2001 International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, Paper #37. Copyright is held by the Authors.

http://www.flyash.info

Use of bottom ash from municipal solid waste incineration as a road material

IZQUIERDO Maria[1], VAZQUEZ Enric[2], QUEROL Xavier[1], BARRA Marilda[2] , LÓPEZ Ángel[1],PLANA Felicià[1].

[1] *Institute of Earth Sciences 'Jaume Almera', CSIC, C/ Lluis Sole i Sabaris s/n, 08028 Barcelona, Spain. Tel. +34-93-4095410, Fax +34-93-4110012 mariaizq@ija.csic.es*
[2] *Department of Construction Engineering, Politechnical University of Catalonia, C/Jordi Girona1-3, 08034 Barcelona, Spain*

KEYWORDS: bottom ash, municipal solid waste incineration (MSWI), road sub-base

INTRODUCTION

Bottom ash is the most significant by-product from municipal solid waste incineration. It accounts for 85-95% of the solid product resulting from MSW combustion. MSWI reduces the volume of waste and its mass by about 70% (around 225-315 kg of bottom ash per tonne of MSW)[1]. About 200000 tonnes per year of bottom ash are currently produced in Catalonia at seven major plants: Tarragona, Mataró, Sant Adrià, Montcada, Girona, Vic and Vielha (Figure 1).

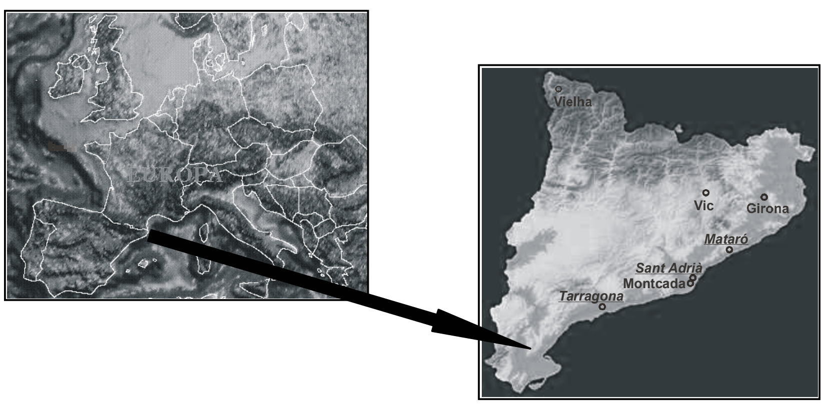

Figure 1. Location of the 7 Catalan MSWI plants. Underlined plants were selected for geotechnical characterisation.

In Catalonia, bottom ash is mainly landfilled, but utilisation of residues is preferred to disposal in accordance with the waste management policy of Autonomous government of Catalonia. In this study, some alternatives for utilisation of bottom ash from MSWI plants and their potential environmental impact were investigated. Since bottom ash is a granular inert and compactable material, it shows a high potential as an aggregate substitute in paving applications.

A typical road pavement consists of a set of the following layers, from the top driving surface down: wearing course, road base, sub-base and subgrade. Each layer requires a material with very specific physical and geotechnical properties. The characterisation of bottom ash must be used to determine the potential application of bottom ash in road construction.

A preliminary chemical and physical characterisation of the bottom ash from the 7 Catalan plants was performed. Two samples (fresh and 3-month old samples) of 300 kg were collected from the stockpiles at the corresponding plant. Furthermore, a 600 kg of 3-month old bottom ash sample was collected for a detailed physical and geotechnical characterisation at three selected plants (Tarragona, Mataró and Sant Adrià, with the largest bottom ash production).

RESULTS AND DISCUSSION

Visual Classification

The morphological characterisation was carried out by visual methods and by SEM, coupled with an EDX (for particles smaller than 0.32 mm). Visual observation was subdivided in grain size ranges by sieving.
Bottom ash is made up of five different types of particles. In addition to the slag particles, relict metal, glass, ceramics and unburned organic matter are also present in a varying proportion depending on the grain size fraction considered, as seen in Figure 2. In this figure, the differences in distribution are attributed to the fact that the Sant Adrià plant (on the left) is equipped with an electromagnet to collect ferrous particles and with a better-operating combustor.

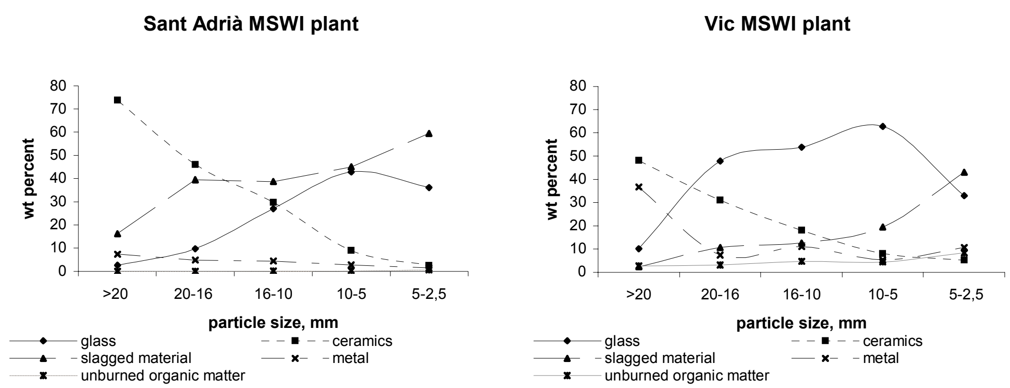

Figure 2. Distribution of glass, slag material, unburned MSW, ceramics and metal particles at two MSWI plants.

Although the grain size distribution of the constituents is different for each plant (as a function of combustor type, MSW feed composition and subsequent treatment of bottom ash), there seems to be a common trend. The coarsest fractions are made up of construction debris, ferrous material, slag particles and unburned MSW. Glass particles are the most abundant material in the 5 to 16 mm range. Slag material is the main component of fine fractions (<5 mm). Finally, the unburned MSW particles are present in low proportions without any grain size trend.

Loss on Ignition

Loss on ignition values depends on the combustion system used and effectiveness. As shown in Table 1, LOI values (under 550º) range from 2 to 9%.

Table 1. Bottom Ash Loss on Ignition (LOI under 550ºC) in % wt.

	TARRAGONA	MATARÓ	MONTCADA	S.ADRIÀ	GIRONA	VIC	VIELLA
LOI %	6.5	4.4	2.6-5.9	2.1-3.4	4.2-4.5	7.9-8.8	8.8-9.8

The maximum value allowed by Catalan standards for bottom ash utilisation is 5%. High values suggest poorly operated systems that should be improved.

Grain size distribution

The analysis of the grain size distribution followed the Spanish standard UNE-EN 933-1[2]. As these analyses were performed in duplicate, it was possible to check whether subsamples were sufficiently representative. Grain size distribution is a parameter that plays an important role in some properties and accurate data are required for other physical and geotechnical tests.
Figure 3 shows the grain size distributions of bottom ash from the three selected plants. These are fairly similar, with major modes in both the coarse and fine sizes. The gentle slopes of the curves suggest a good gradation.

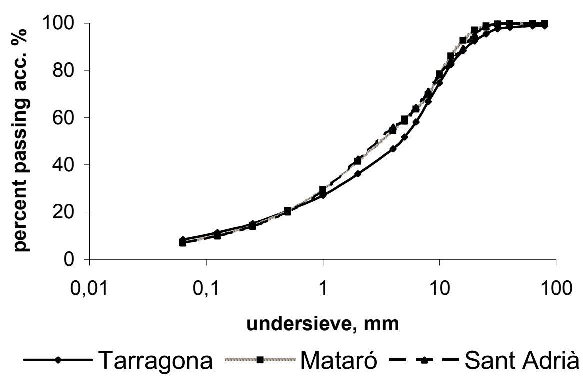

Figure 3. Grain size distribution of bottom ash from the three MSWI plants selected.

Bottom ash is a granular material with a continue grain size distribution and low proportions of non plastic fine (< 63µm, see below Sand Equivalent test) and coarse (>40 mm) fractions. Therefore, this may be easily compacted to obtain a high resistance. Bottom ash could be considered as a 0/40 mm well-graded material.

Particle Morphology

Particle morphology exerts a considerable influence on some mechanical properties and on leaching behaviour. Slag material has a high internal porosity and a vesicular structure, and it is the most common type of particle when considering the fine fractions. Slag particles are irregular and very porous (Figure 4). The high porosity provides a high reactive surface available for leaching. Porosity also exerts an influence on absorption and field compaction. The finest fractions were enriched in metals. Other types of particles such as glass, filaments, calcite crystals, irregular particles of aluminium (sometimes forming melted drops), acicular crystals of ettringite and hexagonal crystals of portlandite were present in bottom ash.

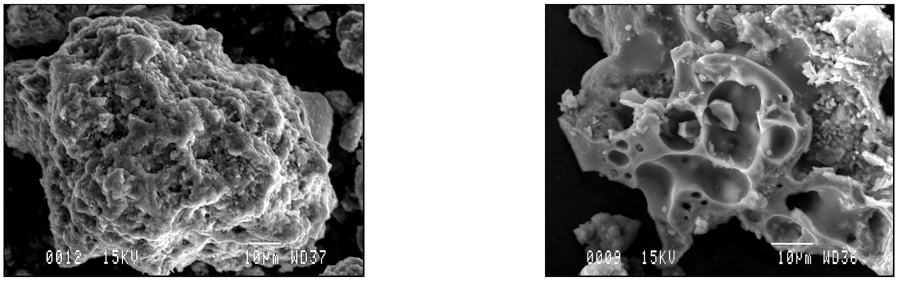

Figure 4. SEM photographs of slag particles.

Chemical characterisation

Major, minor and trace element concentrations in bottom ash were analysed by ICP-AES and ICP-MS except silica contents, which were determined directly by XRF. Although the chemical composition of bottom ash depends on the MSW feed characteristics and on the combustion system, the content of major elements is fairly similar at the seven plants (Table 2), and resembles the average content of these elements in the soil and lithosphere[3].

Table 2. Ranges of contents of major (% wt) and minor and trace ($\mu g\ g^{-1}$) elements in bottom ash from the seven plants.

MAJOR ELEMENTS (%wt)		MINOR AND TRACE ELEMENTS ($\mu g\ g^{-1}$)			
Si	14.9-24.5	Cu	750-4000	Sn	80-340
Ca	9.5-12.8	Mn	550-2800	V	40-302
Na	3.0-4.0	Ba	450-1300	Ni	38-140
Al	2.5-5.2	Zn	380-3400	Co	9-14
Fe	2.0-7.1	Pb	233-3500	As	7-20
Mg	0.8-1.4	Cr	240-450	Mo	3-11
K	0.8-1.3	Sr	200-450	Cd	<1-14
P	0.4-0.8				
S	0.2-0.4				

However, the content of minor and trace elements varies widely at these plants (Table 2) and is highly enriched with respect to the equivalent average concentrations found in the soil and lithosphere[3]. The high variability in trace element contents was also observed between samples from the same plant.

Mineralogy

Although bottom ash contains numerous crystalline phases, the detection limit of XRD is about 3% and only major phases can be identified. The main components of bottom ash are an amorphous glassy matrix, quartz and calcite. Minor proportions of feldspar are usually present in the coarse fractions. Ferrous species such as hematite and magnetite are commonly found at trace levels. Other minor phases identified are diopside, wollastonite, dolomite, cristobalite and clay minerals. Furthermore, fresh bottom ash contains trace levels of lime and portlandite that are very quickly carbonated into calcite or other neomorphic phases in the aged samples. The fine fractions of all bottom ash contain variable proportions of sulphates such as gypsum, bassanite, anhydrite and polyhalite. These sulphates should be taken into account given their influence on the durability of the sub-bases owing to the growth of expansive phases. The development of highly hydrated neomorphic sulphated phases, such as ettringite results in expansion phenomena. Some neomorphic phases such as gehlenite, larnite and tobermorite were also identified, suggesting a certain pozzolanic behaviour that could contribute to field compaction.

Sand Equivalent

The Spanish NLT (Normas del Laboratorio de Transporte, Transport Laboratory Standards) Sand Equivalent standard (NLT 113/87[4]) was carried out using the < 5 mm fraction to determine the proportion of < 63 μm material. This is an important parameter when considering bottom ash as an aggregate substitute in construction applications owing to the plastic behaviour of this fraction in the presence of water. The higher the value, the lower the amount of argillaceous material.

Sand equivalent values obtained from the NLT 113/87 test for the three plants range from 70 to 81, high enough to avoid the durability problems discussed above. Sand Equivalent values >50 indicate optimum aggregates for most of the paving applications[5]. When considering road sub-bases, a Sand Equivalent > 30 is required as established by the Spanish road construction standard.[6]

Density parameters

The determination of the density parameters was carried out following the European EN-1097-6 standard[7]. The procedure is performed on two size fractions: the fine fraction (< 5mm) and the coarse fraction (> 5mm).

Table 3 shows the ranges of apparent particle density, particle density on a saturated and surface-dried basis and particle density on an oven-dried basis (OD) of bottom ash.

Table 3. Apparent particle density, particle density on a saturated and surface-dried basis (SSD) and particle density on an oven-dried basis (OD) of bottom ash. Values in kg m^{-3}.

	Fine	Coarse
Apparent particle density	2500 - 2680	2420 - 2490
Particle density SSD	2100 - 2200	2290 - 2330
Particle density OD	1820 - 1920	2150 - 2250

Since the typical apparent particle density of natural aggregates ranges from 2650 to 2700 kg m^{-3}, the results obtained classify bottom ash as an aggregate lighter than natural ones.

Absorption

Absorption test measures the change in weight between dry and wet bottom ash. Water absorption capacity was also determined for both the fine and coarse fractions following the EN-1097-6 standard[7].

Values obtained for bottom ash range from 3.5 to 6.2% for the coarse fraction and from 14.3 to 17.1 for the fine fraction. These values are considered to be high in comparison with those observed for the most common natural aggregates (< 3%). The highest values obtained for the fine fraction of bottom ash suggest that it is a highly porous material with a high surface area. Since bottom ash is a material with the capacity for absorbing a large amount of water, it must be taken into account during field compaction.

Abrasion Resistance (Los Angeles Test)

Los Angeles (L.A.) abrasion test measures the mechanical resistance of an aggregate under defined abrasive conditions. This is an important parameter to characterise the evolution of a layer after field compaction. The L.A. coefficient was determined following the NLT-149/91 standard[8]. Values measured correspond to the percentage loss in weight during the test.

The Los Angeles Coefficient observed in bottom ash from the three plants is very similar and ranges from 40 to 42%. According to the Spanish road construction standard[6], the Los Angeles Coefficient must be < 35 when considering bottom ash as a potential substitute in a granular sub-base with a relative low traffic. The values obtained don't comply with the above requirement, but a test on experimental road may show if this difference of about 5% involves an excessive crushing by the influence of the traffic and consequently some geotechical problems in the pavement.

Proctor Compaction

Proctor Compaction tests followed the NLT standards *(*Standard Proctor, NLT 107/98[9] and Modified Proctor, NLT 108/98[10]). Proctor compaction test determines the relationship between density and water content under specified compaction energy, which is 4.5 times higher in the case of Modified Proctor with regard to Standard Proctor.

Different Proctor compaction curves were obtained for bottom ash. Two of these curves are shown in Figure 6.

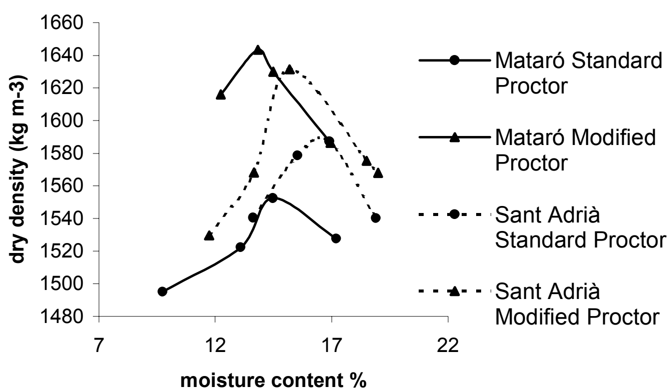

Figure 6. Proctor compaction curves for Mataró and Sant Adrià bottom ash.

Maximum dry densities (which correspond to the maximum compaction) reached by bottom ash are 1520-1580 kg m^{-3} for Standard Proctor and 1580-1640 kg m^{-3} for the Modified Proctor. Little variation at the MSWI plants was obtained with values very close to those determined for bottom ash from different countries (1530 to 1739 kg m^{-3}, as reported by Chandler[1]). Optimum moisture content varies from 13.9 to 18%. Based on the results, bottom ash may be considered as a highly compactable material, which is desirable to prevent future settlements and to increase strength and stability of the layer.

California Bearing Ratio

The California Bearing Ratio (CBR) is used to evaluate the strength of a compacted material, by means of the penetration resistance of a piston. The CBR Index is determined with the measured penetration and the corresponding load applied. The procedure established in the Spanish NLT 111/87 standard[11] was used to this end. The CBR index measured for the different bottom ashes are reported in Table 5.

Table 5. California Bearing Ratios (CBR index) obtained for bottom ash.

	TARRAGONA	MATARÓ	S.ADRIÀ
CBR INDEX	58	65	79

Values suggest that compacted bottom ash could develop resistant and stable systems. According to the Spanish Standard PG3[6] the CBR index must be > 20 when considering bottom ash as a potential substitute in granular sub-base. Bottom ash complies with this requirement.

Leaching tests

The leaching tests focused on the reproduction of field conditions to yield information about the degree of dissolution of bottom ash and the potential environmental impact for the application considered. Bottom ash is an alkaline material. The high pH values of the leachates (from 7 to 11) must be taken into account given that these determines the solubility of many phases, and hence the release of conflictive ionic species. Conductivity values range from 1200 to 4000 µS/cm, decreasing with aging. As shown in Table 6 the results of the leaching tests (based on DIN38414-S4) comply with the requirements on the leachability of trace pollutants of the Catalan standards for bottom ash valorisation[12], and consequently no environmental restrictions should be necessary.

Table 6. Leachable content of major and trace elements ($\mu g\ g^{-1}$ on a dry bulk basis) in bottom ash (DIN38414-S4). Values in brackets are the maximum admissible leachable contents in accordance with Catalan standards for bottom ash utilisation. (NL, no limits are defined by the Catalan Standard)

MAJOR ELEMENTS ($\mu g\ g^{-1}$)			TRACE ELEMENTS ($\mu g\ g^{-1}$)					
Ca	99-425	(NL)	Sr	0.5-10	(NL)	V	0.004-0.1	(NL)
Na	52-390	(NL)	Cu	0.06-0.8	*(2)*	Cr	0.001-0.05	*(0.1)*
K	30-260	(NL)	Ba	0.05-0.8	(NL)	Sn	0.001-0.02	(NL)
S	8-340	(NL)	Zn	0.01-0.1	*(2)*	As	0.001-0.01	*(0.1)*
Al	2-124	(NL)	Mo	0.01-0.1	(NL)	Mn	0.0007-0.3	(NL)
Mg	0.1-8	(NL)	Pb	0.006-0.1	*(0.5)*	Co	0.0001-0.003	(NL)
Si	0.1-1	(NL)	Ni	0.005-0.01	(NL)	Cd	<0.0001	*(0.1)*
Fe	0.01-2	(NL)						
P	<0.03-1.75	(NL)						

CONCLUSIONS

Bottom ash is a well-graded granular and highly compactable material that can develop strong road sub-bases. According to the Spanish road construction standards, bottom ash complies with most part of the technical requirements, and may be successfully used as an aggregate substitute in paving applications, especially in road sub-bases.

Data obtained from the leaching test comply with the limit values established by the Catalan standards for bottom ash valorisation. The use of bottom ash in the envisaged application should therefore not imply any environmental impact.

However, the standard NEN leaching tests will be performed to obtain more data about the leaching behaviour of bottom ash.
To evaluate the properties of bottom ash under field conditions an experimental road is being constructed in a few months, with an unbound road sub-base made up of bottom ash. Data about the leaching behaviour in the field will be compared with the DIN and NEN standard test results.

ACKNOWLEDGEMENTS

The present study has been supported by the CIRIT-Departament de Medi Ambient. The authors wish to thank the ACEVERSU (Association of Catalonian Enterprises for the Valorisation of Municipal Solid Wastes) and the Junta de Residus of Generalitat de Catalunya. Thanks are also given to Dr Albert Roca and Mr Manuel Antomil for expert technical assistance.

REFERENCES

[1] Chandler A.J., Eighmy T.T., Hartlén J., Hjelmar O., Kosson D.S., Sawell S.E., van der Sloot H.A., Vehlow J. (The International Ash Working Group). Municipal Solid Waste Incinerator Residues. Studies in Environmental Sciences, Elsevier 1997.
[2] AENOR-Asociación Española de Normalización y Certificación (1998). UNE-EN 933-1 Ensayos para determinar las propiedades geométricas de los áridos. Parte 1. Determinación de la granulometría de las partículas, Método del tamizado.
[3] Lindsay, W.L. Chemical Equilibria in soils. J.Wiley & Sons, New York 1979.
[4]. Ministerio de Fomento, CEDEX, Normas del Laboratorio de Transporte. NLT-113/87 Equivalente de Arena.
[5] Kraemer, C., Morilla ,I., Del Val, M.A. Carreteras II. Colegio de Ingenieros de Caminos, Canales y Puertos. Madrid, 1999.
[6] Ministerio de Obras Públicas. Pliego de prescripciones técnicas generales para obras de carreteras y puentes (PG3 (1975) más las modificaciones realizadas a partir de 1986 mediante Órdenes Ministeriales y Órdenes Circulares). Dirección General de Carreteras, Madrid.
[7] European Committee for Standardization. EN-1097-6 Tests for mechanical and physical properties of aggregates. Part 6. Determination of particle density and water absorption.
[8] Ministerio de Fomento, CEDEX, Normas del Laboratorio de Transporte. NLT-149-91 Resistencia al desgaste de los áridos por medio de la máquina de Los Ángeles.
[9] Ministerio de Fomento, CEDEX, Normas del Laboratorio de Transporte. NLT-107/98 Apisonado Proctor Normal.
[10] Ministerio de Fomento, CEDEX, Normas del Laboratorio de Transporte. NLT-108/98 Apisonado Proctor Modificado.
[11] Ministerio de Fomento, CEDEX, Normas del Laboratorio de Transporte. NLT-111/87 Índice CBR en el laboratorio.
[12] Generalitat de Catalunya, Departament de Medi Ambient. Ordre del 15 de febrer del 1996 sobre valorització d’escòries. DOGC, Diari Oficial de la Generalitat de Catalunya.