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USE OF INCINERATOR BOTTOM ASH IN CONCRETE

J. Pera, L. Coutaz, J. Ambroise, and M. Chababbet
Unité de Recherche Génie Civil-Matériaux
Institut National des Sciences appliquées de Lyon, France

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ABSTRACT

The aim of the present work was to show if municipal solid waste incinerator (MSWI) bottom ash could be an alternative aggregate for the production of building concrete presenting a characteristic 28-day compressive strength of 25 MPa.

The aggregates passing the 20-mm sieve and retained on the 4-mm sieve were considered for investigation. They showed lower density, higher water absorption, and lower strength than natural gravel. They could be considered as average quality aggregates for use in concrete.

When directly introduced in concrete, they led to swelling and cracking of specimens, due to the reaction between cement and metallic aluminium. Therefore, a treatment by sodium hydroxide was proposed to avoid such degradation, which made possible the partial replacement (up to 50%) of gravel in concrete without affecting the durability.

KEYWORDS: Bottom ash, aggregate, aluminium, concrete, strength, durability.

Introduction

Although incineration is one of the most effective refuse-disposal methods for achieving 70 percent reduction in mass, the amount of residue remaining to be disposed of after incineration is substantial. More than 90% (by mass) of incinerator residues consist of bottom ash, the slag-like material which is dumped from the grate after combustion. At the present time, an important part of this bottom ash is used in road construction (1-4). This practice diverts a significant volume from landfill, and results in conservation of natural aggregate.

The work reported here concerns another way of valorization: the development of concrete usable in the building industry. The specific objective of this research was to examine whether bottom ash could partially or entirely replace natural gravel in the production of a concrete presenting a 28-day compressive strength of 25 MPa.

In cement-treated municipal solid waste incinerator (MSWI) bottom ash, chemical reactions can occur even after a considerable amount of time, resulting in a substantital increase in volume. The causes of this phenomenon have been discussed in several papers (5, 6). Two mechanisms have been formulated :

i) Chemical reactions on non-ferrous metallics, particularly on aluminium and zinc, can cause an increase in volume. Under alkaline conditions, which occur during cement hydration, metallic aluminium can form hydroxides or lead to the emission of hydrogen.
ii) Ettringite formation is another well-known reaction which may occur.

Therefore, the research was focused on the prevention of damage produced by the reaction between metallic aluminium and cement.

Characterization of the MSWI Bottom Ash

The particle size distribution of bottom ash which was investigated was ranging from 4 to 20 mm.

Chemical Composition. The average chemical composition of the main elements present in the MSWI bottom ash is given in Table 1.

The high amount of Na_2O can be explained by the large quantity of waste glass present in the bottom ash. The main mineral phases detected by X-ray diffraction were: anhydrite, calcite, portlandite, quartz, dolomite, gehlenite, rutile, halite, hematite, and albite.

Leaching Behaviour. The leaching tests were carried out according to the French standard NF X31-210, on crushed material (< 4 mm) in presence of de-ionized water. The water to solid ratio is 10. The French leaching test is different from the Toxicity Characteristics Leaching Procedure (TCLP) adopted by the U.S. Environmental Protection Agency (USEPA). TCLP test is carried out on a sample crushed to less than 9.5 mm. Extraction is done at a 20 : 1 liquid to solid ratio using dilute acetic acid. The results obtained by ICP-Plasma are reported in Table 2.

From these results, it can be said that this bottom ash is not very aggressive towards the environment.

Physical Properties. The physical properties of the bottom ash were compared to those of a natural siliceous-calcareous gravel, as shown in Table 3.

The results obtained point out that the natural gravel is stronger (lower Los Angeles value) and less porous than the bottom ash. Bottom ash may be classified as an average quality aggregate.

Development of Concrete Utilizing Bottom Ash

Reaction Between Metallic Aluminium and OPC. A series of tests was carried out on concretes containing natural sand and bottom ash instead of gravel. When placing the concrete,

TABLE 1

Average Composition of the MSWI Bottom Ash (wt.% Dry Solid)

Oxides	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	P_2O_5
Amount (%)	54.6	11.1	8.0	8.5	1.5	1.3	12.8	2.1

TABLE 2

Results of Leaching Test (mg/kg)

Substance	Chloride	Sulphate	Aluminium	Cadmium	Chromium (VI)	Lead
Content	72.3	270.7	94.1	< 0.3	< 0.6	< 6

a high gaseous emission occurred, leading to a porous material and very low strength. Cracks appeared after 28 days of curing in water and the concrete was entirely destroyed after 90 days. This phenomenon results from the reaction between the metallic aluminium present in the bottom ash and the portlandite produced by OPC hydration.

In a basic aqueous media, metallic aluminium becomes unstable and produces aluminate and hydrogen:

$$n\,Al + X\,(OH)_n + H_2O \rightarrow X\,(AlO_2)_n + \frac{3n}{2}\,H_2$$

In presence of portlandite, this reaction can be described as follows :

$$2\,Al + Ca\,(OH)_2 + 2\,H_2O \rightarrow Ca\,(AlO_2)_2 + 3\,H_2$$

To verify that the cracks observed on concrete were due to the above reaction, X-ray diffraction investigations and SEM examinations were conducted. These data showed that gibbsite ($AlOH)_3$), calcium aluminate ($Ca(AlO_2)_2$), and complex silico-aluminate (Na_2O, 1.06 Al_2O_3, 1.6 SiO_2, 1.6 H_2O) were formed. The study of interfaces between waste glass and OPC concluded that waste glass was not attacked by OPC.

TABLE 3

Physical Properties of the Bottom Ash and the Natural Gravel

Properties	Bottom-ash 4/20 mm	Natural gravel 4/16 mm
Particle size distribution (%)		
4-5 mm	6	8
5-8 mm	19	42
8-10 mm	15	21
10-12.5 mm	21	13
12.5 mm-16 mm	22	16
16-20 mm	17	-
Density	2.21	2.47
Water absorption (%)	2.36	1.05

TABLE 4

Mixture Proportions and Compressive Strengths of Concretes

	Type of concrete		
	Control	C1	C2
Mixture proportions (kg/m^3)			
. Cement OPC	290	290	290
. Natural sand	930	930	930
. Natural gravel	970	500	-
. Treated bottom ash	-	420	865
. Water	190	183	183
Slump (mm)	125	145	145
Density	2.27	2.26	2.19
Compressive strength (MPa)			
7 days	28.0 ± 2.4	20.8 ± 1.7	17.0 ± 1.7
28 days	32.9 ± 2.4	29.9 ± 1.3	22.3 ± 2.0
90 days	41.8 ± 2.1	34.6 ± 0.8	28.4 ±1.0

Treatment of Metallic Aluminium (7). The proposed treatment was to immerse bottom ash in a solution of sodium hydroxide, till all hydrogen was produced, according to the following reaction :

$$Na\,OH + Al + H_2O \rightarrow Na\,AlO_2 + \frac{3n}{2} H_2$$

Therefore, bottom ash was immersed in this solution for 15 days, then washed and dried. As its water absorption was higher than that of natural gravel, bottom ash was pre-wetted with 5% water for 24 hrs, before casting concretes.

Performances of Concretes. Two series of tests were carried out :

I) In the first test, concrete was made using natural sand, 50% natural gravel (in volume), and 50% treated bottom ash (in volume). This concrete is referred as C1.
ii) In the second test, natural gravel was entirely replaced by treated bottom ash. This concrete is named C2.

The mixture proportions and compressive strengths obtained are given in Table 4. The strengths were measured on 6 cylinders (H = 220 mm, ∅ = 110 mm).

Concrete C1 fills the requirements to be used as a building concrete presenting a characteristic 28-day strength of 25 MPa. When the gravel is entirely replaced by bottom ash the strength decreases due to the softness of aggregates.

Durability tests were also carried out on the concretes. They consisted in drying-wetting cycles: 14 days at 20°C, 50% R.H., followed by 14 days in water at 20°C. During the drying period, control and C1 concretes reached a maximum shrinkage of 330 µm/m, while that of

C2 was 250 µm/m. After the immersion period, these values were 100 µm/m for control and C1 concretes, and 50 µm/m for C2. These results show that bottom ash has no negative effect on the durability of concrete, when all the reactions due to metallic aluminium are avoided.

Conclusion

When raw MSWI ash is introduced in concrete instead of gravel, problems of swelling and cracking occur due to the reaction between metallic aluminium and cement. This reaction can be avoided by immersing bottom ash in sodium hydroxide, for 15 days. Such treated bottom ash can partially replace natural gravel in concrete without affecting the durability.

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