Journal of Civil Engineering, Science and Technology
Volume 14, Issue 2, September 2023, 117 – 128

COMPACTION CHARACTERISTICS AND WORKABILITY OF THE LATERITIC SOIL-IRON ORE TAILINGS IN PAVEMENT CONSTRUCTION

K. Ishola[1*], K.A. Adeyemo[1], M.A. Kareem[1], O.A. Olawuyi[1], G.L. Yisa[2], T.S. Ijimdiya[3]
[1]Department of Civil Engineering, Osun State University, Osogbo, Osun State, Nigeria
[2]Nigerian Building and Road Research Institute, Abuja, Nigeria
[3]Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria

Date received: 17/01/2023 Date accepted: 27/03/2023
*Corresponding author's email: isholakzm@gmail.com
DOI: 10.33736/jcest.5337.2023

Abstract — The mining waste deposit such as iron ore tailings (IOT) in Nigeria is a menace to the environment by constituting a nuisance to the mining industry, and its effect on lateritic soil as a compaction and plasticity reduction material for road pavement is considered in this study. The used natural lateritic soil was classified as A-7-6(11) or CL by the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) respectively. Up to 16% of the soil's dry weight was modified with iron ore tailings (IOT). Studying the effects of IOT on the altered soil focused on its cation exchange capacity, plasticity, compaction properties and California bearing ratio (CBR). British Standard Light (BSL) energy was used for the compaction process. However, the results of regression analysis showed that the optimum moisture content had a substantial impact on the soil CBR values. The results of the tests show that as the IOT content increased, plasticity and compaction characteristic values increased. Although an optimal 10% IOT treatment of lateritic soil significantly improved its strength properties, the plasticity characteristics recorded exceeded the requirement specified by the Nigerian General Specifications for direct use as a subbase or base material. Thus, reusing 10% iron ore tailings as filling materials required additional percentages of other pozzolanic materials to lessen the environmental problems associated with their deposition.

Keywords**:** Mining waste, compaction, iron ore tailing, lateritic soil, plasticity

1.0 INTRODUCTION

In the tropical regions of the world, particularly in Nigeria and other African nations, lateritic soils are mostly used in the structural layers of road pavement that carry light to moderate traffic for sub-base and base courses [1, 2]. The majority of tropical laterites are composed of kaolinite clay minerals, which also contain some quartz. In this case, lateritic soil that possesses swelling clay mineral type fall in the category of problem laterite due to its reputation of being problematic in road construction This soil needs to be treated with common additives like cement and lime in order to meet the requirements of the foundation engineering design. However, the cost of procuring these conventional materials that will make the lateritic soil meet the specification requirement is increasingly becoming uneconomical.

Interestingly, soil improvement is a standard practice to investigate the effects of locally available materials that are thought of as wastes or leftovers but do not necessarily imply useless resources because they might be commercially feasible for use in construction. Due to the requirement to reduce waste disposal costs and the expense of producing stabilising agents, there is a global push to use wastes for engineering purposes [3]. Numerous studies on the utilisation of agricultural and industrial wastes have been published in the literature in an effort to lower the price of obtaining common stabilising agents. Among the waste products are fly ashes [4], coal bottom ash [5], quarry dust [6], blast furnace slag [7], phosphatic waste [8], bagasse ash [9–12], rice husk ash [13], ash from locust bean [14] and kiln dust from cement [15].

As the economy improves, more minerals are in demand and mining becomes larger while the output of the tailings continues to increase. These resulted in the production of more than 500 million tonnes of tailing discharged per year across the nation [16]. However, with these quantities tailing ponds are formed and resulted to leaching of residual chemicals into the environment causing pollution. The management of tailings emphasizes not only pollution control, but also the conservation of resources [17]. A total of 182.5 million metric tonnes are thought to be contained in the Itakpe iron ore deposit in Nigeria, which primarily comprises of quartz with magnetite and hematite [18]. In the same study, [18] also reported the tailings deposit from Itakpe typically contains 36% iron ore. For use as sinter in the Ajaokuta blast furnace in Kogi State, it processed an annual rate of 8 million tonnes, yielding a concentrate of 64% Fe content. Large amounts of tailings, a byproduct of beneficiating iron ore, are produced at this production rate [19].The need for this study stems from the fact that the majority of lateritic soils are not suitable for use as subbase material in pavement construction, necessitating the investigation. However, this study examined the engineering aspects of lateritic soil and iron ore tailings combinations by evaluating their plasticity and strength characteristics for use as construction materials.

2.0 MATERIALS AND METHODS

The materials used in this study include lateritic soils and iron ore tailing as explained in the subheading below:

2.1 Materials

2.1.1 Lateritic soil

The borrow pit in the Shika was used to obtain the soil sample for this study, neighbourhood of Zaria, Nigeria, at a depth of 1.5 to 2.0 metres. This corresponds to the B-horizon, which is typically characterised by the buildup of material that has been leached from the A-horizon above it. Latitude 11° 4' N and Longitude 7° 36' E are the coordinates of its location [20].

2.1.2 Iron ore tailings

The Kogi State-based Iron Ore Mining Company, Itakpe, which is situated in Nigeria's north-central region, provided the IOT used in this investigation. It provides service to the Ajaokuta and Aladja steel mills and produces ore for export. The IOT was properly combined with lateritic soil after being separated with a No. 200 sieve. Iron ore tailing concentrations of 0, 2, 4, 6, 8, 10, 12, and 16% were applied to soil samples based on their dry weight. The oxide composition of IOT was ascertained through analysis utilising X-ray fluorescence (XRF).

2.2 Methods

2.2.1 Index properties

The sample was tested in the laboratory in accordance with [21] for lateritic soil in its natural state and [22] and [23] for lateritic soil that had undergone IOT treatment. Sieve analysis, cation exchange capacity (CEC), Compaction and Atterberg limits are experiments done on soil-IOT mixes. The compaction procedure made use of British Standard Light, which is the same as standard Proctor energy. Statistics were used to analyse the test findings.

2.2.2 Plasticity characteristics

The following parameters are linked to soil plasticity: [24]

Plasticity Modulus (PM): The ratio of the soil fraction passing the BS No 40 sieve (i.e., % 425 m) to the plasticity index is known as the plasticity modulus.

$$PM = PI * (\% < 425\ \mu m) \tag{1}$$

The plasticity index and the proportion of particles that pass through the No. 200 sieve (75 m aperture) are combined to produce the plasticity product (PP), which is calculated as followed:

$$PP = PI *(\% < 75\ \mu m) \tag{2}$$

The ratio of linear shrinkage to the proportion of materials passing through the BS No. 40 sieve (% 425 m), is known as the shrinkage modulus (Sm):

$$SM = L *(\% < 425\ \mu m) \tag{3}$$

2.2.3 California bearing ratio

Both the natural and treated soils underwent the CBR test as specified in BS 1377 (1990) and BS 1924 (1990). The CBR test measures the force applied by the plunger and the depth to which it penetrates the specimen. For each soil sample, 5.0 kg of soil was mixed with the optimum moisture content and compacted in a 2360 cm^3 mould using a 2.5 kg rammer for the three layers, with each layer receiving 62 blows. The compacted samples were stripped of their base plates and sealed in plastic bags for six days to cure. After curing, the samples were submerged in water for 24 hours to simulate field conditions, as specified in the Nigeria General Specification (1997). The specimens were then placed on a CBR machine for testing, with a plate placed under them. The plunger was forced to fail the specimen by penetrating it at a rate of 1.3 mm per minute. The mold was then turned upside down, the base plate was removed, and the process was repeated for the specimens' bases. The measured penetration and force values were used to create a force-versus-penetration curve. The CBR value was determined by taking the larger 2.5 mm or 5.0 mm penetration values and their means, provided the values were within 10% of one another. The regression equation for the California bearing ratio results were created using the 2013 package of Microsoft Excel.

3.0 RESULTS AND DISCUSSION

The characteristics of the naturally lateritic soil (i.e., containing no IOT) are enumerated in Table 1, and Figure 1 displays the particle size distribution. Table 2 provides an overview of the oxide compositions of the materials used. According to AASHTO and the Unified Soil Classification System (USCS), a lateritic soil that had up to 16% iron ore tailings (IOT) by dry weight was classified as A-7-6(11) or CL, respectively. The specific gravity of IOT is greater (3.66) than that of natural soil (2.59). The concentrations of silicon, aluminium, and iron oxides allow the IOT to be categorised as a class N pozzolan in accordance with [25].

Table 1 Characteristics of lateritic soil in its natural and IOT-treated states

Properties	***IOT (%)***								
	0	2	4	6	8	10	12	14	16
Liquid limits %	43.4	46.2	44.4	43.8	42.3	42.7	41.4	41.3	40.2
Plastic limits %	21.3	24.8	27.4	28.9	29.4	27.4	26.7	25.7	23.54
Plasticity index %	22.1	21.4	17.0	14.9	12.9	15.3	14.7	15.6	16.7
Linear shrinkage %	11.4	11.8	11.9	12.1	12.3	12.6	12.8	13.5	14.3
Percentage passing No 200 Sieve	58.8	58.0	57.8	53.3	51.6	51.8	51.7	52.2	51.6
AASHTO Classification	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6
Group Index	11								
USCS Classification	CL	CL	CL	CL	CL	CL	CL	CL	CL
Specific Gravity	2.59	2.63	2.8	2.9	3.04	3.11	3.27	3.26	3.27
MDD, Mg/m^3	1.72	1.73	1.74	1.76	1.74	1.73	1.72	1.72	1.71
OMC, %	16	17.5	18	18.5	18	17.5	17.2	16.5	15.8

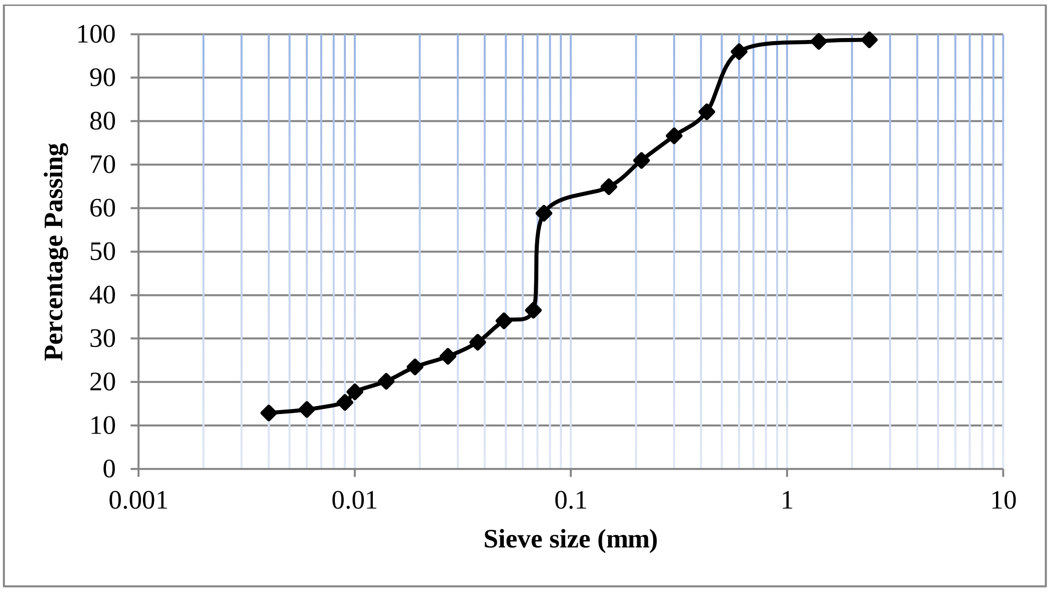

Figure 1 Gradation curve of the natural lateritic soil

Table 2 Oxide compositions of IOT and lateritic soil

Oxide	**Concentration (%)**	
	IOT	**Laterite**
CaO	0.607.	0.280
SiO_2	45.64.	35.600
Al_2O_3	47.70.	24.000
MnO	0.067.	0.0670
TiO_2	0.240.	-
K_2O	0.067.	-
PbO	0.415.	-
Na_2O	0.405.	-
MgO	0.393.	-
SO_3	-	0.850
LOI	3.00.	14.600

3.1 Effect of IOT on the Cation Exchange Capacity of Lateritic Soil

Figure 2 depicts how the cation exchange capacity (CEC) of lateritic soil changes as IOT content increases. When the soil was treated with up to 8% IOT, the CEC increased to 4.7 Cmol/kg from the natural soil's having 3.4 Cmol/kg, and then fell to a minimum of 2.5 Cmol/kg at 16% IOT content. The initial increase in the CEC values of the lateritic soil with the addition of IOT occured as a result of the increase in the soil pH which supplied the require free Ca^{2+} necessary for the CEC between the mineral clay particles while also supplying a small amount of calcium hydroxide [26]. The CEC test results were presented in Table 3 and the ANOVA results of the CEC against IOT demonstrated that IOT has significant effect on the lateritic soil as the $F_{cal} = 5.19$ is greater than the $F_{crit} = 4.49$

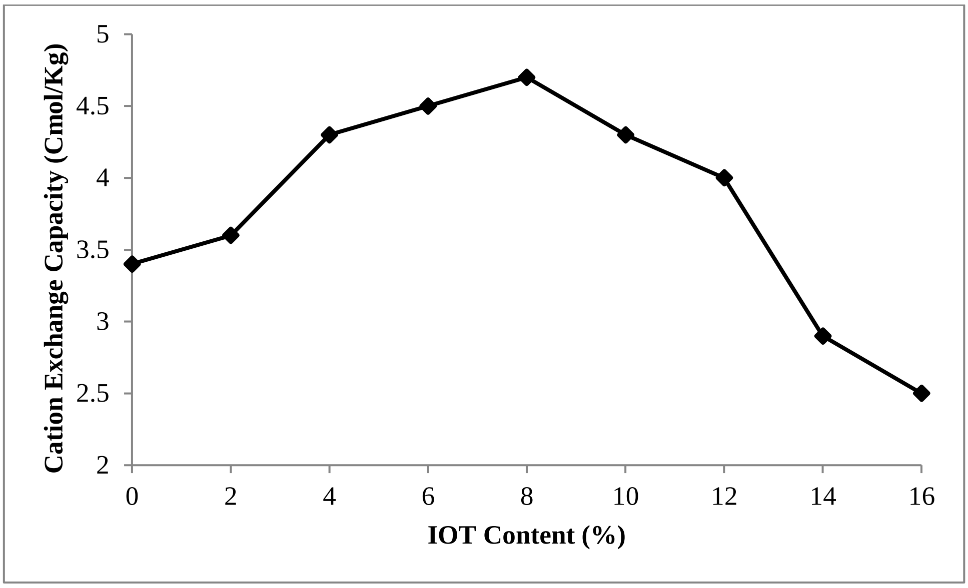

Figure 2 Cation exchange capacity variation of lateritic soil with IOT content

3.2 Effect of IOT on Consistency limit of Lateritic Soil

The difference of consistency limits of the lateritic soil- IOT content which comprised liquid limit, plastic limit, plasticity index and linear shrinkage is depicted in Figure 3.

Liquid Limit: Figure 3 illustrates how the liquid limit for lateritic soil treated with iron ore tailings (IOT) content varies. The liquid limit value increased as the IOT concentration increased, reaching a peak of 46.2% at 2% IOT content from 43.4% for the naturally lateritic soil before falling. The first rise in the liquid limit following the addition of IOT content can be due to the water required for the lateritic soil-IOT mixture to react. The ion exchange at the clay particles' surfaces caused by the reaction between the lower valence metallic ions in the clay structure and the Ca^{2+} in the iron ore tailing led to the agglomeration and flocculation of the clay particles, which caused the liquid limit to be lowered (IOT) [26].

Plastic limit: Figure 3 depicts how the plastic limit varies with IOT content. When IOT treatment was applied at 8%, the PL value rose from 21.3% for naturally lateritic soil to a peak of 29.4% before falling with additional IOT content to 23.5% at 16% IOT content. The first rise in plastic limit value may have resulted from the addition of IOT, which caused the clay particles to aggregate and flocculate as a result of cation exchange at their surface. This matches the results of [27, 28] for the treatment of lateritic soil with cement/bagasse ash and lime/bagasse ash, respectively. Cation exchange reaction causes the plastic limit value to decrease with increasing IOT content. As the more active and higher valence cations in the IOT (i.e., $Ca^{2+)}$ replaced the weakly linked ions in the clay structure, flocculation and the release of water bound at the outer layers occurred [29].

Plasticity Index: Figure 3 depicts how the plasticity index (PI) changes when iron ore tailing content increases. At 8% IOT concentration, the PI value dropped to 12.9% from for the naturally lateritic soil to 22.1%. This trend could be explained by the IOT taking the place of the smaller soil particles, reducing the amount of clay, and increasing the plasticity index. Also, it was shown that a soil's plasticity index rose in correlation with an increase in the clay proportion.

Linear Shrinkage: The changes of linear shrinkage (LS) with IOT content is shown in Fig.3. The linear shrinkage recorded shows a steady increment from 11.4 % for the natural lateritic soil to 14.3 % at 16% IOT content. This could be due to the typical replacement of soil particles by IOT as a result of moisture content variations, which causes a minor increase in the linear shrinkage of the IOT-lateritic soil mixture. After running an ANOVA, the results of the consistency limits test (see Table 3) show that the impact of IOT-lateritic soil is statistically significant.

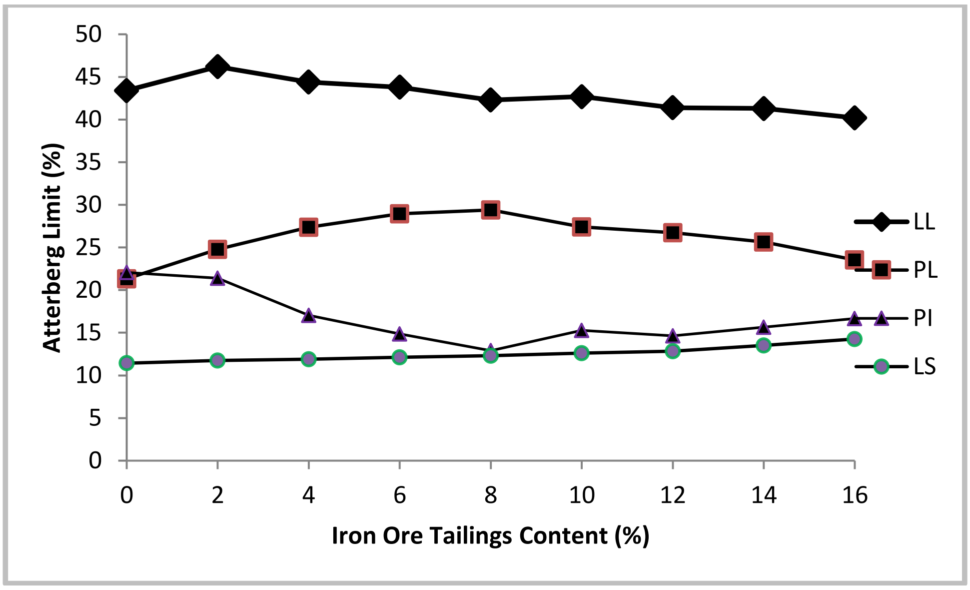

Figure 3 Changes of Atterberg limits of lateritic soil with IOT content

Table 3 ANOVA for Atterberg limits of lateritic soil-IOT mixtures

Property	Source of variation	Degree of freedom	F_{CAL}	P-Value	F_{CRIT}	Remark
Liquid limit	IOT	1	328.1	4.39E-11	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
Plastic limit	IOT	1	80.55	1.31E-07	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
Plasticity Index	IOT	1	17.33	0.00073	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
Linear Shrinkage	IOT	1	5.99	0.02627	4.49	$F_{CAL} > F_{CRIT}$, Significant effect

3.3 Effect of IOT on the Plasticity Characteristics of Lateritic Soil

Plasticity Characteristics: Figure 4 depicts a plot of derivative plasticity features such as shrinkage modulus (SM), plasticity modulus (PM), and plasticity product (PP) related to the plasticity of untreated and treated soil- IOT mixture. In general, it was found that shrinkage modulus (SM) increased with increasing IOT content while plasticity modulus (PM) and plasticity product (PP) decreased with increasing IOT to their lowest values at 8% IOT content. The reduction in plasticity characteristic measures may be a result of a decrease in the amount of fines present as the IOT content increases. Therefore, these measures are connected to the portion of the soil matrix composed of fine particles, such as silt.

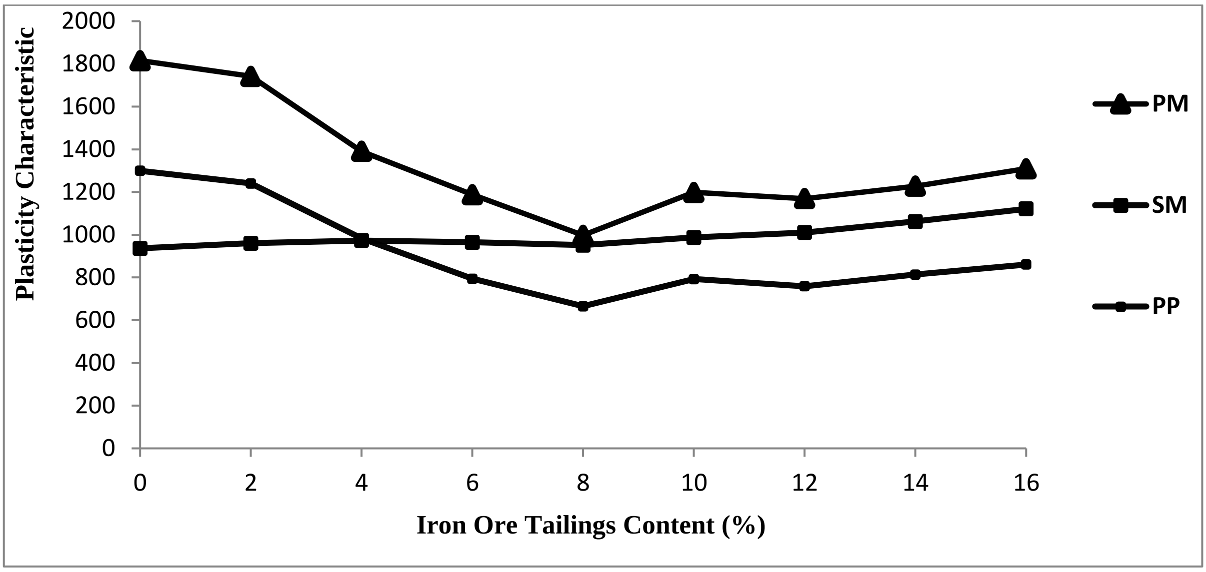

Figure 4 Changes of plasticity characteristics of lateritic soil with iron ore tailings contents

3.4 Effect of IOT on the Compaction Characteristics

3.4.1 Maximum dry density

Figure 5 depicts the variation in MDD of lateritic soil with IOT. In comparison to the natural soil, the MDD value raised from 1.72 Mg/dm^3 to a highest of 1.76 Mg/dm^3 at 6% IOT content before declining with increasing IOT content. The flocculation and agglomeration of clay particles, which is primarily brought on by cation exchange, may have contributed to the initial increases in MDD. It might also be because of specific gravity possess by IOT with 3.66 values and natural soil (2.59) [6] reported the same result. It could also be ascribed to the IOT coating of the soil, which results in larger particles with fewer spaces and hence increased density.

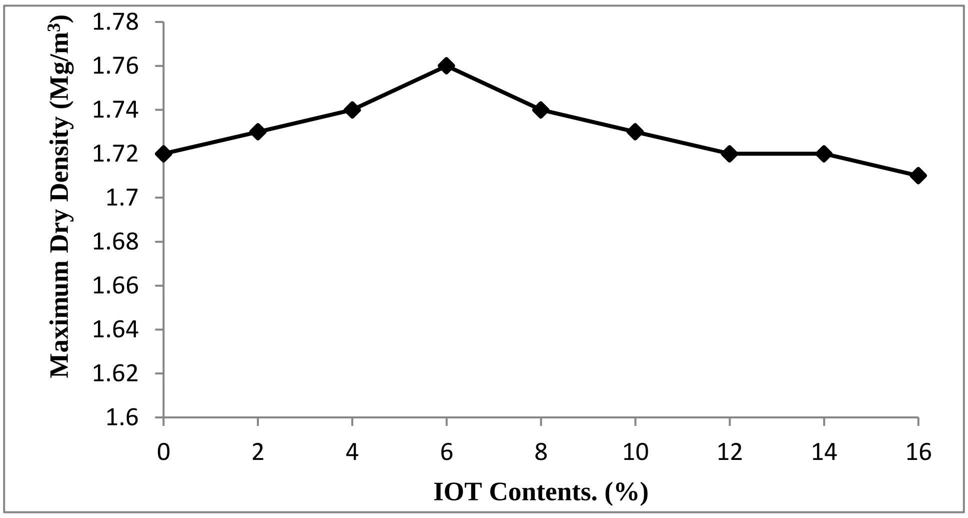

Figure 5 Changes of maximum dry density of lateritic soil with IOT contents

3.4.2 Optimum moisture content

Figure 6 illustrates how the OMC of original lateritic soil varies with IOT. The OMC rose from 16% for natural soil to a maximum 18.5% value at 6% IOT content, then fell with increasing IOT content to 15.8% at 16% IOT content. The increase in the OMC was attributed to the additional water needed for the dissociation of admixtures containing Ca^{2+} and OH-ions in order to supply more Ca^{2+} for the cation exchange reaction, The rise in OMC with

IOT content is consistent with the results reported by [30–33]. The ANOVA results (Table 4) of the MDD test demonstrated the impact of IOT on lateritic soil as statistically significant.

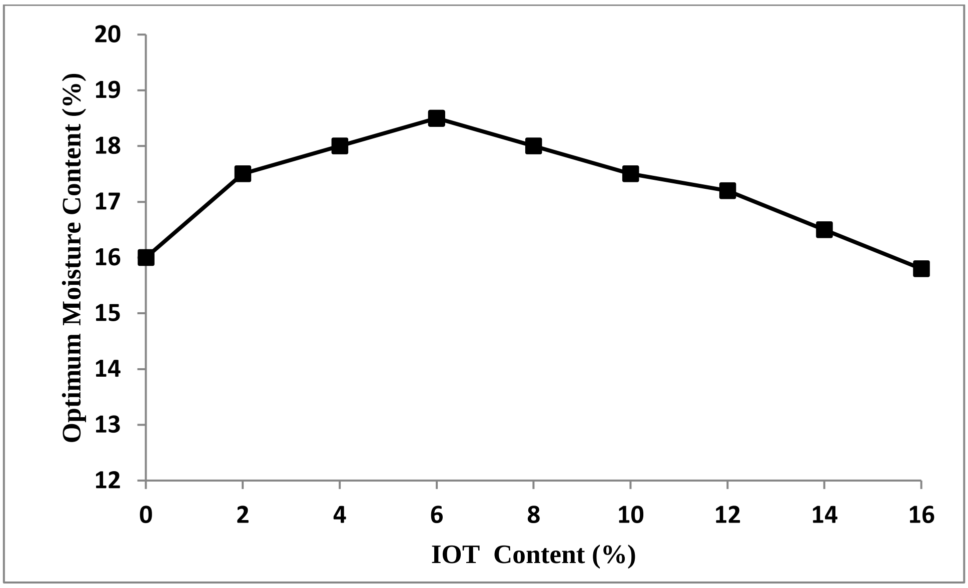

Figure 6 Changes of OMC of lateritic soil-IOT mixture

Table 4 ANOVA for compaction characteristics of lateritic soil – IOT mixtures

Property		Source of variation	Degree of freedom	FCAL	P-Value	FCRIT	Remark
BSL	MDD	IOT	1	11.79	0.00345	4.49	FCAL > FCRIT, Significant effect
	OMC	IOT	1	24.79	0.00137	4.49	FCAL > FCRIT, Significant effect

3.5 California Bearing Ratio

An important factor in determining a soil's suitability for engineering applications is the CBR value of the soil or stabilised soil. The strength and BC of the soil are indicated. Increasing IOT doses and compactive efforts resulted in higher soaked CBR values. Peak CBR values of 7.18, 9.52, and 13.6% for BSL, WAS, and BSH compactive efforts, respectively as shown in Figure 7 and were reported at 10% IOT content for all three compactive effort. The increase in CBR as compactive efforts increased indicates densification of the treated soil due to increased compactive efforts and soil strength. Peak values observed for all the energies did not meet 30% for subbase materials for the Nigerian General Specification (1997).

Table 5 ANOVA for California Bearing Ratio of lateritic soil- IOT mixtures

Property	Source of variation	Degree of freedom	FCAL	P-Value	FCRIT	Remark
CBR	IOT	1	2.77	0.115	4.49	FCAL < FCRIT, Significant effect

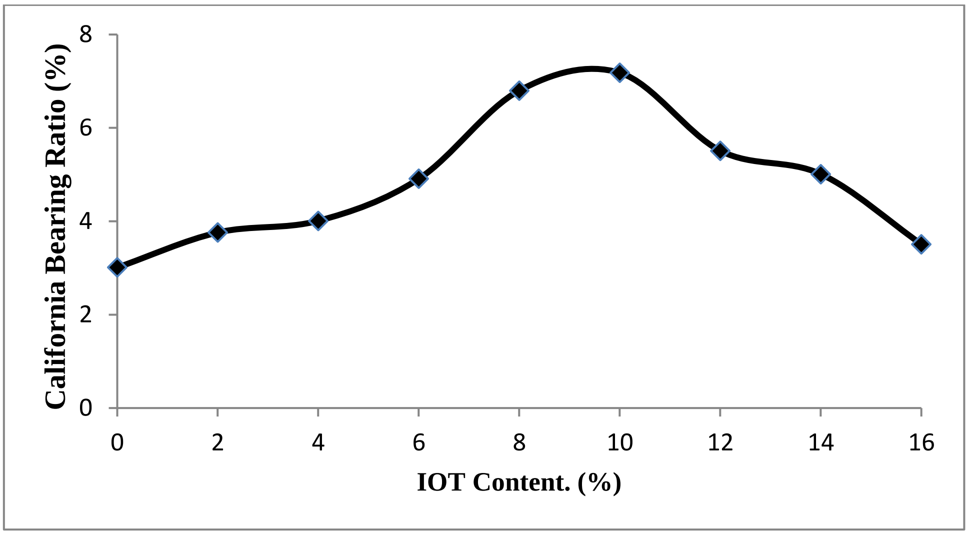

Figure 7 Changes in soaked CBR of lateritic soil- IOT contents

3.6 Regression Analysis of California Bearing Ratio

The grading qualities, MDD, OMC content, plasticity index, and compactive effort used were found to have an impact on the California bearing ratio. According to a research conducted by [2], particle size, type, and strength of the particles, as well as the degree of soil compaction, are the main factors that affect how laterite soil behaves when it is used to build pavement. For this analysis, the geotechnical properties taken into account were the iron ore tailing, MDD, OMC, PF, and PI using CE as a deterministic parameter with compactive effort index values of -1 for BSL.The california bearing ratio responds most significantly and positively to the optimum moisture content. With an R^2 value of 96.90%, there is a significant correlation between the CBR and variables in this study as shown by the correlation coefficient Eqn (4).This is the regression equation:

$$CBR = 161.68 - 0.29\,IOT - 0.58\,PF - 81.31\,MDD + 1.17\,OMC - 0.15PI + CE$$

$$R^2 = 96.90\% \qquad (4)$$

Where: CBR = California bearing ratio, IOT = iron ore tailing, PF = percentage fine, MDD = maximum dry density, OMC = optimum moisture content, PI = plasticity index, CE = compactive effort

A strong correlation can be seen between the obtained CBR measured values through laboratory testing and values predicted from the conceptual regression model, as shown in Eq. 4, which was created using Minitab R15. The coefficient of determination for BSL compaction energy for the model is R = 0.863 as shown in Figure 8. BSL compaction energy has a documented absolute percentage error range of 3.97% –15.38% as stated in Table 6.

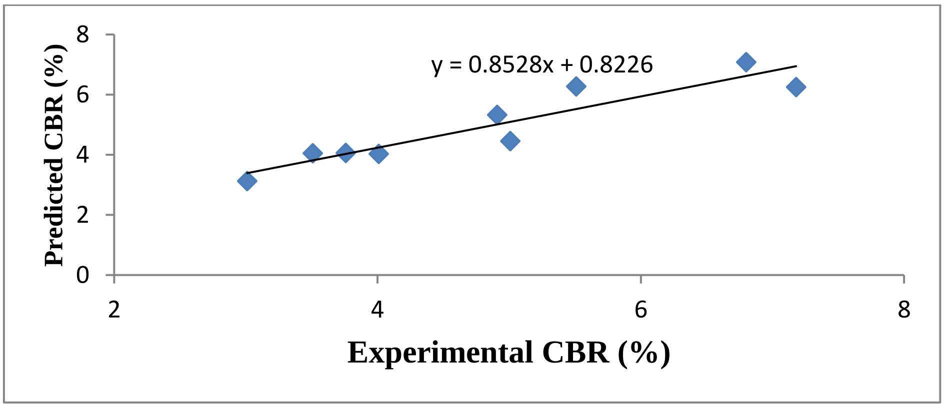

Figure 8 Changes between measured and anticipated CBR values from the BSL compaction model

The results demonstrate a minor increase in the correlation degree that exist between the soil parameters and the CBR values, as shown in Figure 8.

Table 6 Observed CBR values and model-predicted CBR values

Compactive effort	IOT Content (%)	Observed CBR (%)	Predicted CBR (%)	Absolute error	Percentage error
BSL	0	3.01	3.13	0.12	3.98
	2	3.76	4.06	0.3	7.97
	4	4.01	4.03	0.02	0.49
	6	4.91	5.33	0.42	8.55
	8	6.8	7.08	0.28	4.12
	10	7.18	6.25	0.93	12.95
	12	5.51	6.28	0.77	13.97
	14	5.01	4.46	0.55	10.97
	16	3.51	4.05	0.54	15.38

4.0 CONCLUSION

i. According to the AASHTO and the Unified Soil Classification System (USCS), the natural lateritic soil was categorised as A - 7 - 6 (11) or CL, respectively.

ii. Peak MDD value of 1.76 at 6% IOT content and gave a peak OMC value of 18.5 at 6% IOT content.

iii. The minimum plasticity index value of 12.9% was recorded for 8% IOT treatment of lateritic soil.

iv. Analysis of variance (ANOVA) for cation exchange capacity, Atterberg limits and Compaction Characteristics demonstrates that IOT had a statistically significant impact on lateritic soil.

v. The lateritic soil treated with 8% IOT content barely exceeded the 12% maximum plasticity index value, while the liquid limit value exceeded the maximum 35% for use as a sub-base or base material, according to the requirements of Nigerian General Specifications.

vi. The value of the soaked CBR increases as the IOT and compactive effort increase. At 10% IOT for the whole compactive effort, CBR values peak at 7.18, 9.52, and 13.6% for the BSL, WAS, and BSH compactive efforts, respectively.

vii. Maximum CBR values for the soaked CBR were found below the 30% threshold set forth in the Nigerian General Specification of 1997 for subbase materials.

viii. Optimal 10% IOT improved the properties of lateritic soil, but it cannot be used as an independent additive in road construction as a stabilising or modifying agent.

ix. Regression analysis results showed that the optimum moisture content had a substantial impact on the soil CBR values.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgement

The authors wish to acknowledge the support of the laboratory attendants in carrying out this work.

References

[1] Ishola, K., Agbolade, I. C., & Yohanna, P. (2019). Effect of Plantain Peel Ash on Gradation and Compaction Characteristics of Tropical Soil. FUOYE Journal of Engineering and Technology, 4(2). https://doi.org/10.46792/fuoyejet.v4i2.382

[2] Oluremi, J. R., Siddique, R., & Adeboje, E. P. (2016). Stabilization Potential of Cement Kiln Dust Treated Lateritic Soil <sup></sup> International Journal of Engineering Research in Africa, 23, 52–63. https://doi.org/10.4028/www.scientific.net/JERA.23.52

[3] Osinubi, K. J. (2000). Treatment of laterite with anionic bitumen emulsion and cement: A comparative study. Ife Journal of Technology, 9(1), 139–145.

[4] Barstis, W. F., & Metcalf, J. (2005). Practical Approach to Criteria for the Use of Lime–Fly Ash Stabilization in Base Courses. Transportation Research Record: Journal of the Transportation Research Board, 1936(1), 20–27. https://doi.org/10.1177/0361198105193600103

[5] Osinubi, K. J. (2000). Laboratory trial of soil stabilization using pulverized coal bottom ash. NSE Technical Transactions, 35(4), 1–13.

[6] Nweke, O. M., & Okogbue, C. O. (2017). The potential of cement stabilized shale quarry dust for possible use as road foundation material. International Journal of Geo-Engineering, 8(1), 29. https://doi.org/10.1186/s40703-017-0068-5

[7] Darsi, B. P., Molugaram, K., & Madiraju, S. V. H. (2021). Subgrade Black Cotton Soil Stabilization Using Ground Granulated Blast-Furnace Slag (GGBS) and Lime, an Inorganic Mineral. In The 2nd International Electronic Conference on Mineral Science (Vol. 6, p. 15). Basel Switzerland: MDPI. https://doi.org/10.3390/iecms2021-09390

[8] Osinubi, K. J., Eberemu, A. O., & Akinmade, O. B. (2016). Evaluation of Strength Characteristics of Tropical Black Clay Treated with Locust Bean Waste Ash. Geotechnical and Geological Engineering, 34(2), 635–646. https://doi.org/10.1007/s10706-015-9972-7

[9] Eko, R. M., & Riskowski, G. (2001). A procedure for processing mixtures of soil, cement, and sugar cane bagasse. The Journal of Scientific Research and Development Agricultural Engineering International Manuscript BC, 1–5.

[10] Osinube, K. G., & Thomas, S. A. (2008). Influence of Compactive Efforts on Bagasse Ash Treated Black Cotton Soil. Nigerian Journal of Soil and Environmental Research, 7(1), 92–101. https://doi.org/10.4314/njser.v7i1.28422

[11] Osinubi, K. J., Ijimdiya, T. S., & Nmadu, I. (2009). Lime Stabilization of Black Cotton Soil Using Bagasse Ash as Admixture. Advanced Materials Research, 62–64, 3–10. https://doi.org/10.4028/www.scientific.net/AMR.62-64.3

[12] Osinubi, K. J., Bafyau, V., & Eberemu, A. O. (2009). Bagasse Ash Stabilization of Lateritic Soil. In Appropriate Technologies for Environmental Protection in the Developing World (pp. 271–280). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-9139-1_26

[13] Musa, A., & Alhaji, M. M. (2007). Effect of rice husk ash on cement stabilized laterite. Leonardo Electronic J. Practice and Technol., 6(11),47-58

[14] Sen, D. (2021). Stabilization of Black Cotton Soil using Fly Ash. International Journal for Research in Applied Science and Engineering Technology, 9(3), 1100–1106. https://doi.org/10.22214/ijraset.2021.33455

[15] Salahudeen, A. B., Eberemu, A. O., & Osinubi, K. J. (2014). Assessment of Cement Kiln Dust-Treated Expansive Soil for the Construction of Flexible Pavements. Geotechnical and Geological Engineering, 32(4), 923–931. https://doi.org/10.1007/s10706-014-9769-0

[16] Zhang, Y., & Qiong, N. (2007). Test for the Technology of Making Colour Bricks with Iron Tailings. Express information of mining industry, 64–66.

[17] Ghose, M. K. (1997). Environmental Management for the Disposal of Spoils and Tailings . Mines, Environment and Ecology, 15(1), 206–210.

[18] Soframine. (1987). Evaluation of the National Iron ore mining project, Itakpe. National Stell Development Agency (NSDA) – personal communication.

[19] Olubambi, P., & Potgieter, J. H. (2005). Effectiveness Of Gravity Concentration For The Beneficiation Of Itakpe (Nigeria) Iron Ore Achieved Through Jigging Operation. Journal of Minerals & Materials Characterization & Engineering, 4, 21–30. https://doi.org/10.4236/jmmce.2005.41003

[20] Akintola, F. A. (1982). Geology and Geomorphology. In K.M. Barbour, Hodder, & Stoughton (Eds.), In: Nigeria in maps. London, UK.

[21] BS 1377. (1990). Method of Testing Soil for Civil Engineering Proposal. British Standard Institute (BSI), London.

[22] BS 1924. (1990). Method of Tests for Stabilized Soils. British Standard Institute (BSI) London.

[23] Nigerian General Specification. (1997). Roads and Bridges. Federal Ministry of Works, Abuja, Nigeria.

[24] Charman, J. H. (1998). Laterite in road pavements. CIRIA Special Publication 47, Construction Industry Reasearch Information Asscociation., ed., CIRIA, London.

[25] ASTM, C. (2008). 618; Specification for coal fly ash and raw or calcined natural pozzolanas for use as mineral admixtures in Ordinary Portland Cement Concrete. Annual book of ASTM standards, West Conshecken USA.

[26] Akinmade, O. B. (2008). *Stabilization of Black Cotton Soil with Locust Bean waste Ash*. Unpublished M.Sc. Thesis. Civil Engineering Department, Ahmadu Bello University Zaria.

[27] Alhassan, M. A. (2006). *The Effect of Bagasse Ash on lime Stabilized Laterite*." Unpublished M.Sc.Thesis. Ahmadu Bello University, Zaria,Nigeria.

[28] Ijimdiya, T. S. (2011). Effect of Oil Contamination on Particle Size Distribution and Plasticity Characteristics of Lateritic Soil. Advanced Materials Research, 367, 19–25. https://doi.org/10.4028/www.scientific.net/AMR.367.19

[29] Abubakar, J. (2011). *Use of Lime and Locust bean waste ash in the modification of lateritic Soil*.

[30] Osinubi, K. J., Eberemu, A. O., & Aliu, O. S. (2007). Stabilization of laterite with cement and bagasse ash admixture. In Proceedings of the First International Conference on Environmental Research, Technology Policy ERTEP (pp. 1–14).

[31] Okonkwo, U., Agunwamba, J., & Iro, U. (2016). Geometric models for lateritic soil stabilized with cement and bagasse ash. Nigerian Journal of Technology, 35(4), 769. https://doi.org/10.4314/njt.v35i4.11

[32] Moses, G. (2008). Stabilization of black cotton soil with ordinary portland cement Using Bagasse ash as admixture. IRJI Journal of Research in Engrg, 5(3), 107–115.

[33] NE, S. and Oluyemisi, E. H. (2017). Effects of Coconut Shell Ash on Lime-Stabilized Lateritic Soil. MOJ Civil Engineering, 2(4), 140–143. https://doi.org/10.15406/mojce.2017.02.00042