Characterization of Solid Waste Incinerator Bottom Ash and the Potential for its Use

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ABSTRACT
This paper evaluates the properties of incinerator bottom ash from Kano Municipal solid waste to see what uses the material could be put to after incineration. The properties of the material make it suitable for use as fills, low cost road sub-grades and sub-bases. The incinerator bottom ash was found to have specific gravity values ranging from 1.86 to 2.37, moderate alkalinity (P^H 9.90 – 10.45), organic content values between 5.07 to 10.0 and contained silicon, calcium and heavy metals such as zinc, lead, copper and manganese. It can possibly be classified as a well graded material using unified soil classification system, a non-plastic material close to A – 3 soils in AASTHO. Bottom ash exhibits similar characteristics to dense sand when compacted to maximum dry density, values obtained lies in range of 1.57 to 1.75g/m^3. It is a free draining material with coefficient of permeability up to 6.33 x 10^{-4} m/s which is quite comparable to that of sand. It is a fairly stable and durable material with shear strength parameters (Angle of internal friction 17^0- to 25^0, cohesion 2.55 – 10.30KN/m^2). Its C. B. R values up to 70% makes it a possible substitute aggregate in paving application and in modification of other soils to improve their qualities. It is suggested that MSWI bottom ash could be used as an alternative material for low cost road construction such as fills, sub grades and sub-bases

Keywords - **Municipal Solid Waste, Incinerator, Bottom Ash, Pavement Construction, Sub-base.**

1 INTRODUCTION

Civilization and development comes with various adverse impacts on humanity. One such area of severe human impact is the waste management in urban areas. The management of solid waste in urban areas is a growing problem which is being continually aggravated by poor management practices, poor collection and disposal practices as well as non-availability of space in the urban environment to accommodate and store the waste generated. As a result, solid wastes are collected in mixed state and are dumped in environments close to sensitive places like roads sides, marshy lands, low lying areas, public places, vacant lands within residential areas, forests, wild life areas, water courses, etc.

The rate of solid waste generation is an increasing phenomenon and it is accelerated by rapid population growth and urbanization, technological development and changing life styles. A study of the solid wastes generated in states across the country is a testimony to the growing problem of waste management in Nigeria, NEST (1991). One major issue related to solid waste management is how to cope with the huge wastes generated from the municipalities in a sustainable way.

Traditionally, municipal solid wastes have been managed through landfills, recycling, composting and incineration in decreasing order of priority. Whereas modern waste management is focused towards zero waste or wastes prevention, other wastes management techniques such as recycling, re-use, incineration and composting still leaves some residual material to be disposed of. Incineration in particular, has been used as a solid waste management option to reduce the volume of the waste by about 90%, Chandler et al (1997) and to convey the remaining to sanitary land fill sites. Incineration of solid waste also results in the formation of other waste products, such as bottom ash. How to manage this material in a sustainable way is a challenge posed to modern solid waste management (Sussana, 2005).

The high cost of treatment or disposal, the shortage of land fill space and increased environmental awareness in urban areas have prompted the need to find other uses of the incinerated ash than disposal Muhunthan et al, (2004). A wide range of options is available for the re-use of incinerator bottom ash, such as Chang & Wey, (2006): Mohamedzein, (2006) in desert sand stabilization;

(Muller & Rubner, 2006; Rubner, Haamkens, & Linde, 2008) as an aggregate in concrete; (Bessani et al., 2009; Hassan, 2007; Xue, Hou, Zhu, & Zha, 2009) as in bitumen related works; (Becquart, Bernard, Arbiak, & Zentar, 2009; Hjelmar, Holm, & Crillesen, 2007) as sub base in road construction; (Ma, Onitsuka, & Negami, 2007) as an admixture in road embankment material; (Aouad et al., 2008) as in micro-biological studies; (Kasuriya, Jiemsirilers, & Thavorniti, 2008) as in clay based ceramics; (Monteiro et al., 2008; Xiao & 1026., 2008) as a glass raw material; (Qiao, M., Poon, & Cheeseman, 2008) as a cementitious material; (Lee & Li, 2009) as a replacement for cement in cement mortar; (Chen, Wang, & Tang, 2010) as for manufacturing of light weight aggregates. The potential for the re-use of bottom ash is enormous. This paper explores the potential re-use for municipal solid waste incinerator bottom ash generated from Kano in North-West Nigeria.

2 METHODOLOGY

Four major waste dumping sites were identified and used in this study. The dumping sites are fairly representative of the metropolitan area. Each dumping site was carefully examined and random sampled to avoid collecting wastes that are uniform in character such as construction debris and street sweepings. The collected samples at each dumping site were carefully sealed in polythene sacks and cellophane bags to prevent moisture loss and were transported to the incineration sites for further processing and incineration. Before incineration, the samples were air dried for 5 hours and the volume and weight of the samples were recorded.

2.1 DESCRIPTION OF THE BOTTOM ASH

Incinerator ash from combustion of solid waste consists mainly of bottom ash and fly ash. Bottom ash consists of slag, glasses and partially unburned organic matter. It is generally coarse sandy in appearance with a diameter varying between 0.1mm and 100mm. Fly ash on the hand consists of partially burned organic matter and its dust-like grey particles approximating 1-500(micrometer) in diameter. Physical and chemical properties of the incinerated bottom ash vary depending on the type and source of the solid waste.

A standard solid waste incinerator is hard to see in the study area. A locally built incinerator was therefore used to burn the waste. This was a simple fixed type kiln of red burnt bricks capable of withstanding temperatures up to 1000^{o}C. The kiln has a chimney and an oven with openings for loading and for igniting the solid waste. To achieve uniform combustion, air was introduced at intervals and a stirrer manually used to expose the incombustible portions of the waste. The waste was fed into the incinerator in batches of between 5Kg to 15Kg at intervals of 15min to 30min.

To achieve complete combustion, secondary incineration was carried on the waste samples by gas firing. The primary incinerated bottom ash was batch fed into the chamber which stands on top of a metal grate. The chamber was then fired and the batch inside the chamber was ignited for one hour to ensure complete combustion. With the use of the manually operated stirrer, the ash generated dropped through the metal grates into ash trays at the base of the chamber. The bottom ash collected was allowed to cool for 12hours before being prepared for use in the research.

2.2 BOTTOM ASH PREPARATION

The bottom ash collected from the incineration was packed into polythene bags and the volume as well as weight measurements were taken. Standard tests such as Bulk density, specific gravity, moisture content, Atterberg limits, compaction, grading, hydrometer, California Bearing Ratio, Unconfined compression, permeability and shear strength were carried out on the samples in accordance with BS 1377 (1990). Furthermore, X-ray tests and chemical analysis were carried out on the samples.

3 RESULTS

The Municipal Solid Waste was first classified to determine the content of its components'. This characterization revealed the lifestyle as well as the activities taking place within the neighborhood of the dumping sites. The trend is shown in figure 1.1.

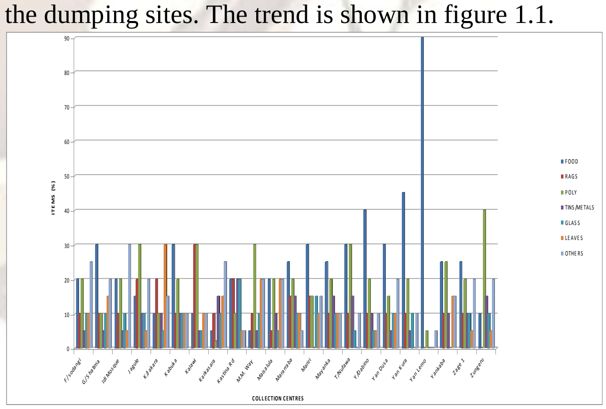

Figure 1.1: Characterization of Municipal Solid Waste

It is evident that food wastes dominate the constituents in the MSW followed by clothes and polythene materials. It must be mentioned that Kano experiences a high degree of scavenging activity mostly on recyclable metal and plastic items, hence the disproportionate amount of these items in the MSW. A large number of groups and individuals make a living through recycling of wastes but not much is taking place in the area of recycling polythene materials.

The moisture contents of the oven dried and air dried wastes are shown in figure 1.2. There is a marginal difference between the two, with oven dried NMC slightly higher in A3 and A4 samples than the A1 and A2 samples.

Results of the bulk and dry densities are showed in figures 1.3. Values for the bulk densities range between 0.54g/cm^3 to 0.96g/cm^3 while those of the dry densities values range between 0.46g/cm^3 to 0.81g/cm^3. Composition of the wastes plays a significant role in the density as well as the rate of loss of moisture. Depending on the time of collection and composition of the waste, one characteristics of the waste is that it tends to be dense and humid due to consumption of fresh fruits and vegetables as well as unpackaged foods. These have their effect on the densities of waste as well as the rate of loss of moisture which greatly affect the incineration of the waste. It takes a longer period under considerable sunlight for the waste to dry up completely.

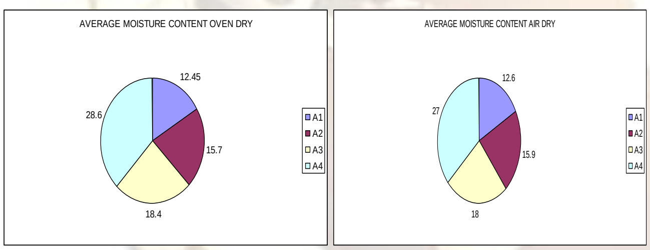

Figure 1.2: Moisture Contents for air dried and oven dried samples.

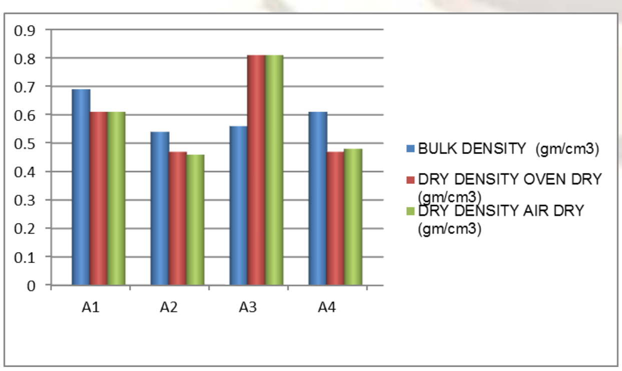

Figure 1.3: Densities of the Municipal Solid Waste.

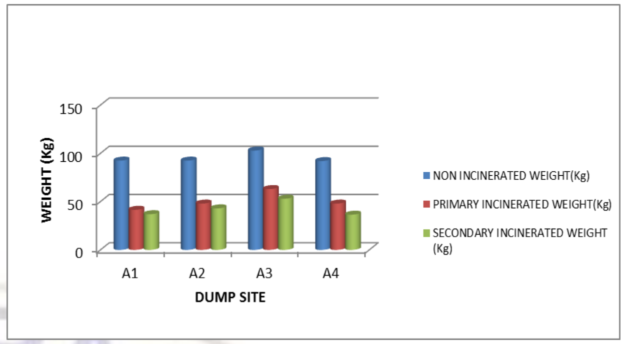

Figure 1.4: Proportion of waste incinerated

After characterizing the waste, the weighted content that could not be incinerated was higher than the incineratable waste as shown in figure 1.4. This is the non-combustible component. By volume the non-incinerated component is also shown in figure 1.5.

3.1 GEOTECHNICAL PROPERTIES OF THE MSWI BOTTOM ASH

The geotechnical properties of the MSWI bottom ash are shown in table 1.0. The CBR results for un-soaked samples range between 50 to 73% while for the soaked samples the values are in the order of 25 to 44%. These values when evaluated from the viewpoint of the Nigeria General Specification (1997), all pass for materials to be used as sub grade, filling and sub bases in road construction while CBR values for the remoulded samples which range between 14 to 42% could only pass to be used as sub grade and fill material (table 4.1).

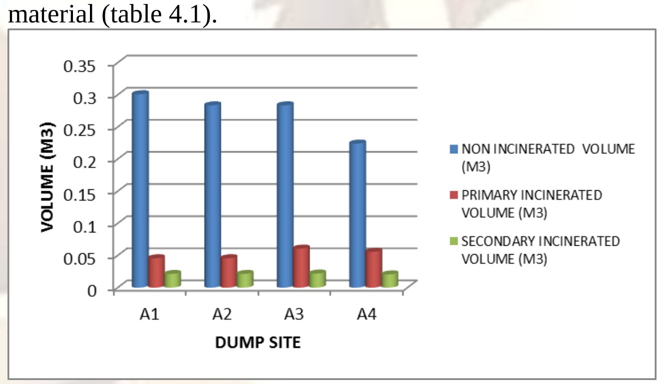

Figure 1.5: Non-Incinerated content by volume.

All the values for the CBR are approximate to the values obtained by other researchers such as Izquierdo et al (2001), Chan and Chen (2005) and Muhunthan et al (2004) respectively. These values are close to values for a well graded road base material. This shows that MSWI bottom ash could be used as road base material with little modification to increase its strength. This corroborates the findings of Ma et al (2007).

Results of the permeability test also presented table 1.0 indicates that bottom ash is a free draining material with coefficient of permeability for all the samples ranging between 5.9 x10^{-4}m /sec to 6.75 x10^{-4}m /sec, which is close to the range for fine sand (K values ranges from 2.6 x 10^{-4} to 4.32 x 10^{-4} m /sec).

According to U.S Bureau of Reclamation, soils are classified to be pervious if K values are greater than 10^{-4}cm/sec. MSWI bottom ash falls into these categories and can be said to be a pervious, free draining material (Garg, 2002).

Drainage is crucial in highway and geotechnical application of construction material. A well-drained material prevents development of pore pressure during loading in fills. It also accelerates the consolidation of the surrounding low permeable soils, leading to enhance stability of structures founded on these materials.

The average shear strength parameters for the MSWI bottom ash fall within the range for sand. Thus the material can be used for a number of applications such as filling, improvement of grading properties for clayey soils, and as a free draining material. The unconfined compression test revealed that the MSWI bottom ash has

Table 1.0: Geotechnical properties of the MSWI Bottom ash

PROPERTIES	**SAMPLES(AVERAGE VALUES)**				
	A1	A2	A3	A4	Mean
Specific Gravity	1.86	2.36	2.37	2.20	2.20
Optimum Moisture Content	10.30	10.50	10.00	10.20	10.25
Maximum Dry Density	1.57	1.73	1.69	1.62	1.65
Gradation: Dry sieving(% passing)					
Fine fraction	87	89	85	88	87.25
Silt fraction	1.50	1.60	1.63	1.27	1.50
Gradation: Dry sieving(% passing)					
Fine fraction	90	89	90	90	89.75
Silt fraction	20	22	19	16	19.25
Atterberg Limit					
Liquid limit					
Cone penetration	37.56	32.45	36.76	37.30	28.52
Casagrande	33.55	34.12	34.60	34.74	34.25
Plastic limit	NP	NP	NP	NP	NP
Permeability (m/s)	6.07 x 10^{-4}	6.20 x 10^{-4}	5.90 x 10^{-4}	6.75 x 10^{-4}	6.23 x 10^{-4}
Shear strength parameters					
Cohesion,c(kN/m2)	5.45	3.70	4.55	14.30	7.00
Angle of friction, φ	21.60	22.30	17.90	16.20	19.50
Unconfined compression strength, UCS (kNm2)	20.60	8.73	5.10	13.24	11.92
Cohesion,c from UCS (kN/m2)	10.30	4.37	2.55	6.62	5.96
CBR unsoaked (soaked) 0.1 penetration	63(27)	44(18)	57(27)	50(36)	53.50(27)
0.2 in penetration	72(34)	56(26)	52(34)	63(49)	60.75(35.75)
California bearing ration for	25(25)	23(14)	16(13)	30(31)	23.50(20.75)

remoulded samples. Unsoaked (soaked) 0.1 penetration					
0.2 in penetration	41(39)	38(15)	26(19)	42(36)	36.75(27.25)

Table 1.2: Chemical Analysis of Incinerator Bottom Ash

S/ NO	PARAMETER	A1	A2	A3	A4	MEAN VALUES
1	Chloride (mg/kg)	41.5	156.04	111.22	31.13	84.97
2	Sulphate (mg/kg)	49	50	56	47	50.5
3	pH	10.3	10.45	9.90	10.22	10.22
4	Loss on Ignition	5.94	6.09	5.07	10.00	6.78
5	Silicon (mg/kg)	680.60	869.80	838.30	847.43	809.03
6	Calcium (mg/kg)	45.70	73.90	88.00	74.70	70.58
7	Iron (mg/kg)	16.1	14.53	24.24	103.75	39.66
8	Magnesium (mg/kg)	24.08	38.18	36.52	44.82	35.90
9	Sodium(mg/kg)	57.03	64.51	51.60	36.16	52.33
10	Phosphoric (mg/kg)	43.99	50.63	47.31	39.01	45.24
11	Sulphur (mg/kg)	0.21	0.40	0.75	0.62	0.50
12	Copper (mg/kg)	1.25	2.32	1.74	1.00	1.58
13	Zinc (mg/kg)	14.86	10.13	14.03	8.88	11.98
14	Lead (mg/kg)	0.06	0.12	0.07	0.05	0.08
15	Chromium (mg/kg)	0.17	0.42	0.25	0.17	0.25
16	Manganese (mg/kg)	4.15	7.47	4.15	3.32	4.77

7-day strength, about 3 times that of clay. Thus MSWI ash could be employed as an admixture in pre-treatment and stabilization of soft clay. The CBR value of the MSWI bottom ash could be used as sub base layer materials for CBR values greater than 40%.

Chemical characterization revealed that SiO_2, a network glass former oxide, was present in a relatively high content (43.28wt %), indicating the suitability for this waste to be employed in the development of vitreous materials. The MSWI bottom ash could be reused as cement replacement materials since it contained SiO_2 which is one of the main building components in cement and concrete utilizations(Chun et al., 2007). CaO, Na_2O and K_2O, which act as fluxing agents, were present in various amounts (1.7-8.20wt %) together with several other oxides normally present in ceramic and glass raw materials. This finding further confirms the work of Monteiro et al, (2008). Furthermore, the MSWI bottom ash contains Ca, Fe, Si, and heavy metals such as Cu, Pb, Mn, Zn, but it is deficient in Al. It must be noted that Zinc is available in significant quantities in all the dumping sites followed by Manganese and Copper. A summary of the chemical composition of the ash is shown in tables 1.2 and 1.3.

Table 1.3: Summary of the Major Chemical Compounds

Major Chemical Constituents	Compound Concentration (%)				
	A_1	**A_2**	**A_3**	**A_4**	**Avg.**
Silicon Oxide (SiO_2)	36.40	46.53	44.85	45.33	43.28
Calcium Oxide (CaO)	1.60	25.85	3.08	2.61	8.20
Iron Oxide (Fe_2O_3)	0.58	0.52	0.85	3.71	1.42
Magnesium Oxide (MgO)	1.00	1.58	1.51	1.86	1.49
Sodium Oxide (Na_2O)	1.92	2.18	1.74	1.22	1.77
Sulphur Oxide (SO_2)	0.01	0.02	0.04	0.03	0.03
Phosphate (P_2O_5)	2.52	2.90	2.71	2.23	2.59
Sulphate	1.23	1.45	1.40	1.18	1.32
Total	**45.26**	**81.03**	**56.18**	**58.17**	**60.10**

Source: study

2 CONCLUSIONS

This study investigated the potential use of municipal solid waste incinerator bottom ash as civil engineering construction material. Based on the results obtained from this study, the following conclusions can be drawn:
Municipal solid waste incineration, from this study achieved 93% reduction in volume and 62% by weight.

The MSWI bottom ash is classified as well graded in the Unified Soil Classification System; Non-plastic A-3 material in AASHTO classification and satisfies the grading of sand particles for zone 2 of the Nigeria General Specification (1997).

MSWI bottom ash is a light weight material from the specific gravity compared to natural sand and gravel. This is an advantage in the construction of fills on grounds with low bearing capacity.

MSWI bottom ash is a pervious material quite comparable to sand. Free draining materials that can prevent buildup of pore water pressure in fills and embankments.

MSWI bottom ash is well graded and compactable material that can be used as a strong road sub base material from the result of C.B.R values.

MSWI bottom ash is a fairly stable and durable material comparable to natural sand as obtained from the shear strength parameters.

Municipal Solid Waste incineration bottom ash is recommended as a waste treatment option because of the advantage it offers in the reduction of waste by weight and by volume up to 62% and 93%, respectively.

Municipal solid waste incineration bottom ash has suitable geotechnical properties and based on the Unified Soil Classification and AASHTO system, it has qualities that can possibly be used in construction of low cost roads.

With further investigation, municipal solid waste incineration bottom ash characteristic nature of being pervious similar to natural sand put it at an advantage to possibly be a substitute in filter material in fills

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