

## EFFECT OF INCINERATOR ASH ON COMPACTIVE BEHAVIOUR OF LATERITIC SOIL

E. W. Gadzama<sup>1</sup>, H. M. Mohammed<sup>1</sup>, P. Yohanna<sup>2</sup> and P. Felix<sup>1</sup>

<sup>1</sup>Department of Civil Engineering, Moddibo Adama University of Technology, Yola, Adamawa State, Nigeria

<sup>2</sup>Department of Civil Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

Corresponding Author: gadzymo@yahoo.com

### **Abstract**

*The effect of Incinerator Ash (IA) on compactive behavior of laterite soil was studied. The soil was classified as A-2-4(0) in accordance with American Association of State Highways and Transportation Officials (AASHTO) classification system. The natural soil has a liquid limit, plastic limit and plasticity index values of 24, 19.6 and 4.4 %, respectively. The natural soil was treated with up to 12% incinerator ash content by dry weight of soil. Specimens of treated soil were compacted with British Standard light, BSL or standard Proctor (relative compaction = 100%), West African Standard, WAS and British Standard heavy, BSH or modified Proctor. Other vital tests such as falling head permeability and California Bearing Ratio (CBR) tests were conducted as well. Results showed that properties of the modified soil improved when treated with Incinerator Ash. There was a decrease in maximum dry density (MDD), with an increase in optimum moisture content (OMC) as well as a decrease in hydraulic conductivity. No general trend was established for CBR values for WAS and BSH compactive effort. The CBR values generally decreased with BSL energy level. Statistical analysis was carried out on results obtained using analysis of variance (ANOVA) with the Microsoft Excel Analysis Tool Pak Software Package to determine the levels of significance of effect of incinerator ash on the properties of laterite soils. XLSTART 2014 statistical tool incorporated as add-in in Microsoft Excel were use for the correlation analysis. Statistical analysis shows that Incinerator ash has significant effect on the geotechnical properties of laterite soils. Based on the result obtained, an optimal blend of 2% incinerator ash content at BSH energy level optimally improved the geotechnical properties of the modified soil and is thus recommended for geotechnical engineering applications as road construction.*

**Key words:** *Compaction effort, Incinerator ash, Compacted Laterite, Improved Geotechnical properties.*

### **1.0 Introduction**

The disposal of municipal solid waste (MSW) has been a major problem all over the world due to increasing world population, industrialization and socio-economic activities. Disposal of waste is becoming an increasing concern for many urban municipalities because of the increasing volume of solid waste generated, costs of operating landfills, and the scarcity of landfill sites [1]. One of the most economical ways of disposal of this waste is the reuse of these residues obtained after burning the waste for engineering applications. Incinerator residue helps to alleviate the ultimate disposal costs, preserve landfill capacity, conserve dwindling resources for natural raw materials, and mitigate potential environmental impacts.

Incinerator residue is potentially useful material for various engineering applications, for example, in experimental bricks, asphalt mixes, concrete and as a fill material for sanitary landfill [2;3;4;5;6;7;8;9]. Past researches, such as [9] have shown that the physical properties

of incineration ash are similar to that of coal fly-ash, which has been in use for several geotechnical engineering applications.

[10], Conducted a research to study the possibility of solidification/stabilization (S/S) of hospital solid waste incinerator ash (HSWIA) with an aim to eliminate/reduce the presence of toxic elements within acceptable limits so that the same may be utilized in a geotechnical construction. The hospital solid waste incinerator ash (HSWIA) was mixed with alluvial soil in different proportions in order to obtain the optimum percentage of HSWIA based on the strength criteria. Leachate tests were conducted on the samples prepared at optimum HSWIA-soil percentage with a view to determine the percentage of toxic elements present. Solidification/stabilization (S/S) was carried out using ordinary Portland cement (OPC) as binder. The degree of effectiveness of S/S product was established by the strength and leaching tests. The experimental result showed a marked decrease in the toxicity with an increase in the strength of S/S product.

The aim of this study is to investigate the effect of incinerator ash on the properties of laterite soils for geotechnical engineering applications; as road construction materials. The objective is to evaluate the changes in the compaction characteristics, hydraulic and strength properties with varying step concentration of incinerator ash.

## **2.0 Materials and Methods**

### **2.1 Materials**

**Laterite Soil:** Lateritic soil was collected from a borrow pit in Girei local government area of Adamawa state on longitude 9°35' 23'E and latitude 11°12'50" N. The soil sample was collected using the disturbed sampling method at a depth of between 600mm and 900mm.

**Incinerator Ash:** Solid waste materials were generated from Modibbo Adama University of Technology (MAUTECH) Yola, in large quantity, and were spread for air drying under the sun. The solid waste were mostly made up of papers, wood, polythene, plastics, leaves were sorted out after drying and packaged in bags. The facility for burning the waste was a hole of about 1.5m deep and plastered with cement mortar constructed for use by environmental design department of the University for that purpose. Fire was set in the hole and the solid waste was burnt, the combustion temperature of the solid waste material was estimated using the colour of the burning flame about 700°C. Oxide composition test on incinerator ash was conducted in Ashaka Cement Factory in Gombe State.

**Water:** Portable tap water obtained from borehole within MAUTECH was used for mixing the soil sample and the incinerator ash.

### **2.2 Methods**

**Index Properties:** Laboratory tests were conducted to determine the index properties of the natural soil and incinerator ash mixtures in accordance with [11 and 12] respectively. Soil samples were mixed with 0, 2, 4, 6, 8, 10 and 12% IA of dry weight of soil.

**Compaction:** Compaction tests were carried out for the natural soil and the modified soils (with different percentages of incinerator ash); all according to [11] Part 4, using the British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) compaction energies. The soil weighed was crumbled and passed through a 4.76 mm sieve aperture on a metallic tray. Using varying percentages of water content at an increment of 2% equivalent for every level of compaction.

**California Bearing Ratio:** The California Bearing Ratio (CBR) test was conducted in accordance with [11] Part 4 for the natural and modified soils. The CBR was expressed by

the force exerted by the plunger and the depth of its penetration into the specimen; it was aimed at determining the relationship between force and penetration. 5 kg by weight of the soil samples were mixed at their respective optimum moisture contents in 2360 cm<sup>3</sup> mould, considering the three compactive efforts. For BSL, the compaction was in three layers each receiving 62 blows from the 2.5 kg rammer; for the WAS, the samples were compacted in five layers with 30 blows from the 4.5 kg rammer and for the BSH, the sample received 62 blows in 5 layers from the 4.5 kg rammer. The CBR value (in percentage) was calculated using equation 1;

$$CBR = \frac{\text{Measured Load}}{\text{Standard Load}} \times 100 \quad (1)$$

Where, standard load = 13.6 kN for 2.5mm penetration and 20 kN for 5.0mm penetration

**Hydraulic Conductivity (k):** Hydraulic conductivity or permeability is a measure indicating the rate at which the soil or rock allows fluids to pass through it. It is often represented by the permeability coefficient value, k defined by Darcy's equation as shown in equation 2.

$$v = ki \quad (2)$$

Where v= apparent fluid velocity through the medium also called the hydraulic gradient.

k = is the coefficient of permeability (hydraulic conductivity) often expressed in m/s.

The permeability coefficient was determined in the laboratory using falling head permeability test. The coefficient of permeability (k) in m/s was calculated using equation 3.

$$k = \frac{2.303al}{100At} \log \left( \frac{h_1}{h_2} \right) \quad (3)$$

Where A = cross sectional area of the compacted sample, a = cross sectional area of tube, L = length of pipe, t = time taken, h<sub>1</sub> = initial level in tube and h<sub>2</sub> = final level in tube.

### 3.0 Results and Discussion

**Index Properties:** Results of the tests carried out on the natural soil are summarized in Table.1. The soil was classified as A – 2 – 4(0) subgroup of the [13] classification system. The soil has liquid limit, plastic limit and plasticity index values of 24, 19.6 and 4.4 %, were respectively obtained. The oxide composition of the incinerator ash is shown in Table 2.

Table 1 Properties of the Natural Soil

Property	Quantity
Natural moisture content	10.15%
Liquid Limit	24.00%
Plastic Limit	19.60%
Plasticity Index	4.40 %
Colour	Light reddish brown
MDD for BSL	1.78 Mg/m <sup>3</sup>
MDD for WAS	1.82 Mg/m <sup>3</sup>
MDD for BSH	1.89 Mg/m <sup>3</sup>
OMC for BSL	11.8 %
OMC for WAS	11.5 %
OMC for BSH	10.0 %
Coefficient of permeability for BSL	8.79x10 <sup>-10</sup> m/s
Coefficient of permeability for WAS	8.094x10 <sup>-10</sup> m/s
Coefficient of permeability for BSH	7.40x10 <sup>-10</sup> m/s
California Bearing Ratio for BSL	22 %
California Bearing Ratio for WAS	27 %
California Bearing Ratio for BSH	43 %

Table 2 Result for Oxide Composition Test of Incinerator Ash

Oxide	Composition by weight (%)
SiO <sub>2</sub>	50.923
Al <sub>2</sub> O <sub>2</sub>	7.583
Fe <sub>2</sub> O <sub>3</sub>	2.051
Total SiO <sub>2</sub> + Al <sub>2</sub> O <sub>2</sub> + Fe <sub>2</sub> O <sub>3</sub>	60.557
CaO	24.207
MgO	4.910
SO <sub>3</sub>	1.632
K <sub>2</sub> O	3.042
Na <sub>2</sub> O	0.366
P <sub>2</sub> O <sub>5</sub>	0.677
Mn <sub>2</sub> O <sub>3</sub>	0.143
TiO <sub>2</sub>	1.136
Cl	0.216
Cr <sub>2</sub> O <sub>3</sub>	0.015
SrO	0.059
Colour	Dark ash

### 3.1 Compaction Characteristics

**Maximum dry density:** The variation of maximum dry density (MDD) with incinerator ash content is shown in Fig 1. The result shows that the maximum dry density generally decreased with increasing incinerator ash content. The MDD decreased by 7, 5 and 6% for BSL, WAS and BSH energy levels respectively, when treated with up to 12% incinerator ash content. The decrease in MDD could be attributed to the low value specific gravity for the

additives replacing the soil particles.[14]Worked on cement modification of black cotton soil using iron ore tailing as admixture reported that the specific gravity of the additives influenced the maximum dry density of the treated soil. Similar behaviour was observed by [15; 16], as well as [17].

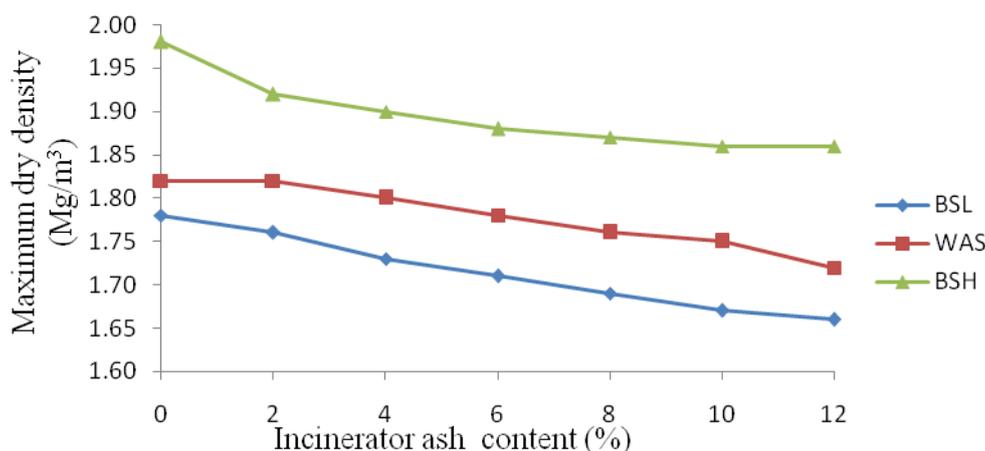


Fig. 1: Variation of maximum dry density of laterite soil with incinerator ash content

The two – way analysis of variance (ANOVA) test on the maximum dry density result is given in Table 3 shows the effect of incinerator ash with compactive effort using laterite soil. It was revealed that the incinerator ash was statistically significant ( $F_{CAL} = 30.9261 > F_{CRIT} = 2.9961$ ) and the compactive effort which showed that ( $F_{CAL} = 367.6552 > F_{CRIT} = 3.8853$ ) indicating a more pronounced effect than that of the incinerator ash.

Table 3: Two-way analysis of variance results for compaction characteristics of laterite soil-incinerator ash mixtures

Property	Source of Variation	Degree of Freedom	$F_{CAL}$	p-value	$F_{CRIT}$	Remark
Maximum Dry Density	Incinerator ash	6	30.9261	1.26E-06	2.9961	$F_{CAL} > F_{CRIT}$ , SS
	Compactive effort	2	367.6552	1.71E-11	3.8853	$F_{CAL} > F_{CRIT}$ , SS
Optimum Moisture Content	Incinerator ash	6	10.7727	0.00031	2.9961	$F_{CAL} > F_{CRIT}$ , SS
	Compactive effort	2	79.4138	1.2E-07	3.8853	$F_{CAL} > F_{CRIT}$ , SS

SS= Significant effect.

**Optimum moisture content:** The variation of optimum moisture content (OMC) with incinerator ash content for BSL, WAS and BSH energy levels are shown in Figs. 2. A general trend of increase in the OMC was observed with increase in incinerator ash content. The OMC generally increased with increase in the incinerator ash content for BSL, WAS and BSH respectively. The OMC decreased with increase in the compactive effort agreed with the finding of [14]. The increase in OMC with an increase in incinerator ash content could be as a result of increasing demand for water by various cations and the clay mineral particles to undergo hydration reaction [18; 19; 20].

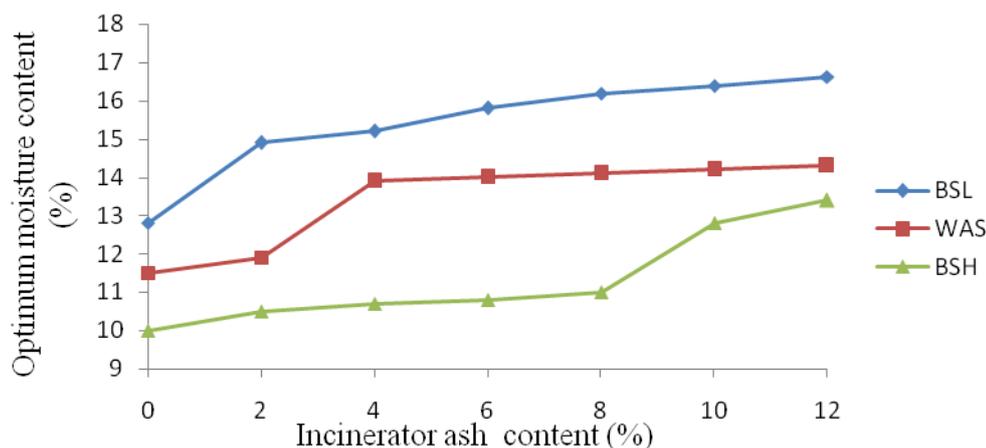


Fig. 2: Variation of optimum moisture content of laterite soil with incinerator ash content

The two – way analysis of variance (ANOVA) test on the optimum moisture content results shown in Table 3, highlight the effects of incinerator ash and compactive effort on lateritic soil with a statistical significance ( $F_{CAL} = 10.7727 > F_{CRIT} = 2.9961$ ) the incinerator ash and ( $F_{CAL} = 79.4138 > F_{CRIT} = 3.8853$ ) for compactive effort, with the compactive effort yielding a more pronounced effect.

### 3.2 Hydraulic Conductivity

The variation of hydraulic conductivity with incinerator ash treatment shown in Fig 3, gave a general trend scenario indicating an increase in the compactive effort. The hydraulic conductivity initially decreased from 0 up to 2% incinerator ash content, and subsequently increased. This initial decrease could be associated with the initial cementing gel of the incinerator ash which plugged the pores in the clay thereby reducing the permeability of the soil [21].

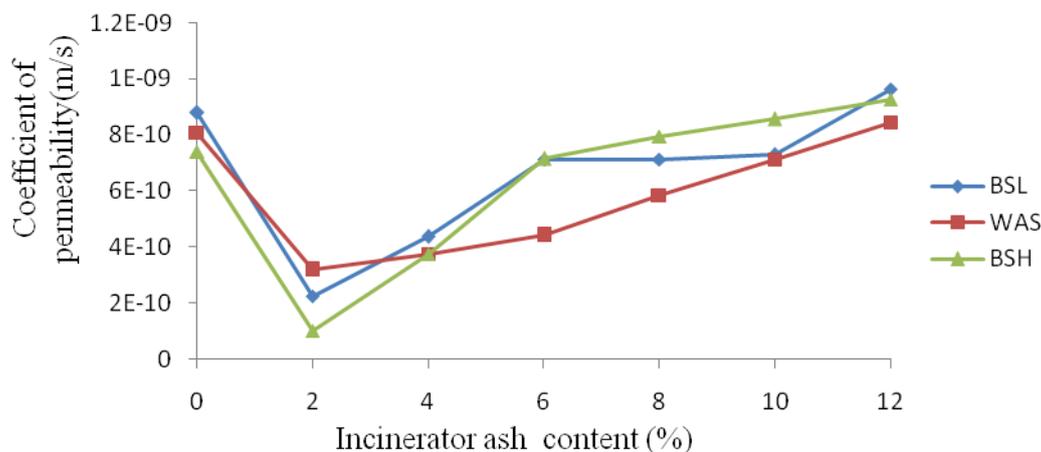


Fig. 3: Variation of coefficient of permeability of laterite soil with incinerator ash content

The two – way analysis of variance (ANOVA) test on the coefficient of permeability result shown in Table 4, highlight the effect of incinerator ash on lateritic soil with a statistical significance ( $F_{CAL} = 21.2170 > F_{CRIT} = 2.9961$ ) for incinerator ash and statistical not significance ( $F_{CAL} = 1.4609 < F_{CRIT} = 3.8853$ ) for compactive effort.

Table 4: Two-way analysis of variance result for Coefficient of Permeability and California Bearing Ratio of laterite soil-incinerator ash mixtures.

Property	Source of Variation	Degree of Freedom	F <sub>CAL</sub>	p-value	F <sub>CRIT</sub>	Remark
Coefficient of Permeability	Incinerator ash	6	21.2170	9.82E-06	2.9961	F <sub>CAL</sub> >F <sub>CRIT</sub> , SS
	Compactive effort	2	1.4609	0.270499	3.8853	F <sub>CAL</sub> <F <sub>CRIT</sub> , NS
California Bearing Ratio	Incinerator ash	6	0.94491	0.499143	2.9961	F <sub>CAL</sub> <F <sub>CRIT</sub> , NS
	Compactive effort	2	190.6778	8.06E-10	3.8853	F <sub>CAL</sub> >F <sub>CRIT</sub> , SS

### 3.3 California Bearing Ratio

The variation of California Bearing Ratio (CBR) with incinerator ash content is shown in Fig 4. These shows erratic trends for CBR, in case of WAS and BSH energy levels with increase in the incinerator ash content. However, the CBR generally increased with higher compactive effort. In the case of BSL energy level, the CBR increased from 22 to 26% at 12% incinerator ash content. This increase in CBR value could be due to the presence of adequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain in treated soils. This is in concordance with an earlier research by [22].

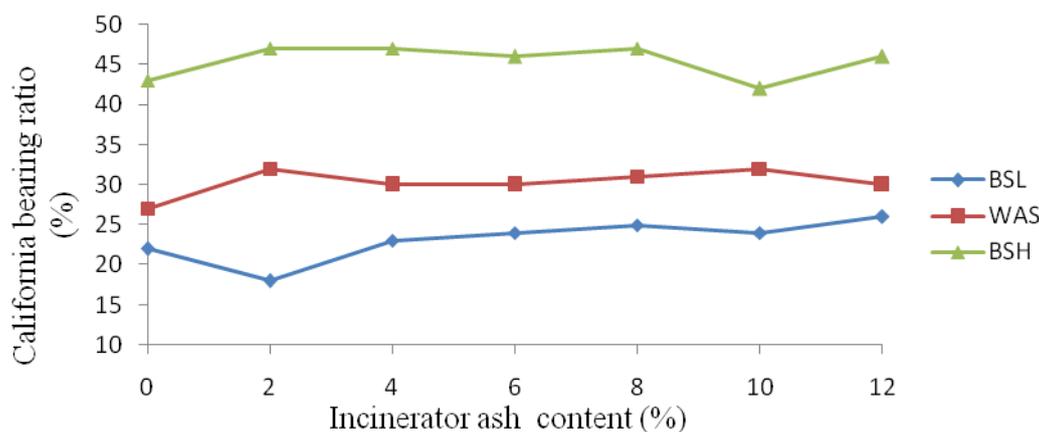


Fig. 4: Variation of California bearing ratio (%) of laterite soil with incinerator ash content

The two – way analysis of variance (ANOVA) test on the California Bearing Ratio test result shown in Table 4, highlight the effect of incinerator ash on lateritic soil with statistical not significance ( $F_{CAL} = 0.94491 < F_{CRIT} = 2.9961$ ) for incinerator ash and statistical significance ( $F_{CAL} = 190.6778 > F_{CRIT} = 3.8853$ ) for compactive effort.

### 3.4 Correlation Analysis

#### 3.4.1 Hydraulic conductivity of laterite soil with incinerator ash

Pearson Correlation analysis was carried out to evaluate the relationship between hydraulic conductivity, k and other associated parameters such as IA, MDD, OMC and CE. This show

varying degrees of relationships, with high and positive correlation values between of hydraulic conductivity,  $k$  and IA content (0.508;  $P < 0.05$ ) as shown in table 5.

Table 5: Correlation matrix (Pearson) for coefficient hydraulic conductivity of laterite soil with incinerator ash content

Variables	K	ASH	MDD	OMC	CE
K	1				
ASH	0.508	1			
MDD	-0.207	-0.442	1		
OMC	0.184	0.511	-0.939	1	
CE	-0.035	0.000	0.876	-0.821	1

$k$  = Hydraulic conductivity,  $ASH$  = Incinerator ash content ,

$MDD$  = Maximum dry density,  $OMC$  = Optimum moisture content,

$CE$  = Compactive effort.

In the case of MDD and CE, high and negative correlations were recorded for MDD (-0.207;  $P > 0.05$ ) and CE (-0.035;  $P > 0.05$ ). In general, there is no significant correlations between hydraulic conductivity  $k$ , MDD and CE. The highest correlation coefficient was observed between hydraulic conductivity and IA content (0.508;  $P < 0.05$ ). In the same vein, the OMC, depicted low correlation (0.184;  $P > 0.05$ ). Detailed results of P-values and coefficient of determination ( $R^2$ ) are shown in Tables 7 and 8 in the appendix. The findings show that IA content greatly influenced the hydraulic conductivity of the treated soil, and must be strictly controlled during field compaction, specifications and control for use as road construction materials. It was observed that addition of IA to laterite soil probably increased the fine content of the soils by the increase the hydraulic conductivity (see fig 3). It implies that AI treated lateritic soil is not suitable for use as road construction material and can only be applied for construction of rural and lightly trafficked roads.

### 3.4.2 California Bearing Ratio of lateritic soil with incinerator ash content

The relationship between California Bearing Ratio and other parameters such as IA, OMC, MDD and CE was established based on correlation analysis. High and positive correlation was observed between CBR and MDD (0.821;  $P < 0.05$ ); and CE (0.957;  $P < 0.05$ ) as shown in table 6. In the case of IA content, low correlations were recorded for IA (0.088;  $P > 0.05$ ). High and negative correlations were recorded for OMC (-0.756;  $P < 0.05$ ). Detailed results of P-values and coefficient of determination ( $R^2$ ) are shown in Tables 9 and 10 in the appendix. Findings showed that only MDD, OMC and CE greatly influenced the California Bearing Ratio of the treated soil and should be strictly controlled during field compaction, and for use as road construction materials. It implies that AI treated lateritic soil is not suitable for use as road construction material and can only be applied for construction of rural and lightly trafficked roads.

Table 6: Correlation matrix (Pearson) for California Bearing Ratio of laterite soil with incinerator ash content

Variables	CBR	ASH	MDD	OMC	CE
CBR	1				
IA	0.088	1			
MDD	0.821	-0.442	1		
OMC	-0.756	0.511	-0.939	1	
CE	0.957	0.000	0.876	-0.821	1

*CBR = California Bearing Ratio*

#### 4.0 Conclusion

The natural soil treated with up to 12% incinerator ash by dry weight of soil improved the geotechnical properties of the soil. Test results showed a decrease in maximum dry density (MDD), with an increase in optimum moisture content (OMC) as well as a decrease in hydraulic conductivity. No general trend was established for CBR values for WAS and BSH compactive efforts. The CBR values generally decreased with BSL energy level. Based on the results obtained, an optimal blend of 2% incinerator ash compacted at BSH energy level optimally improved the geotechnical properties of the modified soil. It implies that AI treated lateritic soil is not suitable for use as road construction material and can only be applied for construction of rural and lightly trafficked roads. Use of more potent additives such as cement and lime admixed with incinerator ash is recommended for improving the geotechnical properties of lateritic soil as well as waste handling.

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**APPENDIX.**

Table 7: p-values for Hydraulic conductivity of laterite soil with incinerator ash content

Variables	k	IA	MDD	OMC	CE
K	0				
IA	0.019	0			
MDD	0.367	0.045	0		
OMC	0.425	0.018	< 0.0001		
CE	0.881	1.000	< 0.0001	< 0.0001	0

Table 8: Coefficient of Determination, R<sup>2</sup> for Hydraulic conductivity of laterite soil with incinerator ash content

Variables	k	IA	MDD	OMC	CE
K	1				
IA	0.259	1			
MDD	0.043	0.195	1		
OMC	0.034	0.261	0.882	1	
CE	0.001	0.000	0.767	0.674	1

Table 9: p-values for California Bearing Ratio of laterite soil with incinerator ash content

Variables	CBR	IA	MDD	OMC	CE
CBR	0				
IA	0.705	0			
MDD	< 0.0001	0.045	0		
OMC	< 0.0001	0.018	< 0.0001	0	
CE	< 0.0001	1.000	< 0.0001	< 0.0001	0

Table 10: Coefficient of Determination, R<sup>2</sup>California Bearing Ratio of laterite soil with incinerator ash content.

Variables	CBR	IA	MDD	OMC	CE
CBR	1				
IA	0.008	1			
MDD	0.674	0.195	1		
OMC	0.572	0.261	0.882	1	
CE	0.916	0.000	0.767	0.674	1