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LABORATORY AND STATISTICAL EVALUATION OF CEMENT AND LIME ON THE PROPERTIES OF TROPICAL BLACK CLAY – IRON ORE TAILINGS MIXTURES

Yohanna, P.[a], Buki, J. M.[b], Ijimdiya, T. S.[b], Eberemu, A. O.[b], Osinubi, K. J.[b]

[a]Department of Civil Engineering University of Jos, Nigeria
[b]Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

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*Corresponding author
paulyohanna45@yahoo.co.uk

Abstract

The need for cheaper and more economical soil improvement methods is of great significance in order to reduce the construction cost of flexible pavements. Also, major problems caused by industrial waste in Nigeria can be minimised by recycling or re-using of such wastes for soil improvement. The application of cement and lime along for such purpose has proven to increase the construction cost. Thus the use of industrial waste such as iron ore tailings (IOT) could aid in reducing the construction cost. Series of laboratory and statistical investigations were performed to compare the effect of cement and lime on the properties of tropical black clay (i.e. black cotton soil, BCS). Soil samples were admixed with up to 10 % IOT content and modified with up to 4 % each of cement and lime by dry weight of soil to evaluate their plasticity and compaction characteristics. Compaction was done with British Standard light (BSL) energy. Statistical tests for regression and correlation was achieved using Mini-tab R15 and Microsoft Excel software correspondingly. Results disclosed decreased in liquid limit and plastic limit. Liquid limit values of 56, 54.8, 54.5, 52.5, 52 and 51% were noted for 0, 2, 4, 6, 8 and 10% IOT content. Similar trend was noted for 1, 2, 3 and 4% lime and cement concentrations. A rise in maximum dry density (MDD) and drop in optimum moisture content (OMC) with greater concentration of IOT for all the lime and cement contents under study was noted. Statistical analysis revealed that soil-lime-IOT mixtures gave higher predicted values than soil-cement-IOT mixture for determining plasticity and compaction characteristics of BCS – IOT mixtures. Thus, 4 % lime – 6 % IOT mixture met the criteria for flexible pavement purpose as proposed by Nigerian General Specifications and is recommended for used as pavement material for roads that are lightly trafficked. While the soil – cement - IOT mixes fell to meet the criteria for used as pavement material.

Keywords: Black cotton soil, Cement, Compaction characteristics, Correlation analysis, Iron ore tailings, Lime, Regression analysis

1.0 INTRODUCTION

Black cotton soils (BCS) are not suitable materials to utilize for highway construction due to their high percentage of plastic clays: high volume changes with permeability as well as low shear strength [1-5]. Most times areas where they are found available are most shot of suitable aggregates or gravels. BCS cover considerably large regions that escaping them is not promising [6]. Alternative improved soils appropriate for construction are most times not easy to get and hence improving such soils are of great commercial significance to industry involved in construction. The geotechnical properties of black cotton soils cannot satisfy the strength and incompressibility requirements for engineering purposes. Therefore, road construction over deficient soils causes a major challenge in road construction. In a demand to make this soil valuable for pavement purposes and satisfy the criteria for foundation engineering intentions, its geotechnical properties need to be improved. The modification of the soils plasticity and compaction properties is familiar to engineers as a key process of enhancing the performance of challenging soils and pave way for marginal soils become better civil engineering materials [7].

Excessive need for conventional soil enhancing additives (cement, lime, bitumen, etc.) has raised construction cost too high for stabilized roads [8]. Researchers worked to obtain cheaper additives for soil improvement which can be used as substitutes for the expensive industrially manufactured soil improving additives. This challenge headed to using agricultural wastes such as bagasse ash [9], locust bean waste ash [10], rice husk ash [11] and industrial waste such as fly ash [12], cement kiln dust[13] and is iron ore tailings [14-16] that have pozzolanic properties.

Mine tailings is an industrial by-product which is produced in huge quantity from mining industries after extraction of minerals from pyretic ores and poses disposal problems and also creates environmental hazard. In recent periods, there is an upsurge in utilization of mine tailings for geotechnical use, so long as they are admixed with some admixtures such as cement and lime since they are low in CaO. The Itakpe iron ore generate a lot of tailings and is a popular mine tailings in Nigeria rich in hematite-rich mineral. The large deposit of the waste led to the need to look for a way of safe disposal of this waste by re-using it in the construction industry. By this approach, the environment is safe from pollution and also minimizes the construction cost.

The study was aimed at comparative influence of cement and Lime mixtures on the plasticity and compaction characteristics of BCS using IOT as admixture. The objective was to check the alterations in the soil plasticity and compaction characteristics when used as road construction materials.

2.0 MATERIALS AND METHODS

2.1 Materials

Soil: Disturbed sample was gotten from Gombe state, Nigeria, with geographical coordinates Longitude 11° 30'E and Latitude 10° 19'N. The soil samples were air-dried and passed through 4.76 mm aperture sieve prior test.

Cement: The ordinary Portland cement (OPC) used was purchase in local market in zaria.

Lime: The Lime used was purchase in local market in zaria.

Iron Ore Tailing: The iron ore tailing (IOT) used was collected from Itakpe National Mining Ore Company in Kogi state.

2.2 Methods

Index Properties: Laboratory tests were carried out on the natural soil and treated soil in accord with [17] and [18], correspondingly. Soil samples were mixed with 0, 1, 2, 3 and 4 % cement and lime, respectively, as well as 0, 2, 4, 6, 8 and 10 % IOT by dry weight of soil.

Compaction: Compaction was done for both natural and treated soil based on [17] and [18] with BSL energy. Test comprises a 2.5 kg rammer falling 300 mm in three layers in a British Standard mould, each getting twenty seven (27) blows. Test was done for the varying additives mixtures.

Statistical Analysis: Laboratory tests on plasticity and compaction characteristics and the factors associated with plasticity and compaction characteristics were obtained from laboratory tests. Factors measured include; Maximum dry density of lime-IOT treated soil (MDDL), Maximum dry density of cement-IOT treated soil (MDDC), Optimum moisture content of lime-IOT treated soil (OMCL) and Optimum moisture content of cement-IOT treated soil (OMCC) as dependent factors and Gravel content(Gr),Sand content(Sa),Percentage of fine(PF i.e proportion of silt and clay),Plasticity index(PI), Specific gravity(Gs), Lime content(Li), Cement content(Ce) and Iron ore tailings content(IOT) as independent factors. A regression model, for predicting MDDL, MDDC, OMCL and OMCC was developed. The statistical studies were done using Mini-tab R15 software. Pearson correlation coefficients was carried out using Microsoft Excel 2007.The Means, standard deviation and coefficient of variation for compaction characteristics and measured parameters are shown in Table 1.

Table 1 Comparative descriptive Statistics for Compaction Characteristics of Lime and Cement Treated BCS with IOT as Admixture.

Variable	Mean	SD	CV	Variable	Mean	SD	CV
MDDL	1.607	0.030	1.848	MDDC	1.607	0.038	2.383
OMCL	22.420	0.920	4.103	OMCC	20.693	1.487	7.186
Gr	1.047	0.929	88.730	Gr	1.377	0.847	61.511
Sa	21.291	4.038	18.966	Sa	24.510	6.290	25.663
PF	77.662	4.065	5.234	PF	74.110	6.720	9.068
PI	27.953	1.176	4.207	PI	35.067	2.224	6.342
Gs	2.519	0.044	1.735	Gs	2.549	0.035	1.365
Li	2.000	1.438	71.900	Ce	2.000	1.438	71.900
IOT	5.000	3.474	69.480	IOT	5.000	3.474	69.480

3.0 RESULTS AND DISCUSSION

3.1 Index Properties

Tests performed on the soil showed that it is fine-grained with greyish-black colour and moisture content of 19.5%. The soil is grouped as A-7-6(24) using [19] and CH using [20].The summarized properties are given in Table 2. The oxide composition is given in Table 3. The particle size curve is displayed in Figure 1

Table 2: Natural Soil Properties

Property	Quantity
Natural moisture content, %	19.5
Percentage passing BS No. 200 sieve	82.0
Liquid Limit, %	56.0
Plastic Limit, %	27.0
Plasticity Index, %	29.0
Linear Shrinkage, %	18.4
AASHTO Classification	A-7-6(24)
USCS Classification	CH
Swelling Potential	Medium
Specific Gravity	2.47
MDD, Mg/m^3	1.58
OMC, %	23.0
Colour	Greyish - black

Table 3: Oxide compositions of OPC, Lime and IOT

Oxide	Composition by weight (%)		
	*OPC	**Lime	***IOT
Lime (CaO)	63.0	63.00	0.607
Silica (SiO_2)	20.0	1.59	45.640
Alumina (Al_2O_3)	6.0	0.50	3.360
Alkali (Na_2O)	1.0	Trace	0.405
Alkali (K_2O)	-	Trace	0.607
Sulphur oxide (SO_3)	2.0	-	-
Titanium oxide(TiO_2)	-	-	0.240
Manganese Oxide(MnO)	-	-	0.067
Iron Oxide (Fe_2O_3)	3.0	3.00	47.700
MgO	-	-	0.393
Loss on Ignition	2.0	26.87	3.000

*[21], ** [22], *** [23]

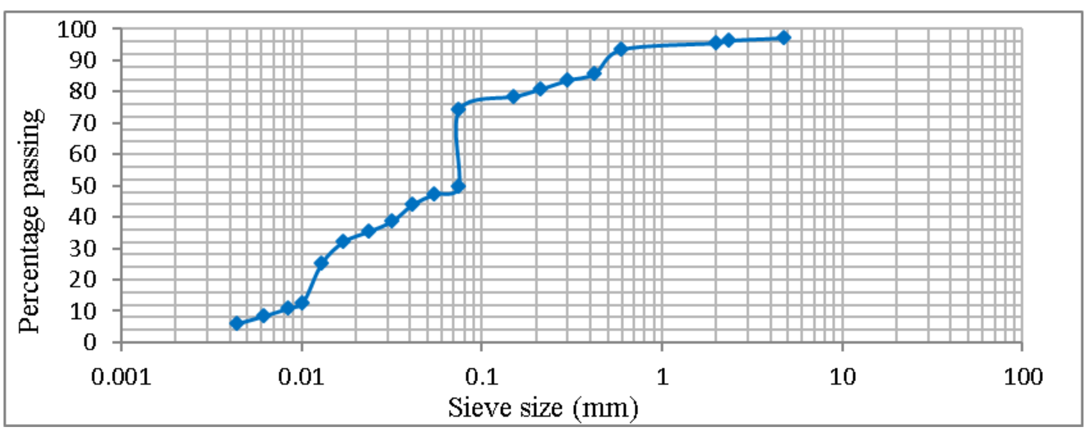

Figure 1 Particle size curve of natural soil

3.2 Effect of Cement and Lime – IOT Blend on the Plasticity Characteristics of BCS

3.2.1 Liquid Limit

The variations of liquid limits (LL) of the soil - lime and soil – cement mixes with IOT content are displayed in Figure 2a and 2b, separately. The LL for the natural soil decreased steadily with rise in IOT content. LL of the natural soil lessened with higher lime, cement and IOT contents (see Figure 2a and 2b). LL values of 56, 54.8, 54.5, 52.5, 52 and 51% were noted for 0, 2, 4, 6, 8 and 10% IOT content. Similar trend was noted for 1, 2, 3 and 4% lime and cement concentrations. However, lower results were recorded with lime treatment than cement treatment which indicates that lime is more potent than cement because lime creates a fast and extensive chemical reaction with soil elements than cement [24]. The drop in LL with higher contents of the additives could be linked to the decline of free silt and clay fractions in the soil due to flocculation and agglomeration of the clay particle as a result of ion exchange at the soil surface of the clay particle as the available Ca^{2+} in the admixtures reacted with the metallic ion in the clay structure [6, 25-26].

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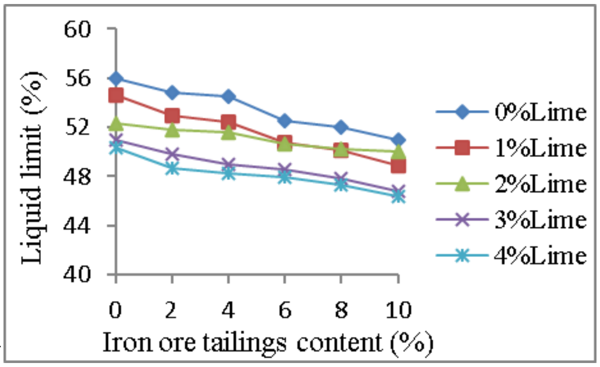

Figure. 2a Graph of liquid limit of BCS-lime mixes with IOT content

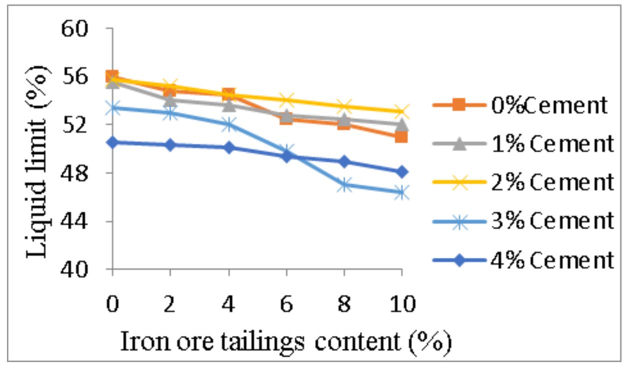

Figure. 2b Graph of liquid limit of BCS – cement mixes with IOT content

3.2.2 Plastic Limit

The variations of plastic limit of soil - lime mixes and soil – cement mixes with IOT content are displayed in Figure 3a and 3b, respectively. Generally, for lime and cement treatments, the plastic limit drop with rise in IOT content. Plastic limit values of 26.4, 24.7, 24, 22, 21.4 and 20% were noted for 1% lime and 0, 2, 4, 6, 8 and 10% IOT content. Also values of 22.2, 20.5, 20, 18.18, 17.14 and 16% were noted for 1% cement and 0, 2, 4, 6, 8 and 10% IOT content. Same trend was noted for higher concentrations of lime and cement. The decreases in plastic limit recorded may perhaps be linked to cation exchange reaction that released adsorbed water particles in the soil that led to flocculation and aggregation. Similar trends were reported by [6, 15, 27].

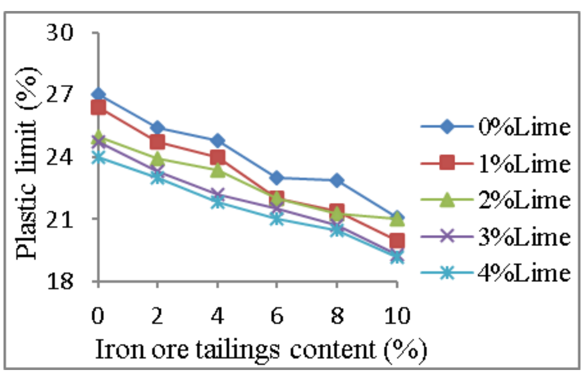

Figure 3a Graph of plastic limit of BCS -lime mixes with IOT content

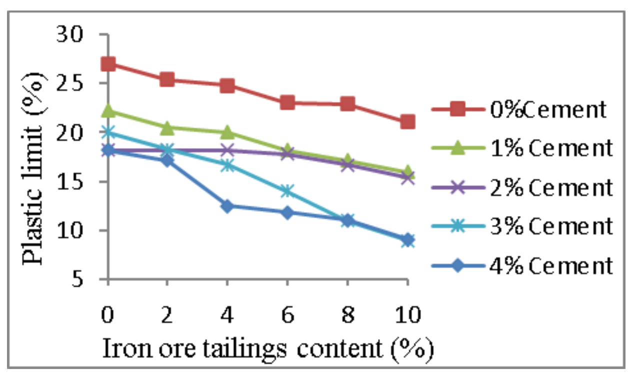

Figure 3b Graph of plastic limit of BCS –cement mixes with IOT content

3.2.3 Plasticity Index

The variations of plasticity index of soil - lime and soil – cement mixes with IOT content are displayed in Figure 4a and 4b individually. Plasticity index of the mixtures generally increased with increase in IOT content. Plasticity index values of 28.2, 28.3, 28.4, 28.8, 28.7 and 28.9% were noted for 1% lime and 0, 2, 4, 6, 8 and 10% IOT content. Also values of 33.28, 33.50, 33.60, 34.62, 35.36 and 36% were noted for 1% cement and 0, 2, 4, 6, 8 and 10% IOT content. Same trend was noted for higher concentrations of lime and cement content. Higher plasticity index values were recorded for soil – cement – IOT mixtures when compared to soil – lime – IOT mixtures because not much silt particles might have precipitated during flocculation and agglomeration, while the lower values recorded for soil – lime – IOT mixtures had extensive chemical reactions in accord with the outcomes described by [24, 28-29].

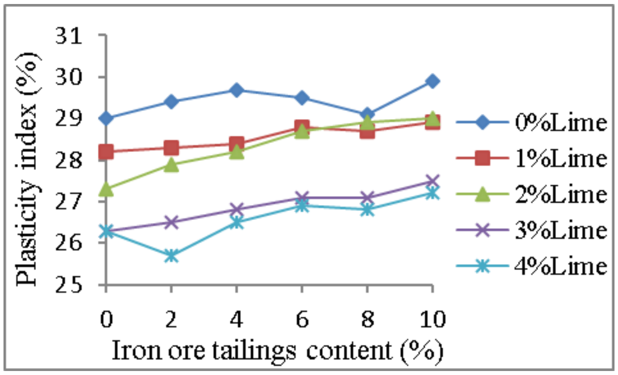

Figure 4a Graph of plasticity limit of BCS -lime mixes with IOT content

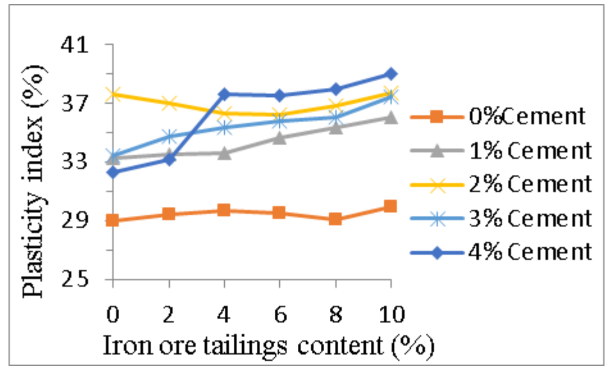

Figure 4b Graph of plasticity limit of BCS -cement mixes with IOT content

3.3 Effect of Cement and Lime – IOT Blend on the Compaction Characteristics of BCS

3.3.1 Maximum Dry Density

The variations of MDD of BCS – lime and BCS – cement mixes with IOT content are displayed in Figure 5a and 5b, respectively. The general increase in MDD values of soil treated with lime and cement increased with higher IOT content may perhaps be linked to IOT with greater specific gravity (3.29) filling the voids inside the soil medium and also, the flocculation and accumulation of the clay particles due to ion exchange [15,26,30-32]. MDD values of 1.57, 1.59, 1.62, 1.63, 1.64 and 1.64Mg/m^3 were noted for 1% lime and 0, 2, 4, 6, 8 and 10% IOT content. Also values of 1.58, 1.59, 1.62, 1.64, 1.64 and 1.64 Mg/m^3 were noted for 1% cement and 0, 2, 4, 6, 8 and 10% IOT content. Same trend was noted for higher concentrations of lime and cement content. The higher MDD values recorded for soil – cement mixes compared to soil – lime mixes is linked to the fact that cement is more denser than lime when compared, hence cement having higher weight and specific gravity than lime, Hence the higher MDD values. Similar trend of increase in MDD values was recorded by [33].

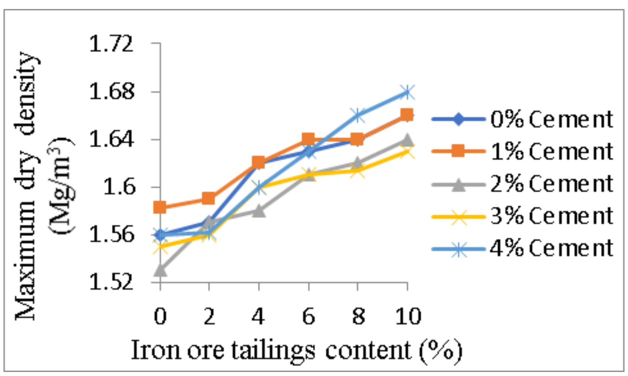

Figure 5a Graph of MDD of BCS -lime mixes with IOT content

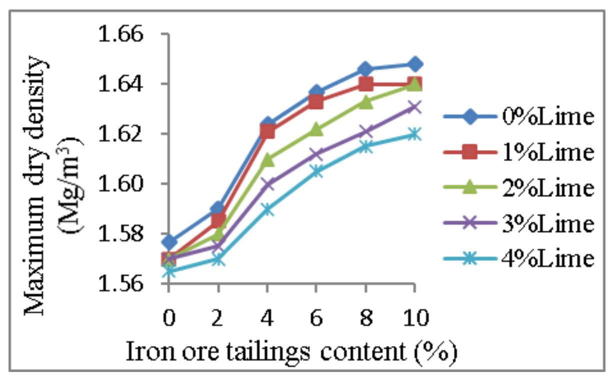

Figure 5b Graph of MDD of BCS -cement mixes with IOT content

3.3.2 Optimum Moisture Content

The variations of OMC of BCS – lime and soil – cement mixes with IOT content are displayed in Figure 6a and 6b, separately. Generally, OMC of the two mixes considered decreased with rise in IOT content. OMC values of 23.8, 23, 22.5, 22.2, 22 and 21.4% were noted for 2% lime and 0, 2, 4, 6, 8 and 10% IOT content. Also values of 22.6, 22.4, 22.2, 22, 20.8 and 19% were noted for 2% cement and 0, 2, 4, 6, 8 and 10% IOT content. Same trend was noted for other concentrations of lime and cement content. Similar trend of decrease in OMC values was recorded by [33].The introduction of IOT into the mixtures could have supplied calcium cations that cause low and incomplete hydration reaction thus reducing the OMC. However, the values increased with greater lime content that may possibly be attributed to the rise in the volume of water necessary for pozzolanic reaction to occur. On the other hand, the reduction in OMC values observed for 3 and 4% cement contents was probably linked to dehydration induced by the addition of IOT into the soil voids that were initially filled with moisture and air within the soil mass. In this case, no water migration to or from soil-IOT-cement matrix is allowed, the available water was consumed by the hydration reaction, till too little was left to saturate the solid faces and thus a decline in soil relative humidity [15, 26, 34-35]. The implication of moisture control during field compaction is a very important factor that has to be put into consideration. The number of passes of the compaction machine and the desire field density that need to be attained relative to the laboratory measured value can only be achieve via proper moisture control in the field. This in addition to achieving the Nigerian General Specifications criteria [36].

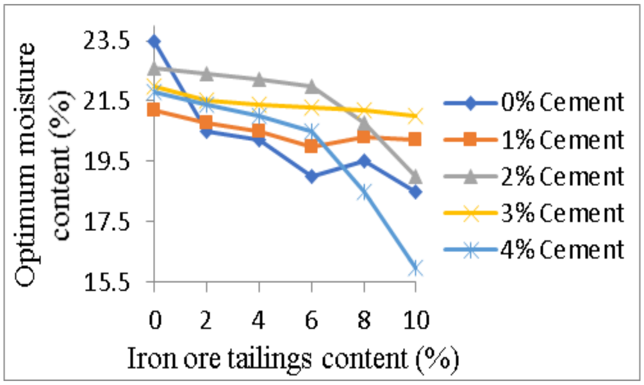

Figure 6a Graph of OMC of BCS -lime mixes with IOT content

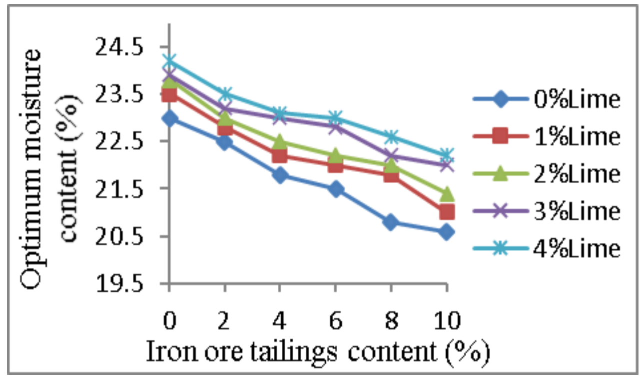

Figure 6b Graph of OMC of BCS -cement mixes with IOT content

3.4 Comparative Statistical Analysis for Compaction Characteristics of Lime and Cement Treated BCS with IOT as Admixture.

3.4.1 Regression Analysis

The application of regression and correlation techniques for engineering analysis has been reported by researchers [37-38]. Results of multiple regression analysis for MDDL and MDDC are contained in equation 1 and 2 respectively. The MDD for both lime and cement treated soil were subjective to the soil grading properties, specific gravity and the amount of admixture added to the soil during experiment. The geotechnical factors measured for these analysis consist of the percentages of gravels, sand, plasticity index, lime/cement content, percentage fine,(proportion of silt and clay) in conjunction with their corresponding specific gravities. The coefficient of each factor in the regression equations shows the degree of affiliation between the MDD (dependent factor) and the soil geotechnical properties (independent variables) for all the treatments considered. Generally, sand content, percentage fine (proportion of silt and clay), specific gravity and IOT content has the point peak effect on the MDDs with a positive coefficient with others having negative coefficient for both MDDL and MDDC. However it was noticed that cement treated soil has higher coefficients for sand content and IOT over lime treated soil this can be linked to higher specific gravity of cement over lime filling the empty spaces inside the soil skeleton.

The correlation coefficient values (R^2) displays a strong affiliation between MDDL, MDDC and the geotechnical factors considered with R^2 values of 95.4 % and 85.2 % for MDDL and MDDC respectively. Generally, the correlation coefficient values shows that the factors are more correlated to the MDDL than MDDC. This implies that field compaction specification and control can easily and more reliable be monitored for BCS treated with lime and IOT than cement-IOT treated soil. The regression equations are

$$MDDL = 0.216 - 0.00081Gr + 0.000330Sa + 0.00PF - 0.0029PI + 0.582Gs - 0.00275Li + 0.00087IOT \quad (1)$$

$$R^2 = 95.4\%$$

$$MDDC = 0.529 - 0.00417Gr + 0.00143Sa + 0.00PF + 0.00128PI + 0.391Gs - 0.0119Ce + 0.00633IOT \quad (2)$$

$$R^2 = 85.2\%.$$

Where;

MDDL=Maximum dry density of lime-IOT treated soil (Mg/m^3), MDDC=Maximum dry density of cement-IOT treated soil (Mg/m^3), Gr= Gravel content(%), Sa=Sand content(%), PF=Percentage of fine(proportion of silt and clay),PI=Plasticity index(%), Gs=Specific gravity, Li=Lime content(%), Ce=Cement content(%), IOT=Iron ore tailings content(%).

In the case of OMCL and OMCC, geotechnical factors measured for these analysis comprise the percentages of gravels, sand, plasticity index, lime/cement content, percentage fine,(proportion of silt and clay) together with their corresponding specific gravities. Results showed that sand content and lime content had more impact on OMCL with positive coefficient. However, for OMCC is significantly related to sand content and cement content with positive coefficient. The percentages of fine (proportion of silt and clay) have no impact on the OMCs of both treated soils.

The correlation coefficient values (R^2) displays a strong affiliation between OMCL, OMCC and the geotechnical factors considered with R^2 values of 93.8 % and 52.8 % for OMCL and OMCC correspondingly. Generally, the correlation coefficient values shows that the factors are highly correlated to the OMCL than OMCC. This implies that field compaction specification and control can easily be monitored for BCS treated with lime-IOT than cement-IOT treated soil. In view of these reasons, a good approach of moisture control can easily be monitored using those variables during field compaction of soil-lime-IOT treated soil. The regression equations are;

$$OMCL = 31.4 - 0.136Gr + 0.0125Sa + 0.00PF - 0.017PI - 3.28Gs + 0.24Li - 0.172IOT \quad (3)$$

$$R^2 = 93.8\%.$$

$$OMCC = 73.0 - 0.025Gr - 0.104Sa + 0.00PF - 0.09PI - 18.5Gs + 0.642Ce - 0.125IOT \quad (4)$$

$$R^2 = 52.8\%.$$

Where;

OMCL=Optimum moisture content of lime-IOT treated soil (%), OMCC=Optimum moisture content of cement-IOT treated soil (%).

3.4.2 Correlation Analysis

The coefficient of correlations between MDDs and geotechnical factors of lime and cement treated BCS with IOT are presented in table 4. Results showed that for MDD of lime-IOT treated soil, positive and highly significant correlations were obtained for gravel content, sand content, plasticity index, specific gravity and IOT indicating strong association between the factors and the MDDL. When compared with MDD of cement-IOT treated soil, sand content, plasticity index, specific gravity and the IOT content showed strong affiliation between the factors and the MDDC.

Table 4 Pearson's Coefficients of Correlation for MDD and Geotechnical Properties of Lime and Cement Treated BCS with IOT.

	MDDC	Gr	Sa	PF	PI	Gs	Li	IOT
MDDL	-	0.294	0.111	-0.177	0.619	0.979	-0.382	0.877
Gr	-0.280	-	-0.086	-0.143	0.012	0.314	0.035	0.410
Sa	0.079	0.458	-	-0.974	-0.293	0.049	0.222	0.104
PF	-0.039	-0.554	-0.994	-	0.288	-0.121	-0.229	-0.197
PI	0.365	-0.122	0.200	-0.172	-	0.651	-0.905	0.311
Gs	0.704	-0.010	0.449	-0.419	0.555	-	-0.395	0.891
Ce	-0.090	0.297	0.650	-0.646	0.580	0.530	-	0.000
IOT	0.908	-0.261	0.004	0.029	0.513	0.764	0.000	-

Lower diagonal: MDDL=Maximum dry density of lime-IOT treated soil (Mg/m^3), Upper diagonal: MDDC=Maximum dry density of cement-IOT treated soil (Mg/m^3), Gr= Gravel content(%), Sa=Sand content(%), PF=Percentage of fine(proportion of silt and clay),PI=Plasticity index(%), Gs=Specific gravity, Li=Lime content(%), Ce=Cement content(%), IOT=Iron ore tailings content(%).

Coefficient of correlations between OMC and the geotechnical factors of lime and cement treated BCS with IOT, (see Table 5). Results show that for OMCL, positive and highly significant correlations were obtained for sand content, percentage fine and lime content indicated by strong association between the factors and OMCL. In the case of OMCC, gravel content, percentage fine and cement content showed strong association between the factors and OMCC.

Table 5 Pearson's Coefficients of Correlation for OMC and Geotechnical Properties of Lime and Cement Treated BCS with IOT

	OMCC	Gr	Sa	PF	PI	Gs	Li	IOT
OMCL	-	-0.444	0.081	0.021	-0.682	-0.938	0.464	-0.846
Gr	0.066	-	-0.086	-0.143	0.012	0.314	0.035	0.410
Sa	-0.266	0.458	-	-0.974	-0.293	0.049	0.222	0.104
PF	0.241	-0.554	-0.994	-	0.288	-0.121	-0.229	-0.197
PI	-0.252	-0.122	0.200	-0.172	-	0.651	-0.905	0.311
Gs	-0.600	-0.010	0.449	-0.419	0.555	-	-0.395	0.891
Ce	0.023	0.297	0.650	-0.646	0.580	0.530	-	0.000
IOT	-0.690	-0.261	0.004	0.029	0.513	0.764	0.000	-

Lower diagonal: OMCL; Upper diagonal: OMCC

3.0 CONCLUSION

The BCS is fine-grained fits into the CH group in the USCS and A-7-6(24) soil group in the AASHTO grouping method for soils. The plasticity of the BCS treated with lime and cement improved with higher IOT content. Generally, MDD increased while OMC declined with rise in IOT content. However, with increase in lime content, MDD drop while the OMC increased. On the other hand, for increased cement treatment, MDD values increased while OMC decreased with higher IOT content. Results of statistical analysis show that soil-lime-IOT mixture gave higher prediction values than soil-cement-IOT mixture for determining plasticity and compaction characteristics of tropical black clay – IOT Mixtures. This implies that field compaction specification and control can easily be monitored for BCS treated lime-IOT than cement-IOT treated soil. Thus, a good measure of moisture control can easily be monitored using those variables during field compaction of soil-lime-IOT treated soil. Based on the Nigerian General Specifications requirements, the 4% cement / 6 % IOT optimally improved soil did not fulfill the criteria of not greater than 35 % passing sieve No. 200 and 30 % as peak plasticity index value for use as materials for sub-grade. But, an optimal blend of 4% lime/6 % IOT improved the properties of BCS and met the said criteria. The paybacks of the application include the re-use of a mining waste in road construction and the economy of the proposed technique on the construction cost.

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