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Suitability of Municipal Solid Waste Incineration Bottom Ash as Sub-Base Material for Construction of Road T

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Authors' contributions

This work was carried out in collaboration among all authors. Author POY designed the study, performed the statistical analysis and wrote the protocol. Author BSO wrote the first draft of the manuscript. Author BSO managed the analyses of the study and managed the literature searches under the supervision of authors POY and CLE. All authors read and approved the final manuscript.

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ABSTRACT

Incineration bottom ash is a form of ash produced in incineration facilities and this material is discharged from the moving grate of municipal solid waste incinerators. Geotechnical investigation is one of the effective means of detecting and solving pre, syn and post constructional problems. The geotechnical properties of incineration bottom ash and their suitability as sub-base and base materials for road construction have been evaluated. All analyses were carried out in accordance with the British Standard Institution. The natural moisture content ranged from 10.20% to 10.27%, specific gravity ranged from 2.36 to 2.39, liquid limits ranged from 40.50% to 41.00%, all samples were non plastic. The maximum dry density ranged from 1.81 mg/m^3 to 2.39 mg/m^3 while the optimum moisture content varied from 9.21% to 9.29%. The particle size distribution for percentage passing BS sieve size 200 (0.075 mm) ranged from 0.66% to 0.69% and fall under-fine grained silt sand samples according to the USC system. The california bearing ratio was low at 6% for all samples which makes them fail for use as sub-base materials, thereby requiring application of stabilizing agent such as cement, lime, gravel, etc before use for road construction. The evaluation

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reveals that all the samples of incineration bottom ash contain no plastics, Maximum Dry Densities (MDD) and Optimum Moisture Contents (OMC) are lower. The samples of incineration bottom ash were classified as A-2-7, group index 0, granular based and are suitable for use as sub-base materials for road construction when compared to the standards prescribed by American Association of State Highway and Transport Officials system (AASHTO 1986), Unified Soil Classification System (USCS) and Federal Ministry of Works and Housing (1997) for use of materials as sub-base materials for road construction. The information obtained from the geotechnical properties of incineration bottom ash obtained from Halden Nigeria Limited, Golden Years Nigeria Limited and Boskel Nigeria Limited will serve as baseline information for use as a sub-base material for road construction and as supporting data for waste to road resources material

Keywords: Geotechnical; municipal; solid; waste; incineration; bottom; suitability.

1. INTRODUCTION

Civilization and development comes with various adverse impacts on humanity. One such area of severe human impact is increase in waste generation and the challenges of waste management in rural and urban areas around the world. Nigerian Environmental Study/Action Team [1].

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 [1]. 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%, [2] 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 [3].

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 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 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.

The aim of this study was to investigate the geotechnical properties of incineration bottom ash from three different sites incineration plants in Port Harcourt and determine their suitability as sub-base material for construction of roads.

1.1 Description of Study Area

Port Harcourt, a capital city of Rivers State is situated in the Niger Delta. It Lies along the Bonny River (an eastern distributary of the Niger); 41 miles (661 cm) upstream from the Gulf of Guinea and is located in the Delta region of the River Niger. The main city in Port Harcourt is the Port Harcourt City Local Government Area. Port Harcourt city lies at latitude 05°21'N and longitude 06°57'E. The municipal waste incineration bottom ashes were collected at

Halden Nigeria Limited, Golden Years Nigeria Limited and Boskel Nigeria Limited. Halden Nigeria Limited lies at latitude 4°80'02.39" and longitude 7°39'1.69", Golden Years Nigeria Limited lies at latitude 4°79'65.90" and longitude 6°95'8.973" and Boskel Nigeria Limited lies at latitude 5°02'10.02" and longitude 7°31'33.03". Shown in the map below:

2. METHODOLOGY

2.1 Sample Collection and Source

Three samples of bottom ash were collected from three plants namely: Halden Nigeria Limited, Golden Years Nigeria Limited and Boskel Nigeria Limited in Port Harcourt City as seen in Table 1. A preliminary physical characterization of the bottom ash was carried out, before a detailed geotechnical analysis was carried out at the civil engineering laboratory, Rivers State University, Port Harcourt, Rivers State, Nigeria.

2.2 Laboratory Analysis

The laboratory analysis was performed according to British standard methods of test for soil civil engineering purposes [4]. The laboratory test was carried out to determine the suitability of the municipal solid waste incineration bottom ash for use as sub-base material using the AASHTO [5] standard method in relation to the generation specification for roads and bridges. Sieve analysis was performed in order to determine the soil particle size distribution. Representative sample of approximately 500g was used for the test after washing and oven-dried. The sample was washed using the BS 200 sieve and the fraction retained on the sieve was air dried and used for the sieve analysis.

Liquid Limit was determined by passing the samples through 425 μm sieve, weighing 200 g was mixed with water to form a thick homogenous paste. Plastic limit determination, the samples weighing 200 g was taken from the material passing the 425 μm sieve and then mixed with water till it became homogenous and plastic was shaped to ball. Moisture content is defined as the ratio of the weight of the water in a soil specimen to the dry weight of the specimen. The degree of compaction was measured in terms of its dry weight and it increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and curb undesirable settlement of structure. The moulds was filled and compacted with samples in three layers via 25 blows of a 2.5kg rammer. The California bearing ratio (CBR) test is a penetration test that was carried out to evaluate the mechanical strength of a sub-base material. It measured the shearing resistance, controlled density and moisture content. The unsoaked method of CBR was conducted to characterize the bottom ash samples for use as subbase material. A portion of air dried bottom ash samples was mixed with about 5% of its weight of water. This was put in CBR moulds in 5 layers with each layer compacted with 25 blows using 4.5 kg hammer a drop of 450 mm. The compacted soil and the moulds was weighed and placed under the CBR machine and a seating load of approximately 4.5 kg was applied,Load was recorded at penetration of 0.625, 1.9, 2.25, 6.25, 7.5, 10 and 12.5 mm. Unconfined Compression Test was carried out to quickly determine a measure of the unconfined compressive strength of fine-grained soils that possess sufficient cohesion to permit testing in the unconfined state. This measure is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions.

In the unconfined compression test, the samples were placed in the loading machine between the lower and upper plates. Before starting the loading, the upper plate was adjusted to be in contact with the sample and the deformation was set as zero. The test then started by applying a constant axial strain of about 0.5 to 2% per minute. The load and deformation values were recorded as needed for obtaining a reasonably complete load-deformation curve. The loading was continued until the load values decrease or remain constant with increasing strain, or until reaching 20% (sometimes 15%) axial strain. At this state, the samples were considered to be at failure. The sample was then removed for measurement of the water content.

As for the results, the axial stress is usually plotted versus the axial strain. The maximum axial stress, or the axial stress at 20% (sometimes 15%) axial strain was reported as the unconfined compressive strength σc.

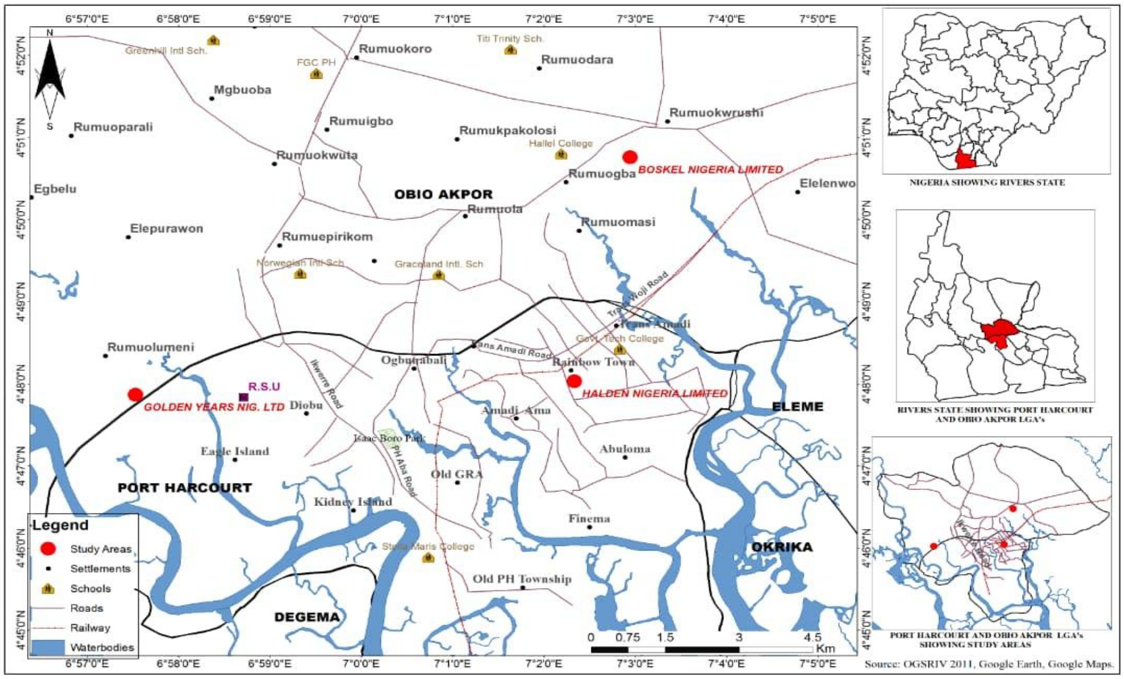

Fig. A. Map of port harcourt showing the Study Area

Table 1. Incineration plants where bottom ash samples were obtained

Incineration Plants in Port Harcourt				
S/No	**Company name & location**	**Type of facility**	**Administrative address & contact details**	**Status**
1.	**Halden Nig. Ltd.** Km 17, PHC/Aba expressway Port Harcourt	• 1 High Temp. Incinerator • 1 Trash Incinerator	Ekpeli Drive, Plot 229 Trans-Amadi Industrial layouts, Phase II Port Harcourt.	**Operational**
2.	**Golden Years Ltd,** Igwuruta, Ikwerre LGA, Rivers state.	1 Incinerator	1 George close, opposite Somitel hotel, Off peter Odili road, Trans Amadi Industrial layout, Port Harcourt, Rivers state	**Operational**
3.	**Boskel Nigeria Ltd** Elelenwo Flow station road, Km 17, PHC/Aba Expressway, Port Harcourt, Rivers state,	• 1 Thermal Desorption Unit (TDU) • High Temp. Incinerator • High Temp. Liquid Waste Incinerator	37 Nembe roads, Rumuibekwe Estate, Port Harcourt, Rivers State.	**Operational**

3. RESULTS, DISCUSSION AND RECOMMENDATION

3.1 Results

The results of the geotechnical properties such as natural moisture content determination, atterberg limits, particle size distribution, hydrometer analysis, moisture density relationship, permeability test, specific gravity test, unconfined compressive strength and california bearing ratio (CBR) of incineration bottom ash obtained from Halden Nigeria Ltd, Golden Years Limited, and Boskel Nigeria Limited are presented in Table 2 and Fig. 1 - Fig. 8. The incineration bottom ash is inorganic silt having low or no plasticity. The incineration bottom ash samples collected from the incinerator plants were classified under American Association of State Highway and Transport Officials system [5], Unified Soil Classification System (USCS) and [6] general specifications for roads and bridges.

3.1.1 Geotechnical properties

3.1.1.1 Natural moisture content (%)

Natural moisture content values for the three samples of incineration bottom ash ranged from 10.20% in Sample G to 10.27% in Sample B. The result for natural moisture content is shown in Fig. 1.

3.1.1.2 Specific Gravity

Specific gravity values for the three samples of incineration bottom ash ranged from 2.36 in Sample G to 2.39 in Sample B. The result for specific gravity is shown in Fig. 2. The Figure indicated that natural moisture content varied for the three samples.

3.1.1.2 Atterberg Limit

3.1.1.2.1 Liquid Limit (%)

Liquid limit values for the three samples of incineration bottom ash ranged from 40.50% in Sample H to 41.00% in Sample G. The result for liquid limit is shown in Fig. 3. The Figure indicated that liquid limit slightly varied for the three samples.

3.1.1.2.2 Plastic limit (%)

All the incineration bottom ash samples tested during the period of study were non-plastics.

3.1.1.2.3 Plasticity index

All the incineration bottom ash samples tested during the period of study were non-plastics and had no plasticity index.

3.1.1.3 Compaction test

3.1.1.3.1 Maximum dry density (mg/m^3)

Maximum dry density values for the three samples of incineration bottom ash ranged from 1.81 mg/m^3 in Sample G to 2.39 mg/m^3 in Sample H. The result for maximum dry density values is shown in Fig. 4. The Figure indicated that maximum dry density slightly varied for the three samples.

3.1.1.3.2 Optimum moisture content (%)

Optimum moisture content values for the three samples of incineration bottom ash ranged from 9.21% in Sample G to 9.29% in Sample H. The result for optimum moisture content values is shown in Fig. 5. The Figure indicated that optimum moisture content slightly varied for the three samples.

3.1.1.4 Particle size distribution (Sieve Analysis)

The particle size distributions of the constituents were almost the same for all samples.. Particle size distribution values for percentage passing BS sieve size 200 (0.075 mm) for the three samples of incineration bottom ash ranged from 0.67% in Sample H to 0.69% in Sample B. The result for particle size distribution values for the different percentage passing BS sieve is shown in Fig. 6. The Figure indicated that particle size distribution slightly varied for the three samples. However on a sample to sample comparison, the particle size distribution for percentage passing BS sieve size 200 (0.075 mm) in Table 2. The percentage passing BS sieve size 200 (0.075 mm) was less than 50% for all the samples, however, all the samples fall under-fine grained samples according to the USC system.

Table 2. Geotechnical properties of incineration bottom ash samples

			Compaction Test		Atterberg Limit			Particle Size Distribution (Sieve Analysis)	Strength Characteristics				
Incineration Bottom ash Code	**Natural Moisture Content (%)**	**Specific Gravity**	**Maximum dry density (mg/m^3)**	**Optimum Moisture Content (%)**	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index**	**% passing BS Sieve 200**	**UCS Value (kN/m^2)**	**Unsoaked CBR Value (%)**	**Colour**	**AASHTO classification & group index**	**Unified soil classification system (USCS)**
H	10.21	2.38	2.35	9.29	40.50	NP	NP	0.67	817	6	Black ash	A-2-7 (0) granular material	Silty sand (ML)
G	10.20	2.36	1.81	9.21	41.00	NP	NP	0.66	813	6	Black ash	A-2-7 (0) granular material	Silty sand (ML)
B	10.27	2.39	1.95	9.24	40.80	NP	NP	0.69	820	6	Black ash	A-2-7 (0) granular material	Silty sand (ML)

**All incineration bottom ash are non-plastics*
H----- Halden Nigeria Limited
G----- Golden Years Limited
B------ Boskel Nigeria Limited
NP- Non- Plastics

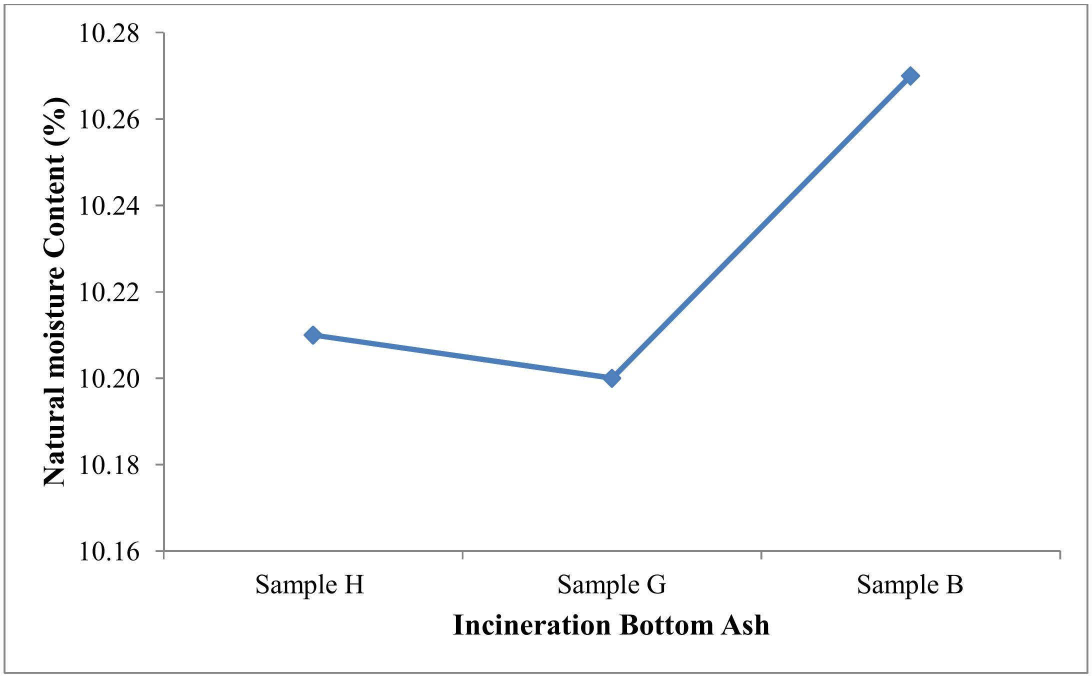

Fig. 1. Natural moisture content (%) of incineration bottom ash samples

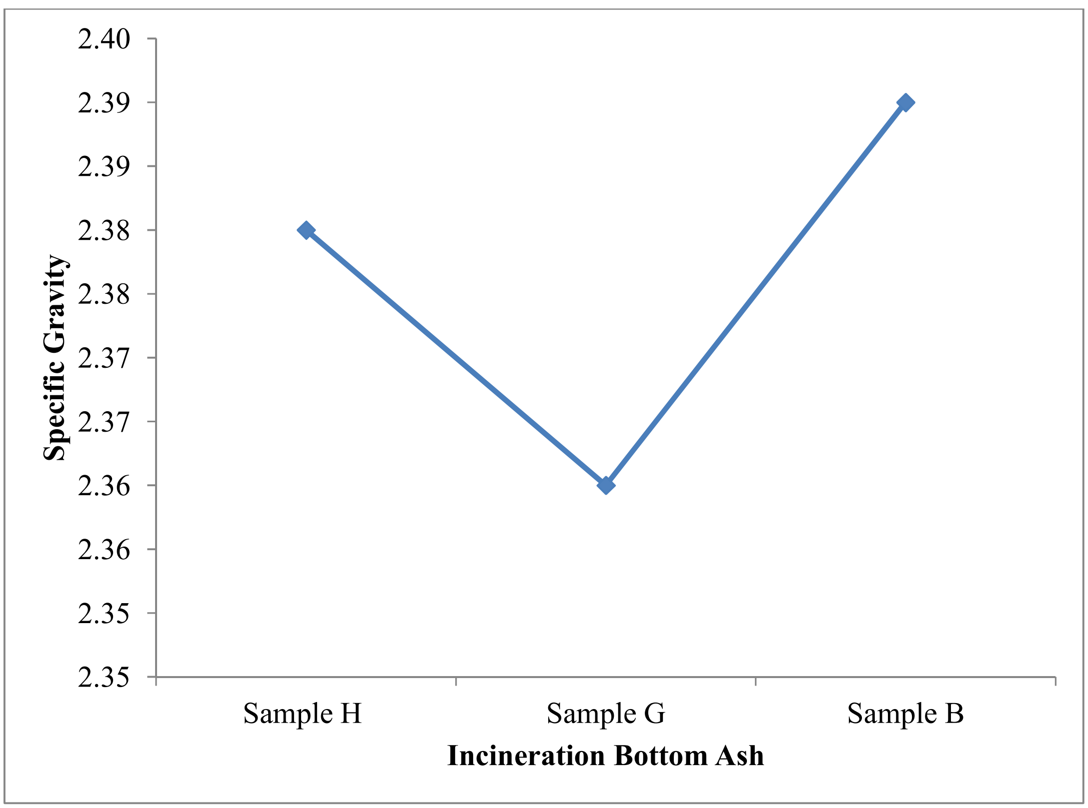

Fig. 2. Specific gravity of incineration bottom ash samples

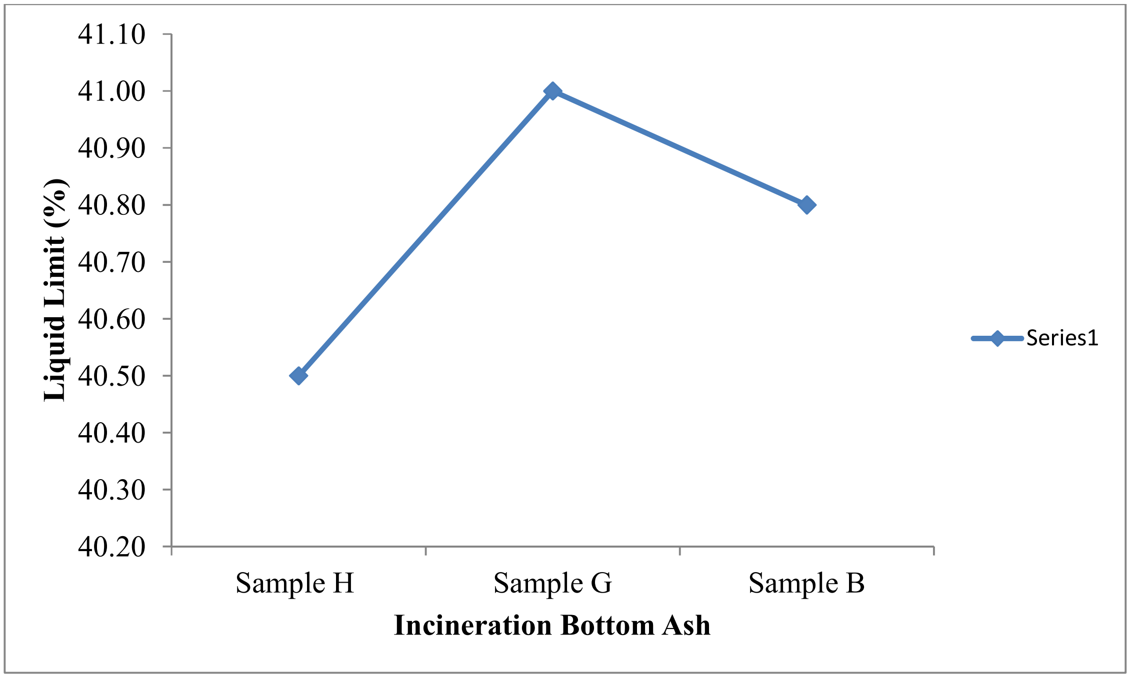

Fig. 3. Liquid limit of incineration bottom ash samples

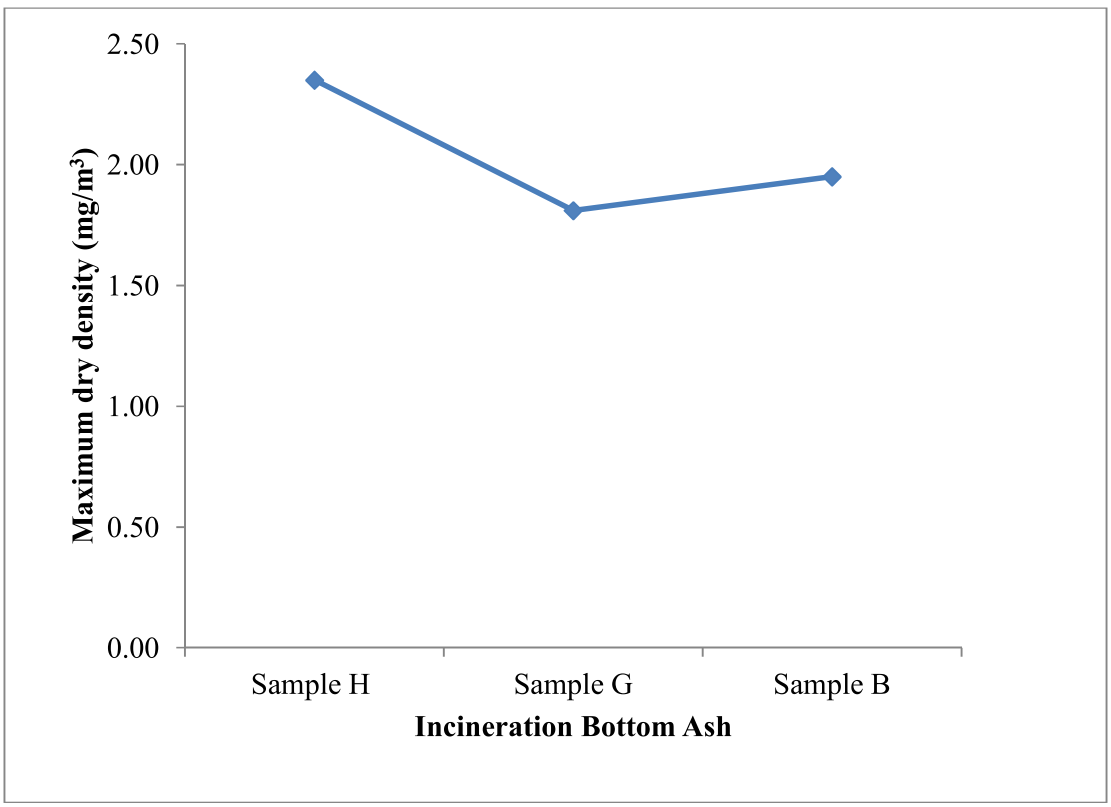

Fig. 4. Maximum dry density of incineration bottom ash samples

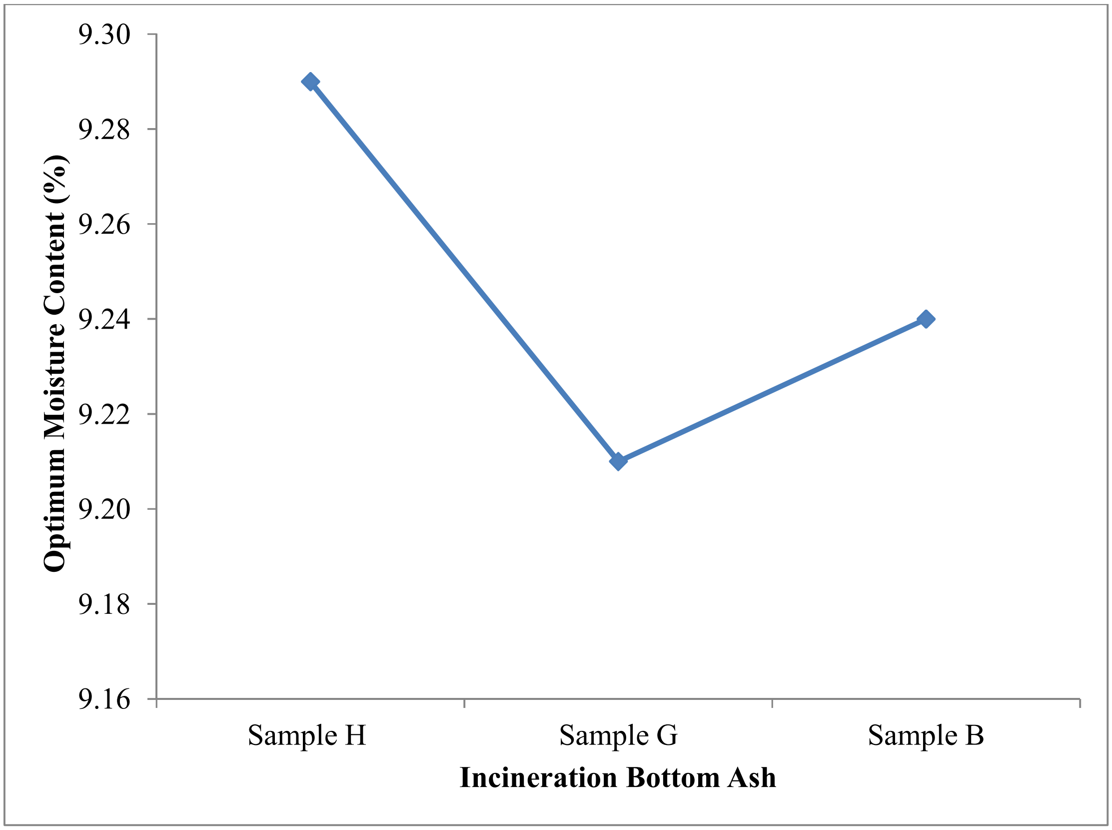

Fig. 5. Optimum moisture content of incineration bottom ash samples

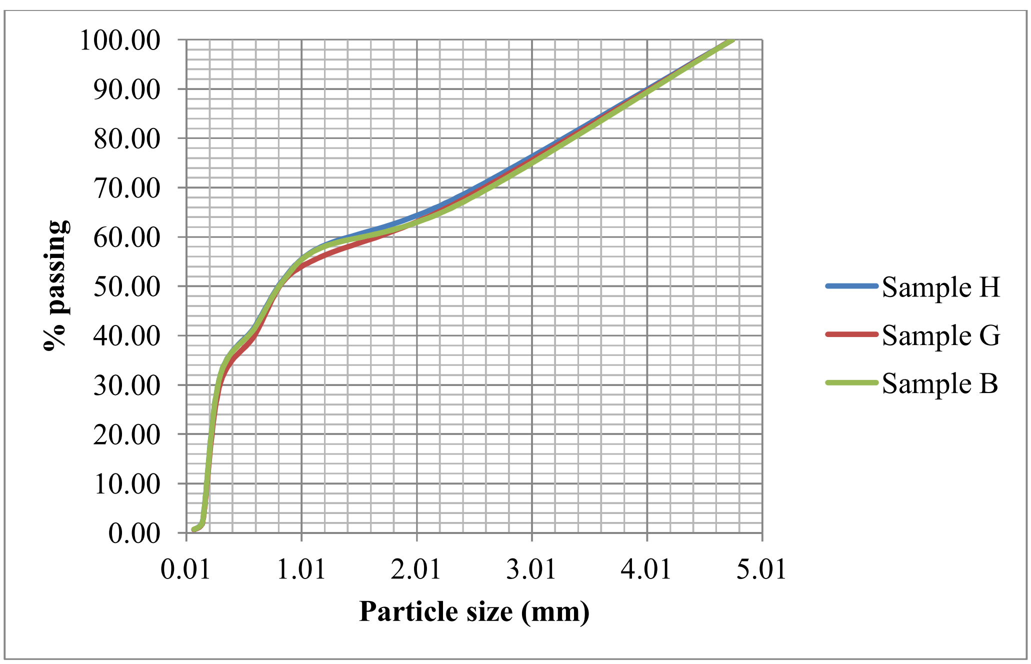

Fig. 6. Particle size distribution of incineration bottom ash samples

3.1.1.5 Strength characteristics

3.1.1.5.1 Unconfined compression strength value (kN/m^2)

The unconfined compression strength values for the three samples of incineration bottom ash ranged from 813.4kN/m^2 in Sample G to 820.3kN/m^2 in Sample B. The result for unconfined compression strength values is shown in Fig. 7. The Figure indicated that unconfined compression strength values varied for the three samples.

3.1.1.5.2 California bearing ratio (%)

The California Bearing Ratio values for the three samples of incineration bottom ash was 6% for all samples. The result for unsoaked california bearing ratio values is shown in Fig. 8 A, B and C. The Figure indicated that unsoaked california bearing ratio values did not vary significantly for the three samples.

3.2 Discussions

3.2.1 Natural moisture content (%)

Moisture content is the ratio of the weight of the water in the incineration ash specimen to the dry weight of the specimen. Moisture content of the ash is dependent on post-combustion treatments and storage methods. Moisture is important for dust control and also for proper compaction. The natural moisture content of the values showed the natural quantity of water in the ash samples with an average that ranged from 10.21%-10.27% as shown in Table 2. This indicated that all the samples were silt with low or no plasticity (material passing sieve No.200) and this finding is in agreement with other determined geotechnical parameters.

3.2.2 Specific gravity

Specific gravity is an important physical property of incineration bottom ash in the field of

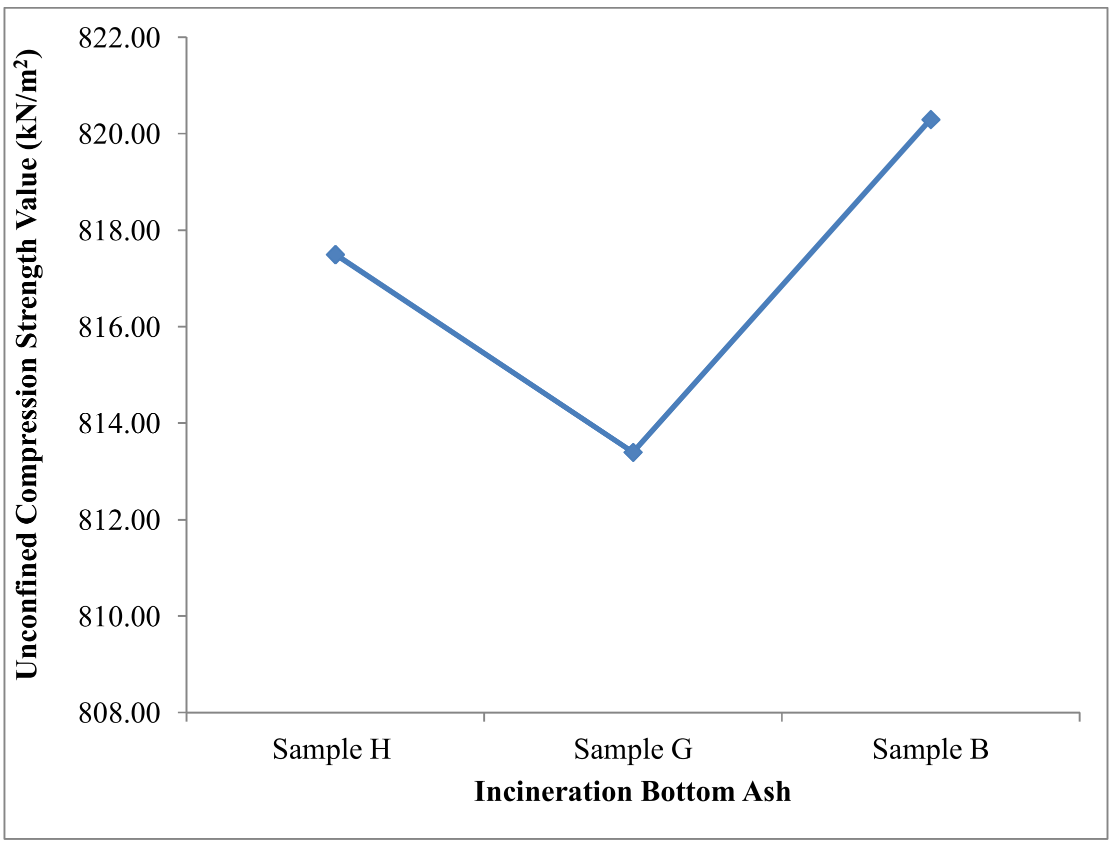

Fig. 7. Unconfined compression strength of incineration bottom ash samples

geotechnical engineering. Specific gravity of sample G was lower than that of sample H and sample B respectively. The specific gravity of the three samples which ranged from 2.36 to 2.39 corroborates with [7] who discovered that bottom ash has a specific gravity of 1.1–2.7. Bottom ash with specific gravity (below 2.5) is often indicative of the presence of porous popcorn particles while bottom ash with relatively high specific gravity (above 3.0) may indicate high iron content [7].

3.2.2.2 Atterberg limits

3.2.2.2.1 Liquid limit (%)

The liquid limit was determined to be 40.50% for samples H, 41.00% for samples B and 40.80% for samples G as shown in Table 2. FMW&H [6] for construction of road works recommends liquid limits of 50% maximum for subbase and base materials. The liquid limits were below 50% indicating that these properties of the material render it suitable and, therefore, all the samples incineration bottom ash (H, G and B) can be used directly as sub-base material as specified by the [6] specification requirement. This finding is in line with [8] who conducted a study on the use of municipal solid waste incineration bottom ash as road construction material in Minna where it was discovered that the liquid limit of all samples A-D was >35% thus, all samples were above the standard set by [6] for construction of roads and bridges and can be used directly as subbase material for road construction.

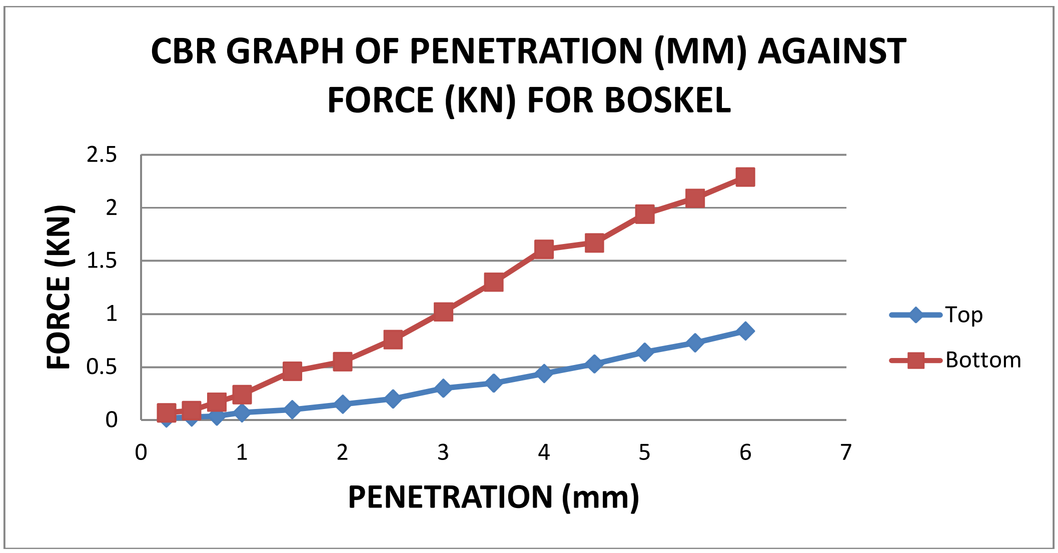

Fig. 8A. Unsoaked CBR graph showing slope for top and bottom

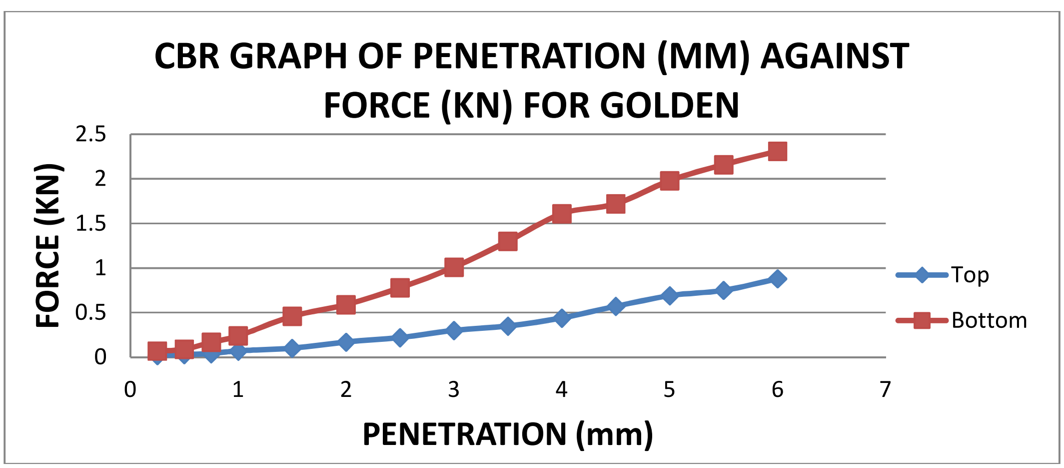

Fig. 8B. Unsoaked CBR graph showing slopes for top and bottom

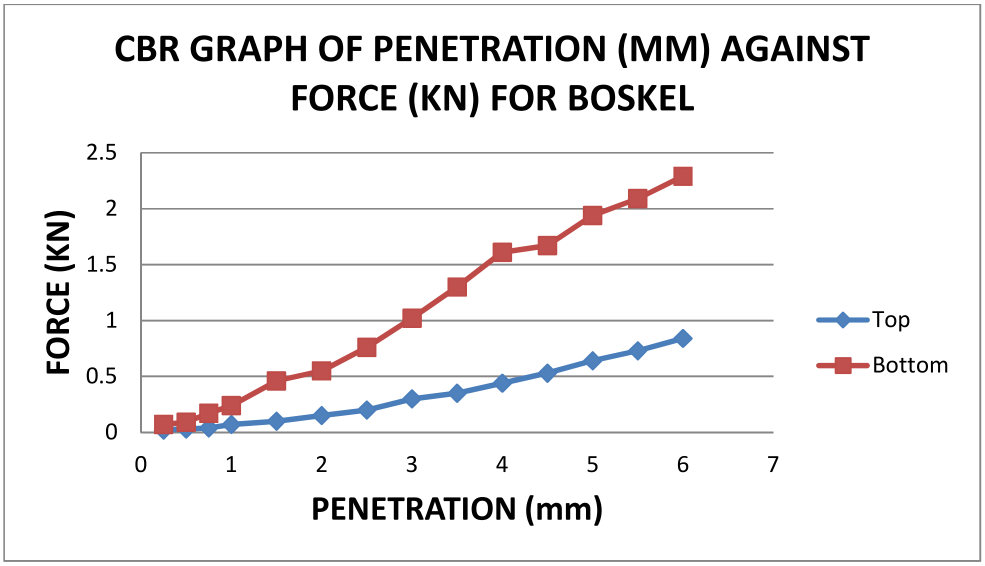

Fig. 8C. Unsoaked CBR graph showing slopes fortop and bottom

3.2.2.2.2 Plastic limit (%)

All the samples were non-plastics and had low or no plasticity according to the Unified soil classification system (USCS).

3.2.2.2.3 Plasticity index (%)

The plasticity index was determined and it was discovered that all three samples are non-plastic because they all displayed no plasticity.

3.2.2.3 Compaction test

The density as well as the moisture content at which the density was compacted determines many of the geotechnical properties of the incineration bottom ash samples. The moisture-density relationships for samples H, B and G are shown in Table 2. Considering the effect of compaction on incineration bottom ash samples, the results show the variation of density with moisture content. The maximum dry density for the samples ranged between 1.81 mg/m^3 to 2.35 mg/m^3 while that of optimum moisture content ranged between 9.21% to 9.29%. According to O" Flaherty (1998), the range of values that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density (MDD) may fall between 1.44 mg/m^3 and 1.685 mg/m^3 and optimum moisture content (OMC) may fall between 20-30%. For silty clay, MDD is usually ranged between 1.6 mg/m^3 and 1.845 mg/m^3 and OMC ranged between 15-25%. For sandy clay, MDD usually ranged between 1.76 mg/m^3 and 2.165 mg/m^3 and OMC between 8-15%.

3.2.2.4 Particle size distribution (Sieve analysis)

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. Particle size distribution is a parameter that plays an important role in some properties and accurate data are required for other physical and geotechnical tests. Fig. 8 showed the particle size distribution of incineration bottom ash from Halden Nigeria Limited, Golden Years Nigeria Limited and Boskel Nigeria Limited. These are fairly similar, with the major modes in both the coarse and fine sizes. The gentle slope of curves in Fig. 3 suggests a poor gradation. This is line with [8], who conducted a study on the use of municipal solid waste incineration bottom ash as road construction material in Minna and discovered that the gentle slope of particle size distribution curves suggests a poor gradation.

Soil gradation is very important to geotechnical engineering. It is an indicator of other engineering properties such as compressibility, shear strength, and hydraulic conductivity. A poorly graded soil will have better drainage than a well graded soil because there are more void spaces in a poorly graded soil [9].

Incineration bottom ash is a granular material with a continuous grain size distribution and low proportion of 0non-plastic fine (<0.075 mm) and coarse (>0.075mm) fractions and this may be easily compacted to obtain a high resistance making incineration bottom ash to be considered as poorly graded material [10]. The incineration bottom ash was classified under the unified soil classification system. As shown in Table 2.

3.2.2.5 Strength characteristics

3.2.2.5.1 Unconfined Compression Strength Value (kN/m^2)

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 [11]. The result in Table 2 indicated that the unconfined compression strength value for the three incineration bottom ash samples ranged from 813.4 kN/m^2 to 820.3 kN/m^2 showing that all samples of incineration bottom ash is a fairly stable and durable material when compared to natural sand and can be utilized as sub-base materials for road construction in Port Harcourt [12,13].

3.2.2.5.2 California Bearing Ratio (CBR) (%)

The California bearing ratio (CBR) test is a penetration test that was carried out to evaluate the mechanical strength of a samples of incineration bottom ash. CBR measured the shearing resistance, controlled density and moisture content of all incineration bottom ash samples. The un-soaked california bearing ratio value for incineration bottom ash samples is generally 6% as shown in Table 2. Federal Ministry of Works and Housing recommends that before a soil is used as sub-base materials, un-soaked soils have a california bearing ratio CBR≤10%. However, the result indicated that all samples of incineration bottom ash had CBR values of 6% which is a fail and makes them unsuitable materials for sub-base. It is therefore recommended that, with these low CBR values, MSW incineration bottom ash need to be stabilized with other agent such as cement, gravel, lime etc. before use as a sub base materials for the construction of road.

4. CONCLUSION AND RECOMMENDATION

The result showed that all incineration bottom ash samples are non-plastic and were classified as A-2-7 under the [5] classification system and belonged to group 0 according to the group index classification. The soils with group index near to zero are considered as good soils which make samples of these incineration bottom ash good soils.

The result showed that the studied samples are classified as silty sands, easily compactible with fairly good drainage. The incineration bottom ash samples test result indicates a general low moisture content, high granular material which is suitable as sub-base material for road construction. However, it is recommended that bottom ash should be stabilized with cement, lime or crushed stone (gravels) of ½ and ¾ inch size in appropriate ratios in order to meet the sub-base requirement due to their low CBR value. This research data can be beneficial for civil engineers in the design and construction of roads for maximum durability and efficiency.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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