

Municipal Solid Waste Incineration Bottom Ash as Road Construction Material

Mohammed Muazu Abdulahi

Civil Engineering Department, Federal University of Technology
Minna, Niger State, Nigeria

E-mail: <mmuazuabdulahi@yahoo.co.uk>

Abstract

Bottom ash from municipal solid waste incinerator plants in Minna metropolis was characterized to investigate some alternatives for its utilization in road construction and their potential environmental impact. After detailed physical and geotechnical properties were investigated, the study focused on the use of bottom ash as an aggregate substitute in pavement applications. The results show that this material may successfully be used as a compacted material in unbound road sub-grade or filling. According to the Federal Ministry of Works and Housing, Nigerian General Specifications (Roads and Bridge Works), bottom ash complies with the technical requirements for sub-grade or filling. The use of bottom ash envisaged application should therefore not result in any environmental impact.

Keywords: *Minna metropolis, environmental impact, road base and sub-base.*

Introduction

Municipal solid waste (MSW) refers to the material discarded in the urban areas for which municipalities are usually held responsible for collection, transportation and final disposal. MSW encompasses household refuse, institutional waste, street sweeping, commercial waste, as well as construction and demolition debris. In developing countries, MSW also contain varying amount of industrial waste from small industries, as well as dead animals and fecal matters (Belevi 1998). The management of MSW in urban areas is a growing problem which is further aggravated due to absence of proper solid waste management systems. At present, in many instances, solid waste is collected in mixed state and is being dumped in environmentally very sensitive places like road sides, marshy lands, low lying areas, public places, forests, wildlife areas, water courses, etc., causing numerous negative environmental impacts.

The rate of generation of solid waste in our society is increasing with increase in population, technological development and change in our lifestyle. With this scenario, management of MSW gives a serious concern

to municipality to cope with the situation. This has to lead to various ways and methods of management of MSW in a sustainable way. The solid waste management systems in many countries are reinforcing the focus away from land filling and towards waste prevention (zero waste), recycling, composting and energy from waste (incineration) in that order of priority. This hierarchy prioritizes waste prevention and waste management techniques like, reuse, recycling and composting as superior to both the incineration/ash management alternatives and to land filling for a number of reasons such as economics, energy efficiency, and environmental soundness when evaluated from the standpoint of life cycle assessment (Chimenos *et al.* 1999).

In an integrated waste management approach, incineration occupies the nest of the last priority, after waste prevention, reuse, recycling and composting have been undertaken. Nowadays, incineration from waste to energy plant is gaining wider acceptance in the developed world under strict guidance. Waste generated in developing countries, however usually does not allow for energy recovery, due to its high moisture and high content of organic matter.

The increasing cost associated with the state of the art design and siting of landfills, coupled with the rapidity with which they approach capacity has forced municipalities to consider combination of recycling and incineration to minimize problems associated with the proper disposal of MSW (Barbieri *et al.* 2002). Incineration of municipal solid waste can significantly reduce the volume of the material to be land filled.

The incinerator ash from combustion of MSW consists mainly of bottom ash and fly ash. Bottom ash consists of slag, glass and partially unburned organic matter. It is a coarser or sand or clay in appearance, with a diameter varying between 0.1 mm and 100 mm. Fly ash consisting of partially burned organic matter is dust like grey particle, approximately 1-500 μm in diameter. Physical and chemical properties of the incineration ash vary depending on the type and source of the municipal solid waste. The high cost of treatment or disposal, the shortage of landfill space and increased environmental awareness have prompted incinerator managers and federal or state agencies to find other uses of the incinerator ash than disposal (Jelena 2006). Incineration or "mass-burn incineration" is a waste treatment technology that involves the combustion of waste at high temperatures.

Incinerators are ovens with chimneys. To incinerate means to burn something until only ashes are left over.

The management of solid waste, particularly the role of incinerator, is currently a subject of public debate. Whilst municipal solid waste incineration (MSWI) is found at the most advanced level of waste disposal treatment hierarchy: indiscriminate dumping, controlled dumping, land filling, sanitary land filling, and mechanical treatment (e.g., composting and incineration). Deciding to incinerate waste instead of, for instance, dumping it, takes careful consideration of the criteria for success. Bottom ash is that solid waste that is not completely burned on the grate. It is the ash fraction that remains on the stoker or grates at the completion of the combustion cycle. It is similar in appearance to porous, grayish, silty sand with gravel and contains small amounts of un-burnt organic

material and chunks of metal. It consists primarily of glass, ceramics ferrous and non ferrous metal, and other materials. It comprises approximately 75-80% of the total combined ash. Bottom ash is coarser somewhat like concrete/sand with diameter varying between 0.1 and 100mm (Chandler *et al.* 1997).

Fly ash is that solid and condensable particular matter which leaves the furnace suspended in the combustion gases and which is subsequently collected in emission control devices. It consist of a more homogeneous mixture of fine ash particles that were carried out of the combustion chamber, composed of metals, organics and acids condensed into the surfaces of the ash particles. It has dust like grey particles, approximately 1-5,000 μm in diameter. Fly ash comprises up to 10 to 15% of the total combined ash. Fly ash characteristically contains more toxic pollutant bottom ash. It is therefore managed well separately.

Materials and Methods

Bottom ash is the most significant by-product from MSWI. It accounts for 85-95% of the solid product resulting from municipal solid waste combustion.

MSWI reduces the volume of waste and its mass by about 70% (around 225 – 315kg of bottom ash per tones of municipal solid waste) (Chimenos *et al.* 1999).

In Nigeria (Minna), bottom ash is mainly land filled, but utilization of residues is preferred for disposal in accordance with the waste management policy of the Federal Government. In this study, some alternatives for utilization 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 sub-grade. Each layer requires a material with very specific physical and geotechnical properties (Khanna *et al.* 2001).

A preliminary and physical characterization of the bottom ash from the four plants in Minna town was performed. The samples of bottom ash were collected from the four plants for a detailed physical and geotechnical characterization at four selected locations.

Municipal solid waste generally comprises household and commercial garbage constitutes a serious problem in our cities. It is a growing problem further aggravated by lack of proper management system.

Urbanization and population growth lead to substantial quantities being generated on a daily basis in urban areas. Waste generation increases with increase in income, technology advancement and change in lifestyle.

Large percentage of the waste is disposed in the form of landfill and in other insensitive places causing negative environmental impact and risk to human life. Disposal of waste is resource consuming. In addition, the space at existing landfills is limited and it is hard to find new suitable areas for waste disposal. To stimulate the reuse of waste, the society has therefore issued a variety of directives (fees on deposited waste, ban on disposal of certain types of waste, etc.). The high cost of treatment of disposal, the shortage of landfill space due to increase in MSW and the speed at which landfills approach maximum capacity has forced municipalities to consider combination of recycling and incineration to minimize problems associated with the improper disposal of MSW.

In addition, incineration reduces the volume of waste by values up to 90% thereby allowing landfills to act as the ultimate receptacle for a much large initial volume of MSW (Chandler *et al.* 1997). However, incineration of the municipal solid products results in the formation of other waste products in the form of ashes of different kind. The management of this material in a sustainable way is now an important issue. This leads to stronger incentives to find ways to utilize this material in road construction.

This study is aimed at determination of the proper use of municipal solid waste incineration (MSWI) bottom ash in road construction.

Location of Study Area

The location of study area was in Minna metropolis, located at longitude 6°59' north and latitude 4°53', where four municipal solid waste incineration plants were identified as follows:

Union Bank, along Paiko road (A); Unity Bank, along Paiko road (B); Bahago Secondary School, along Bosso road (C); and GRA (Government House) Minna (D).

The study was limited to determine the physical and geotechnical properties of MSWI bottom ash. The following tests were carried out: natural moisture content determination, Atterberg limits test, particle size distribution, hydrometer analysis, moisture density relationship, permeability test, specific gravity test, unconfined compressive strength and California Bearing Ratio (CBR) test.

All these tests were carried out in accordance with BS 1377 (1990) methods of test.

Results and Discussion

Sample Identification

The MSWI bottom ash was made up of five different types of particles. In addition to the slag particles, metals, glass, ceramics, and unburned organic matter are also present in a varying proportion.

The results for the identification and classification of the MSWI bottom ash samples are presented in Table 1.

The MSWI bottom ash samples collected from the incinerator plants were classified under visual classification, unified soil classification system (USC) and Highway Research Board (HRB) known as American Association of State Highway and Transport Officials system (AASHTO 1986).

Visual Classification

The MSWI bottom ash is organic silt having plasticity and exhibits marked dilatancy, dries moderately quickly and can be dusted off the finger. Dry lumps possess cohesion, but can be powdered easily in the finger.

Grain Size Distribution

The grain size distributions of the constituents were almost the same for each plant. The coarsest fraction is made up of construction debris, ferrous materials, slag particles and unburned MSW. Glass particles are the most abundant material in the 1.18 to 5.00 mm range. Slag material was the main component of fine fraction (<2 mm). Finally, the unburned MSW particles are present in low proportions without any grains size trend.

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 1 shows the grain size distribution of bottom ash from the four selected plants. These are fairly similar, with the major modes in both the coarse and fine sizes. The gentle slope of curves suggests a poor gradation.

Bottom ash is a granular material with a continuous grain size distribution and low proportion of non-plastic fine (<0.075mm) and coarse (>0.075mm) fractions. Therefore, this may be easily compacted to obtain a high resistance; bottom ash could be considered as poorly graded material.

The MSWI bottom ash was classified under the unified soil classification system.

As shown in Table 1, the percentage passing BS sieve size 200 (0.075mm) was less than 50% for all the samples. Therefore, according to the USC system, all the samples fall under-fine grained samples.

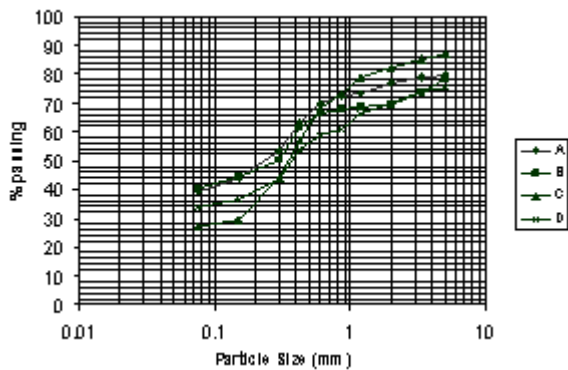


Fig. 1. Particle size distribution for various MSWI.

Table 1. The index properties of the MSWI bottom ash.

Properties	Quantities			
	A	B	C	D
Natural moisture content (%)	18.5	18.0	17.5	20.0
Specific gravity	1.68	1.70	1.87	
Liquid Limit (%)	48.0	43.0	40.0	48.0
Plastic Limit (%)	40.0	35.0	-	39.0
Maximum dry density (Mg/m ³)	1.502	1.444	1.625	1.675
Optimum Moisture Content (%)	8.2	7.8	8.4	8.8
Coefficient of Permeability (mm/s)	5.3x 10 ⁻³	5.5x 10 ⁻³	7.0x 10 ⁻³	5.9x 10 ⁻³
Group Index	1	1	2	0
AASHTO Classification	A-5	A-5	A-4	A-5
UCS Value (kN/m ²)	244	238	253	253
CBR Value (%)	13	12	13	13
Plasticity index (%)	8.0	8.0	-	9.0
Linear shrinkage (%)	4.0	4.0	-	5.0
% passing BS Sieve 200	39.1	40.4	27.2	33.9
Color	Black ash	Black ash	Black ash	Black ash

Using the limits and their respective plasticity index, the groups where bottom ash samples fall under were read from the USC graph (plasticity chart) for fine grained samples. The bottom ash samples were classified as follows:

Samples A, B and D fall under organic silt and silty clays (OL) group, while C falls under (ML) group, all from plasticity chart.

OL soils are organic silts and organic silty clays of low plasticity. They are organic silts of low to medium plasticity. These MSWI bottom ash samples behave poorly as sub-grades when not under frost action.

However, they are unsuitable as bases or sub-bases under frost action, because they have medium to high susceptibility to frost action. Also, they have a medium-high range of response to volume changes and poor drainage characteristics.

ML soils are inorganic silts, very fine rock floor, clayed silt or fine sand. The bottom ash samples of this group behave fair to poor as sub-grade, slight to medium of volume changes, high to very high of potential frost action and fair to poor drainage characteristics.

The MSWI bottom ash samples A, B and D were classified under the AASHTO (1986) classification system as A-5 groups, while sample C was A-4 group all from plasticity chart, and it is black ash in color.

Chemical Characteristics

Major, minor and traces oxide compositions of the bottom ash were analyzed by XRF (see Table 2). The chemical composition of bottom ash depends on the municipal solid waste feed characteristics and on the combustion system.

Plasticity Characteristics

The liquid limit was determined to be 48% for samples A and D, 43% for sample B and 40% for sample C, as shown in Table 1. It was greater than 35% and the plasticity index was 8% for samples A and B, 0% for sample C, and 9% for sample D, which fall within the range of not greater than 12%.

The percentage passing BS sieve 200 was also greater than 35% for samples A and B, while samples C and D were less than 35%. These properties of the material render it unsuitable and, therefore, the MSWI bottom ash cannot be used directly as base and sub-base material as specified by the FMW&H (1994) specification requirement.

Compaction Characteristics

Many of the engineering properties of the MSWI bottom ash samples are dependent upon the density as well as the moisture content at which the density was compacted.

The moisture-density relationships for samples A, B, C and D are shown in Table 1. Considering the effect of compaction on MSWI bottom ash samples, the results show the variation of density with moisture content, there was a gradual increase in dry-density with increase in moisture content before decreasing

the dry density at fourth and fifth trials, but with increase in moisture content as it is used to be in normal moisture-density relationship.

Strength Characteristics

The Unconfined Compressive Strength (UCS) value is an indicator of unconfined compressive strength that is widely used in the design of foundation, base and sub-base for pavement construction (Punmia *et al.* 2000). The sample was tested in unsoaked condition. The values of USC and CBR for all the samples are shown in Table 1. The CBR value is the method for evaluating stability of MSWI bottom ash materials for bases, sub-bases and other flexible pavement materials.

It is also used in selecting the strength and bearing capacity that is widely used in the design of base and sub-base materials for pavement construction (Craig 1997). The results of the CBR values of MSWI bottom ash samples A, B, C, and D are nearly the same, i.e., having a CBR value of 13%.

Table 2. Oxides composition of the samples.

Name	Chemical Formulae	Oxides composition (%)			
		A	B	C	D
Silicon Oxide	SiO ₂	53.25	54.7	50.15	51.05
Aluminium Oxide	Al ₂ O ₃	7.3	7.18	5.25	5.2
Iron Oxide	Fe ₂ O ₃	17.69	18.34	8.55	6.7
Calcium Oxide	CaO	3.25	3.18	11.21	10.39
Magnesium Oxide	MgO	0.25	0.16	0.59	0.46
Sulphur Oxide	SO ₃	0.9	0.05	0.18	0.14
Potassium Oxide	K ₂ O	1.55	1.65	1.74	1.69
Sodium Oxide	Na ₂ O	0.41	0.44	0.93	0.89
Manganese Oxide	MnO ₂	0.05	0.03	0.07	0.12
Titanium Oxide	TiO ₂	0.52	0.39	0.42	0.63
Loss on Ignition-LOI		10.89	11.61	12/96	13.42

Conclusion

The collection of MSWI bottom ash samples from the four study areas shows that the bottom ash samples are black ash and are organic silt. Soil classification test results on the samples encountered in the study area show that they are fine materials with the samples A and B having percentage passing BS sieve No. 200 greater than the specification

For a requirement of 35% maximum (FMW&H 1994), samples C and D fall within the range of not greater than 35%.

Also, samples A, B, C and D have plasticity index which falls within the acceptable range. The MSWI bottom ash samples of A, B and D are of A-5 while sample C is of A-4 AASHTO classification, respectively, and the linear shrinkage falls within the acceptable range.

The MSWI bottom ash samples A and B fall within the group index of 1 while samples C and D fall within the group index of 2 and 0. Note that the higher the group index the poor the quality of material (pavement evaluation of FMW&H Kaduna, Nigeria)

Compaction of MSWI bottom ash samples A, B, C and D shows that the maximum dry density was achieved at 8% to 9% of moisture content (1.502Mg/m^3 , 1.444Mg/m^3 , 1.625Mg/m^3 and 1.675Mg/m^3). And samples A, C and D have a CBR value of 13%, and 12% for sample B.

Although the specification is silent on liquid limit, plasticity index, sieve analysis and CBR for sub grade/fill material, nevertheless, 45% maximum liquid limit, 12% maximum plasticity index, 35% maximum sieve analysis and CBR 3-10% are common. Therefore, the samples meet the requirement with MSWI bottom ash samples A, C and D having the highest CBR value of 13%, and 12% for sample B.

Recommendation

The knowledge of municipal solid waste incineration bottom ash should be broadly disseminated to aid the optimum use of the most available MSWI bottom ash in the tropical regions.

Knowing the physical and geotechnical properties of MSWI bottom ash from Union Bank, Unity Bank, Bahago Secondary School, and GRA (Government House), it should be stabilized with lime or cement in appropriate ratios before being used as sub-base and Base course in flexible pavements. When used as sub-grade or fill material, proper drainage must be provided for the pavement to prevent the retaining of water in the sub-grades.

References

- AASHTO. 1986. Standard specifications for transportation materials and methods of sampling and testing. 14th ed., American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, USA.
- Barbieri, L.; Corradi, A.; Lancellotti, I.; and Manfredini, T. 2002. Use of municipal incinerator bottom ash as sintering promoter in industrial ceramics. *Waste Management* 22(8): 859-863.
- BS 1377. 1990. Methods of test for soils for civil engineering purposes. British Standards Institution (BSI), London, England, UK.
- Belevi, H. 1998 Environmental engineering of municipal solid waste incineration. *Habil.-Schr., Hochschulverl. ETH, Zürich, Switzerland*, pp. 1- 3.
- Chandler, A.J.; Eighmy, T.T.; Hartlén, J.; Hjelm, O.; Kosson, D.S.; Sawell, S.E.; van der Sloot, H.A.; and Vehlow, J. 1997. Municipal solid waste residues. *The International Ash Working Group, Studies in Environmental Science* 67, Elsevier Science, Amsterdam, the Netherlands.
- Chimenos, J.M.; Segarra, M.; Fernandez, M.A.; and Espiell, F. 1999. Characterization of the bottom ash in municipal solid waste incinerator. *J. Hazard. Mater.* A64: 211-22.
- Craig, R.F. 1997. *Soil Mechanics*. 6th ed., E. & F.N. Spon Press, London, England, UK, pp 5-37.
- FMW&H. 1994. Nigerian general specifications. Roads and bridge works. Federal Ministry of Works and Housing (FMW&H), Lagos, Nigeria.
- Highway Research Board. 1943. Use of soil-cement mixture for base course. *Wartime*

Road Problems, No. 7, Nat. Res. Council, Div. Eng. Indust. Res., Washington, DC, USA.

Khanna, S.K.; and Justo, C.E.G. 2001. Highway engineering. 8th ed., Nem Chand & Bros., Roorkee, India, pp. 269-92, 471-3.

Khanna. S.K.; and Justo, C.E.G. 2001. Highway material testing. 8th ed., Nem Chand & Bros., Roorkee, India, pp 40-198.

Todorović, J. 2006. Pre-treatment of municipal solid waste incineration (MSWI) bottom ash

for utilization in road construction. Doctoral Thesis, Division of Waste Science and Technology, Department of Civil and Environmental Engineering, Luleå University of Technology, Luleå, Sweden, pp. 6-25.

Punmia, B.C.; Jain, A.K.; and Jain, A.K. 2006. Soil mechanics and foundations. 16th ed., Laxmi Publ., New Delhi, India.