates substitutes on the bulk density of the matured concrete.

The negative effect of MSWI ashes on the compressive strength and the observed different influence of particular ashes can not be explained by a simple reason. All the ashes caused perceivable expansion of the concrete mixture during first hours of setting in moulds. The concrete expansion is documented also in Fig. 6. where the bulk density of specimens after 28 days of maturing is plotted as function of the ash content. The highest decrease of bulk density caused fly ashes A and B which is in agreement with the measured decrease of compressive strength. The smallest decrease of bulk density caused the ESP fly ash C. The expansion of concrete is caused by high content of anhydrite and other sulfates in all studied ashes (Tab. 1.) which was indicated by chemical analysis and calorimetry [Keppert et al. 2010]. In addition the expansion of concrete containing the bottom ash is probably caused also by hydrogen evolution due to the presence of aluminium metal which is not separated neither from the incinerated waste nor from the bottom ash. The bottom ash is risky also due to the visible content of scrap glass which can induce alkali-silica reaction in concrete in a longer time period. The negative effect of expansion processes overweight the positive pozzolanic activity of A and B fly ash. Only in case of bottom ash used in low amounts (Fig. 4.) was observed certain positive effect of its pozzolanity and granulometry on the concrete strength. Sort of enigma was the behavior of fly ash C which had very negative influence on the setting time but the final properties of the concrete were not the worst.

Since the pH of leachate of ESP and bottom ash was lower than 12 [Šyc et al. 2010] the possible effect of MSWI ashes admixture on pH of the prepared concrete was examined. The pH of concrete containing the ashes in the amount of 10 % fine aggregates replacement was not influenced by the ashes presence and was constant and the same as the pH of the control sample (pH = 12) during two months.

CONCLUSIONS

Three fly ashes and bottom ash from the modern MSWI incinerator in Liberec were used in state “as received” from MSWI plant as cement and fine aggregates replacing admixture. The only utilization which did not influence negatively the strength of the prepared concrete was application of bottom ash as partial – up to 10 % – replacement of fine aggregates (sand 0-4 mm). The fly ashes had too fine particle size distribution to be able replace the sand. On the other hand, the ashes would have to be grinded in order to achieve the granulometry of concrete filler. The bottom ash did not influence the setting time of the mixture and the expansion of concrete mixture was not as detrimental as in the case of boiler fly ashes A and B. The ESP fly ash C retarded the setting time in an unacceptable way due to high content of various salts but the expansion and the reached strength was comparable with the bottom ash. Only the bottom ash might be used as concrete admixture without any treatment and without sacrificing of the concrete quality. The durability of the prepared concrete has to be evaluated. The fly ashes have to be treated in some way in order to be applicable as concrete admixture. The most promising seems to be vitrification.

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