EVALUATION OF THE STATISTICAL SIGNIFICANCE OF COMPACTIVE EFFORTS, SLAG AND CEMENT ON THE GEOTECHNICAL FEATURES OF LATERITE SOIL

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Abstract: This study investigated the statistical significance of compactive efforts, steel slag and cement on the geotechnical features of the laterite soil. Steel slag and cement were incorporated into the soil. Some geotechnical tests were performed on slag-cement-soil samples. Findings showed that the liquid limit (LL) and plasticity index (PI) decreased with increasing slag content, while cement addition increased LL and PI. As compactive efforts increased, MDD and CBR increased with a corresponding decrease in OMC. A more significant influence of the compactive effort and steel slag on the geotechnical features of the laterite than that of cement was observed.

Keywords: compactive effort, steel slag, lateritic soil, regression, analysis of variance, geotechnical properties

1. INTRODUCTION

Steel slag, a by-product of the iron and steel industries, has different features depending on the raw materials, burning temperature and processes it underwent [1]. Due to significant global increase in the production of these industries the world over, there is a rising concern on how to effectively and sustainably manage the waste products generated from these industries. According to Devi and Gnanavel [2] and Liu and Guo [3], 16-20% of production from the iron and steel industries is generated as slag from one tonne (1000 kg) of steel produced. In Nigeria, the quantity of slag generated from steel production amount to nearly 96-145 million metric tons annually, and greater portion of these productions are accumulated around the steel producing industries posing serious disposal and health challenges to the environment [4-5]. Due to rapid urbanization and increased industrial production in Nigeria, the volume of waste generated annually has increased beyond what could be handled by city authorities, and this has led to a poor waste management system resulting into serious environmental crises in many Nigerian cities [6-8]. Studies have also clearly shown that not more than 50% of these wastes are currently converted into different purposes while larger percentages are dumped in the environment [9-13]. However, a sustainable and environmentally friendly way of solving these challenges is to consider the possibility of waste minimization by

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recycling and reusing [14-15], and one of such ways that has received the attention of environmental researchers, considered in this study, is by incorporating the industrial waste steel slag into the weak lateritic soil as a means of improving the properties of the soil and at the same time reducing the accumulation of the waste material in the environment. As the continuous production of wastes without proper disposal system will always pose a great threat to the environment. In addition, most lateritic soils that are frequently used as foundation (subgrade) materials in road construction are very weak and are usually subjected to seasonal swelling and shrinkage, which need to be stabilized or modified before they can meet specific engineering applications.

Several studies have ascertained steel slag to be a potential material for either partial or total replacement for cement and aggregates in the production of concrete [14, 16-23]. Additionally, Kothai and Malathy [24] reported that steel slag has several advantages in terms of its high strength, high density, relative availability and abundance of this material in many countries, which has enhanced its usage as a replacement material for coarse aggregate in concrete production. The study conducted by Barra et al. [25] on the stabilization of soils with steel slag and cement for rural and low trafficked roads found that there was an improvement in the soil bearing capacity. A review work carried out by Hainin et al. [26] on the use of steel slag as a road construction material, showed that existing studies focused extensively on the use of steel slag as a coarse aggregate for wearing course. Because the existing studies on the potentials of steel slag as a construction material, have been largely centred on the concrete production, there is need to comprehensively investigate the potential of this waste material on the geotechnical properties of soils.

Cement, which is a common and mostly stabilizing agent, has become very expensive lately in Nigeria and many other developing countries. Production of this stabilizer has also been associated with high emission of CO_2 to the environment and the continuous usage can no longer be sustainable and environmentally friendly. Manasseh [27] and Vijayakumar et al. [28] noted that carbon dioxide, which is a major greenhouse gas, contributes approximately 65% of global warming. This therefore leads to the search for alternative local materials as partial or total substitution for cement [29-30], and the search has resulted into the discovery of steel slag, an industrial waste, as a potential cementitious material [5, 15, 25, 31].

Few researches have reported on the effects of the compactive energy level on the geotechnical properties of the soil. Joel and Joseph [32] investigated the influence of compactive energy on the strength indices of lateritic soil stabilized with calcium carbide waste and reported an increase in CBR and UCS of the soil. The effect of different Compaction Energy (Standard Proctor and Modified Proctor) on geotechnical properties of Kaolin and Laterite was investigated by Yussof et al. [33]. The finding from the study showed that strength characteristics of Kaolin and Laterite increased with increasing energy level. Oluremi et al. [34] studied the effects of three different compactive efforts (British Standard Light compaction, West Africa Standard compaction and British Standard Heavy compaction) on geotechnical properties of spent engine oil Contaminated laterite soil, and concluded that the higher the compactive effort the higher the maximum dry density and unconfined compressive strength of the soil.

Laterite soils are formed in tropical and sub-tropical regions of hot and humid climatic condition with heavy rainfall and warm temperature like Nigeria. They have found their extensive use in numerous construction activities such as subgrade material for road construction and brick production material [35, 36]. However, most of these soils are very weak and are usually subjected to seasonal swelling and shrinkage, which need be stabilized or modified before they can meet specific engineering applications. Accordingly, the potential of steel slag as an alternative stabilizing material for weak lateritic soils was investigated in this study, under different cement contents and compactive efforts, so as to serve as alternative means of minimizing environmental waste. The main aim of this study is therefore to investigate the impact of compactive efforts, steel slag and cement on the geotechnical properties of the laterite soil.

2. MATERIALS AND METHODS

2.1. Materials

The materials used for this study are laterite soil samples, steel slag and ordinary Portland cement.

2.1.1. Lateritic soil

Disturbed lateritic soil samples used for various experimental tests were collected from a borrow pit near the 1200 Lecture Hall, LAUTECH, Ogbomoso (Latitude 8.13333° N and longitude 4.26667° E) of Oyo State, Nigeria. This soil sample, obtained at depth of 1.0m below the natural ground level, was preserved in water proof bag and labeled to indicate the soil description, sampling depth and date of sampling, however the natural moisture content was determined immediately. The soil sample was later air dried to allow partial exclusion of natural water which may affect analysis. It was slightly crushed with minimal pressure to remove the lump and then sieved with BS sieve No. 4 (4.76mm opening) to obtain the final soil samples for tests. The soil specimens were subjected to geotechnical tests in relation to British Standard Codes of practice BSI 1377 [37] for the unstabilized (natural) soil and BSI 1924 [38] for the stabilized soil specimens, respectively.

2.1.2. Steel slag

The powdered steel slag was collected from Dolphin steels Nigeria Limited, Papalanto, Ogun state. The slag specimen was allowed to pass through British Standard sieve No 200 (75 µm aperture) so as to increase its surface area for better reactivity and the steel slag was then mixed with the soil – cement in certain percentages as shown in Table 1. The chemical composition of the slag sample was conducted with aid of X-ray Fluorescence Spectrometry (Model QX 1279) at Lafarge Cement, West Africa Portland Cement Company (WAPCO), Sagamu, Ogun State, Nigeria and its result is as presented in Table 2.

Table 1. Slag-cement mixtures by the percentage of the soil sample.

Steel slag (%) / Cement (%)	0	5	10	15	20
0	0.0	0.2	0.10	0.15	0.20
2	2.0	2.5	2.10	2.15	2.20
4	4.0	4.5	4.10	4.15	4.20
6	6.0	6.5	6.10	6.15	6.20

**%age of soil in each mixture = 100 – sum of the %age of cement & steel slag*

Table 2. Oxide constituents of the steel slag and cement.

Metal Oxides	Steel slag (%)	Cement (%)
CaO	1.21	64.19
Fe_2O_3	96.02	1.80
SiO_2	0.86	20.09
Al_2O_3	0.18	4.98
SO_3	0.03	1.80
M_2O_5	1.3	-
P_2O_5	0.21	-
TiO_2	0.17	-
Na_2O	-	0.21
K_2O	-	0.53
MgO	-	1.92
LOI*	0.002	0.08
Total $SiO_2+Al_2O_3+Fe_2O_3$	97.06	26.87

**LOI = Loss on ignition*

2.1.3. Cement

Dangote ordinary Portland cement used for this study was purchased from a local retail shop in Ogbomoso, Oyo State, Nigeria. The proportions of oxides present in this cement are presented in Table 2.

2.2. Experimental methods

The experimental methods applied in this study are in accordance with British Standard Codes of practice BSI 1377 [37] for the unstabilized (natural) soil and BSI 1924 [38] for the stabilized soil.

2.2.1. Preparation of sample

Specimen of ordinary Portland cement and steel slag were carefully mixed together with the soil sample in certain proportions as presented in Table 1, and this was followed by the addition of water to the mixtures. Various tests such as liquid limit and plastic limit determinations, compaction and California bearing ratio were then conducted on the mixed specimens.

2.2.2. Sieve analysis

Particle size distribution analysis of the lateritic soil sample was conducted in accordance with British Standard code [33] that is specified for unstabilized soil.

2.2.3. Atterberg limits

Atterberg limits such as liquid limit, plastic limit and plasticity index were carried out in conformity with British Standard Codes of Practice, BS 1377 [37] and BS 1924 [38] for natural and stabilized soils, respectively.

2.2.4. Compaction

Moisture-density relationship tests were carried out on slag-cement-soil mixtures shown in Table 1 using Bristish Standard Light (BSL) compaction, West African Standard (WAS) compaction and Modified AASHTO compaction to determine their maximum dry density and optimum moisture content (similar to those of Ijimdiya et al. [39] and Oluremi and Adedokun [40]).

2.2.5. California bearing ratio

California bearing ratio tests were conducted on slag-cement-soil mixtures using three energy levels (BSL, WAS and Modified AASHTO) in accordance with BS 1377 for natural soil and BS 1924 for treated soil. Air-dried slag-cement-soil mixture mixed with their respective OMC was placed in the CBR mold in three layers with each layer receiving 62 blows of 2.5 kg rammer. The compacted admixed soil sample was placed Under the CBR machine until the spacer disc comes flush with the top of the mold. A load of about 2.5 kg was applied held for about 30 secs and then release; the load was recorded at the penetration of 0.5, 1.0, 2.0, 2.5, 3.5, 5.0, 5.5, 6.0, 6.5 and 7.0 mm. The mold was removed from the CBR machine, the spacer disc was also removed and the mold with the compacted soil was weighed. The moisture content of the compacted soil was determined. The aforementioned procedures were repeated for all admixed soil samples shown in Table 1.

3. RESULTS AND DISCUSSION

Detailed test results and its discussions are presented in the following sections.

3.1. Chemical properties of steel slag and cement

The proportions of oxides present in steel slag and cement samples are presented in Table 2. These results showed that the summation of (SiO_2 + Al_2O_3 + F_2O_3) for steel slag was 97.06%, which is more than 70%, and the loss on ignition of the slag of 0.002 was also less than 6% recommended for class F pozzolanic material by ASTM C618-12 [41]. This steel slag can therefore be categorized as Class F pozzolan. Cement indicated much higher CaO content of (64.19%) than steel slag (1.21%) but the Fe_2O_3 content of cement (1.80%) was significant lower than that of Steel slag (96.02%). In addition, the maximum value of 5 and 6% specified by ASTM C618-12 [41] for the SO_3 of cementitious material is satisfied by this steel slag with 0.03%. According to Gidigasu [42] and Apata and Adedokun [43], the ferric oxide is an important cementing agent in lateritic soils and higher content of this oxide could lead to the formation of strong bond and strength in the lateritic soil when dried.

3.2. Geotechnical properties of the natural soil

Table 3 presents the geotechnical properties of the natural (unstabilized lateritic) soil used for the experimental tests. The percentage passing BS sieve No. 200 was 38.58%. This result does not meet the maximum limit of 35% required for soil to be used as a road construction material in accordance to Road and Bridges Specification Revised Edition of Federal Ministry of Works, Nigeria [44]. The overall geotechnical characterization of the soil is A-6 (9) under AASHTO [45] and SC (Clayey sands or sand-clay mixtures) under USCS [46] classification systems, which are based on the percentage finer, liquid limit and plasticity index of the soil. This soil can be generally rated as poor and soft in relation to AASHTO and USCS classification systems. All these classification systems therefore showed that this soil falls below the standards recommended for most geotechnical construction works and would therefore require stabilization.

3.3. Consistency limits

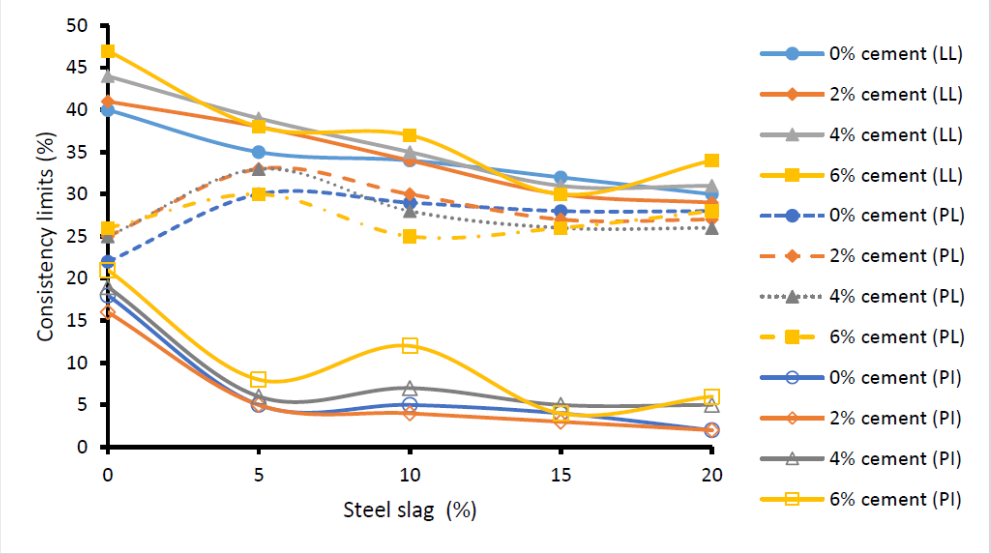
Figure 1 shows the impact of steel slag and cement on the Liquid limit (LL), Plastic limit (PL) and Plasticity index (PI) of the laterite soil. It was observed from the figure that LL and PI decreased significantly with the increasing content of the steel slag. At 0% cement, the LL and PI values decreased from 40 - 30% and 18 - 2% from 0 -20%

steel slag, respectively. However, the corresponding values of LL and PI at 6% cement decreased from 47 - 34% and 21 - 6% from 0 -20% steel slag.

Table 3. Geotechnical properties of the unstabilised lateritic (natural) soil.

Property	Quantity
Percentage finer	38.58
Liquid limit (%)	40
Plastic limit (%)	22
Plastic index (%)	18
Linear shrinkage (%)	3
AASHTO classification	A-6 (9)
USCS	Clayey-sands, sand-clay mixtures
MDD (g/cm^3)	
BSL[*]	1.68
WAS	1.79
Modified AASHTO	1.90
OMC (%)	
BSL	12.44
WAS	11.84
Modified AASHTO	11.25
CBR (Unsoaked, %)	
BSL	22
WAS	31
Modified AASHTO	43
CBR (soaked, %)	
BSL	6
WAS	10
Modified AASHTO	15

[*]BSL = British Standard Light, WAS = West African Standard



**LL = Liquid limit, PL = Plastic limit, PI = Plasticity index*

Fig. 1. Influence of steel slag and cement on Atterberg limits.

Unlike those of LL and PI, the inclusion of steel slag slightly increased the plastic limit of the lateritic from 22% at 0% cement and 0% steel slag to 28% at 0% cement and 20% steel slag. The same increasing trend of plastic limit with steel slag was also observed for other samples with different cement contents. The slight increase in PI at 10% steel slag might result from an increase in liquid limit due to the hydration reaction of cement as its content increased. A decrease in LL and PI values as well as increase in PL values with increasing contents of steel slag agreed with the results of study conducted by Adedokun et al. [15]. They both showed that steel slag and cement have effects on the Atterberg limits of the soil, although the impact of steel slag that is considered to be a waste material, is more significant than of cement. This behaviour could be as a result of high content ferric oxide in the steel slag which is an important cementing agent that might be responsible for the formation of stronger bond within soil-slag mixtures.

The effect of the two additives on the PI of the soil using 2-way Analysis of Variance (ANOVA) at 5% level of significance is shown in Table 4. From this table, it is clearly shown that both steel slag (P-value = 7.91E-09 < 0.05) and cement (P-value = 0.0012 < 0.05) have effects which are statistically significant on the steel slag-cement stabilized lateritic soil. However, the lower P-value of steel slag (7.91E-09) than that of cement (0.0012) also confirm that the greater impact of steel slag on the index properties of the lateritic soil when compared to that of the cement.

Table 4. Statistical influence of steel slag and cement on PI using two-way analysis of variance.

Properties	Source of Variation	Degree of freedom	Fcal*	P-value*	Fcrit*	Remark
Plasticity index	Cement	3	10.35	0.0012	3.490295	SS*
	Steel slag	4	89.52	7.91E-09	3.259167	SS

**Fcal* = variance ratio after treatment, *P-value* = probability value, *Fcrit* = stipulated ratio of variance, SS = Statistically Significantly

3.4. Compaction

The impacts of compactive energy, steel slag and ordinary Portland cement on the MDD and OMC of the soil are shown in Figures 2 and 3, respectively. The MDD of the soil increased with increasing contents of steel slag and also increased as the compactive energy increased. The MDD values for BSL, WAS and Modified AASHTO ranged from 1.73 - 1.93 g/cm^3, 1.77 - 2.10 g/cm^3 and 1.92 - 2.20 g/cm^3, respectively. This implies a 11.56%, 18.64% and 14.58% increase in the MDD of the soil under BSL, WAS and AASHHTO, and this shows that compactive efforts have significant effect on the maximum dry density and the impact is more significant under the West Africa Standard. The increase in the values of MDD is as a result of densification of the lateritic soil mass due to rise in compaction energy. As the steel slag contents increased in the soil mass, the MDD as well increased from 6.90 - 9.00%, 7.80 - 16.7% and 6.30 - 12.8% for BSL, WAS and Modified AASHTO, respectively. Similarly, the increase in MDD values with increasing amount of slag is quite distinctive under the WAS energy level than the other compactive efforts. The same trend of increase in MDD values with the addition of steel slag was noted by Adedokun et al. [15]. For varying cement contents, it was also observed that the values of MDD increased with increasing cement content from 2.30 - 4.30% for BSL, 2.20 - 8.20% for WAS and 2.60 - 8.70% for AASHTO. These results clearly showed that the impact of the steel slag that is regarded to be a waste material is more significant as compared to that of cement. This is an indication that the strength and density of the soil can be enhanced with the addition of steel slag. This is because steel slag exhibited strong binding medium between the micro-sized clay particles leading to the formation of macro-sized particle of higher density and compactness which is primarily due to the high pozzolanicity as a result of high iron oxide content in steel slag [14, 47].

The impact of the two additives (steel slag and cement) and compactive efforts on the MDD of the soil was examined using ANOVA at 5% level of significance and the result is as presented in Table 5. Results from the table show that steel slag (P-value = 1.87323E-13 < 0.05), cement (P-value = 2.74451E-09 < 0.05) and compactive efforts (P-value = 9.14924E-29 < 0.05) have statistically significant effects (P-values < 0.05 level of significance) on the maximum dry density of the lateritic soil. The influence of compactive effort on the MDD (due to its lowest P-value) was the highest, followed steel slag while the impact of cement was the lowest. The lower P-value of steel slag (1.87323E-13) than that of cement (2.74451E-09) also confirmed that the greater impact of steel slag on the density of the lateritic soil as compared to that of the cement.

Table 5. Impact of steel slag, cement and compactive effort on MDD and OMC using ANOVA at 5% significant level.

Compaction parameters	Source of variation	Standard Error	P-value	Lower 95%	Upper 95%	Remark
MDD	SS*	0.000943332	1.87323E-13	0.007225567	0.011006527	Significant

	C*	0.002018767	2.74451E-09	0.01025584	0.018347237	Significant
	CE*	0.00498196	9.14924E-29	0.098765928	0.118734072	Significant
OMC	SS	0.01317843	1.04067E-06	-0.098811933	-0.045991604	Significant
	C	0.028202342	8.73033E-09	-0.247658149	-0.134620637	Significant
	CE	0.069598415	1.04887E-11	-0.73572834	-0.45677166	Significant

**SS = Steel slag, C = Cement, CE = Compactive effort*

Regression analysis of results for the maximum dry density of the lateritic soil is as presented in Figure 3. The parameter considered for this analysis are the steel slag content, cement content, and plasticity index using compactive effort as a deterministic parameter with its index values of -1, 0 and 1 for British Standard light, West African Standard and Modified AASHTO compactive efforts, respectively. These results showed that the steel slag, cement and compactive effort had the most significant effect on the maximum dry density of the lateritic soil with positive coefficients. The correlation coefficient values (R^2) indicates a strong relationship between MDD and the parameters in equation (1) with R^2 value of 93.6%. The conceptual regression model in equation (1) shows a very strong correlation between the observed MDD values (Figure 3. a-c) from the experimental test and the predicted values from the model with coefficient of determination with the R^2 values of 0.95, 0.94 and 0.87 for BSL, WAS and AASHTO compaction energy, respectively. In addition, this equation will be useful in predicting the compaction characteristics of this type of soil under different compactive efforts, steel slag and cement contents, with much higher accuracy.

$$\mathrm{MDD} = 0.00912SS + 0.01430\mathrm{C} + 0.10875\mathrm{CE} - 0.00033\mathrm{PI} + 1.793545 \tag{1}$$

where SS are Steel slag, C are cement, CE are Compactive effort.

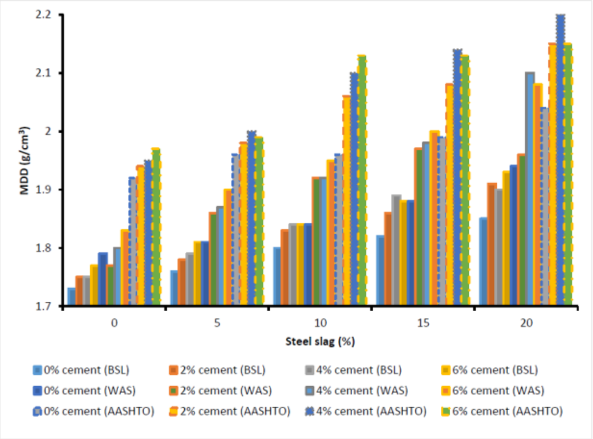
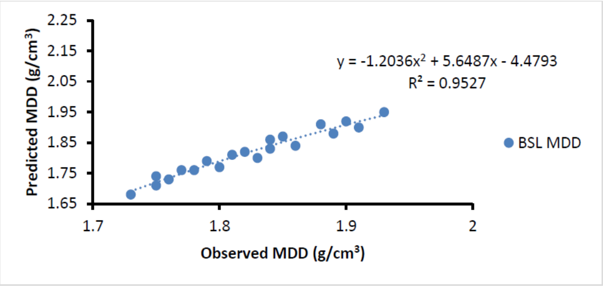


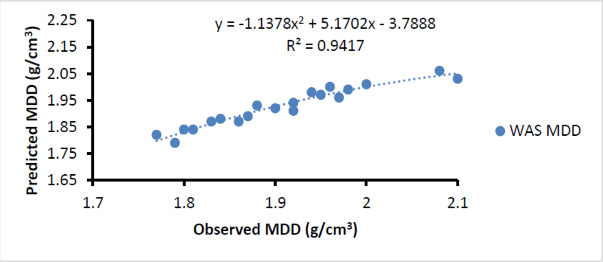
Fig. 2. Influence of compactive effort, steel slag and cement on MDD.

The optimum moisture content (OMC) results as presented in Figure 4 showed that OMC values decreased with increase in compactive efforts, as well as with steel slag and cement contents. The OMC values for BSL, WAS and Modified AASHTO decreased from 12.4 - 9.25%, 11.8 - 8.8% and 11.4 - 8.4%, respectively. The decreased in OMC as the compactive efforts increased is as a result of reduction of voids present in the soil due to increase in the density of the soil. This is also in agreement with the previous findings by Oluremi et al. [48] and Adedokun et al. [15]. The OMC for BSL, WAS and AASHTO for samples with 0% cement content decreased from 12.4 - 10.9%, 11.8 - 10.7 and 10.6 - 9.4 for 0 - 20% steel slag inclusion respectively, while the corresponding OMC values for samples with 6% cement content decreased from 12 - 9.25%, 10.9 - 8.8% and 10.6 - 8.4% for 0 - 20% steel slag. This also showed that the OMC of the soil decreased with increasing content of steel slag and cement, and agrees with the findings of Portelinha et al. [49] and Adedokun et al. [15].

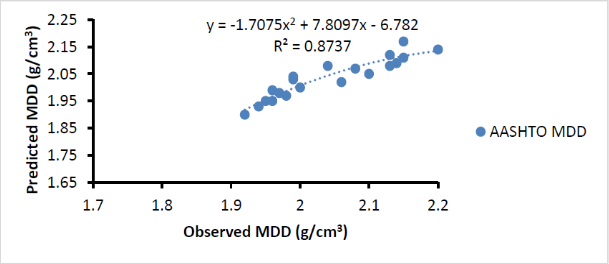
Results from the table 5 also show that steel slag (P-value = 1.04067E-06 < 0.05), cement (P-value = 8.73033E-09 < 0.05) and compactive efforts (P-value = 1.04887E-11 < 0.05) have significant influence on the optimum moisture content of the soil. The influence of compactive effort on the OMC was the highest, followed cement while the impact of steel slag was the lowest.



(a) BSL compaction



(b) WAS compaction



(c) Modified AASHTO compaction

Fig. 3. Observed and predicted MDD values for various compactive efforts:
a) BSL compaction; b) WAS compaction; c) modified AASHTO cmpavction.

Regression analysis of results for the optimum moisture content that considered steel slag content, cement content, and plasticity index and compactive efforts are as presented in Figure 5. These results showed that plasticity index had the most significant effect on the optimum moisture content of the lateritic soil with positive coefficient. The correlation coefficient values (R) indicates a strong relationship between OMC and the parameters in equation (2) with R^2 value of 83.1%. The regression model in equation (2) indicates a strong correlation between the observed OMC values (Figure 5, a-c) from the experimental test and the predicted values from the model with coefficient of determination with R^2 values of 0.75, 0.87 and 0.91 for BSL, WAS and AASHTO compaction energy, respectively.

$$\mathrm{OMC} = -0.0724\ \mathrm{SS} - 0.19114\ \mathrm{C} - 0.59625\ \mathrm{CE} + 0.043249\ \mathrm{PI} + 11.32311 \tag{2}$$

where SS are Steel slag, C are cement, CE are Compactive effort

3.4. California bearing ratio

The impacts of compactive efforts, steel slag (SS) and cement on the unsoaked California bearing ratio (CBR) of the lateritic soil are presented as shown in Figure 6. From the figure, the unsoaked CBR values generally increased with increase in SS content and cement content. For BSL compaction, the unsoaked CBR values increased from 22% for 0% SS / 0% cement to a peak value of 48% at 20% SS / 4% cement. The unsoaked CBR values for WAS compaction increased from 31% for 0% SS / 0% cement to 81% at 20% SS / 6% cement. In addition, the CBR for

AASHTO compaction reached a peak value of 86% at 20% SS / 6% cement from 43% for 0% SS / 0% cement. These results also indicated that unsoaked CBR increased as the compactive efforts increased from BSL compaction to Modified AASHTO compaction, which is an indication the denser the soil as a result of larger compactive effort the higher the strength of the lateritic soil. This is also in agreement with the findings reported by Ijimdiya and Igboro [50]. It is very clear from the results that the stabilised soil can be used as sub-base course based on the recommendation of Gidigasu and Dogbey [51], which proposed a minimum CBR value of 20-30% for sub-base course and 60-80% for base course of flexible pavement when compacted at optimum moisture content and 100% West African standard.

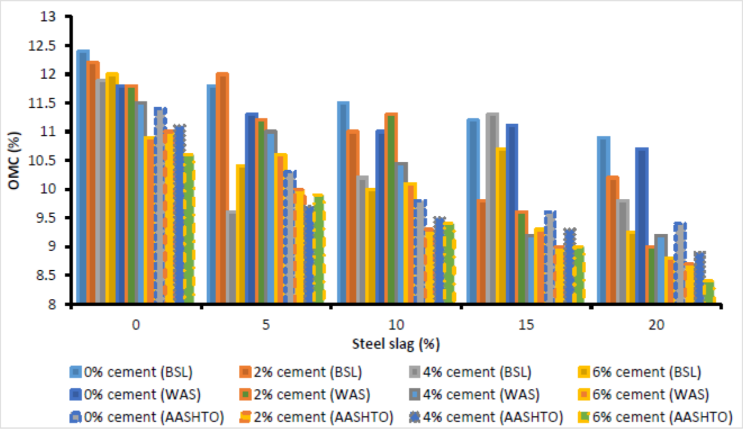
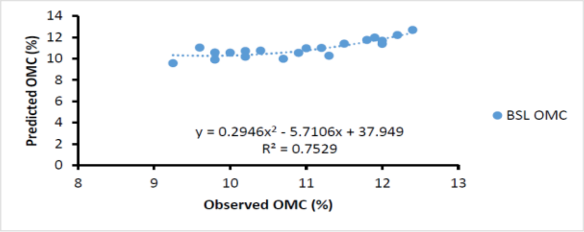
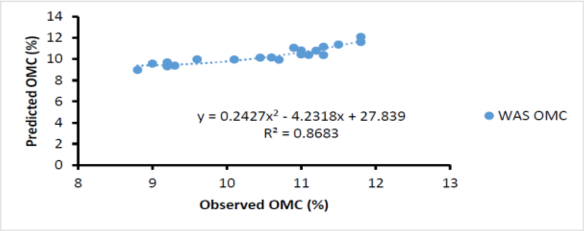


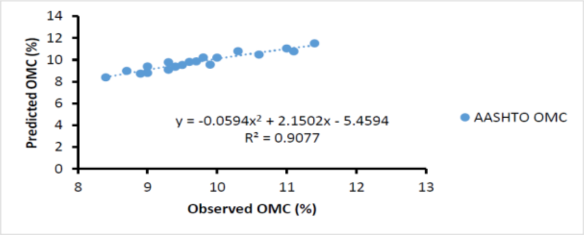
Fig. 4. Influence of compactive effort, steel slag and cement on OMC.



(a) BSL compaction



(b) WAS compaction



(c) Modified AASHTO compaction

Fig. 5. Predicted and Observed OMC values under different compactive efforts:
a) BSL compaction; b) WAS compaction; c) modified AASHTO cmpavction.

Figure 8 presents the influence of compactive efforts, ordinary Portland cement and steel slag (SS) on the soaked CBR of the soil. For BSL compaction, the soaked CBR decreased slightly with increasing quantity of steel slag but showed a very increase with increase in cement content. The CBR values decreased from 8% and 13% for 0% SS / 2% cement and 0% SS / 6% cement to 4% and 9% at 20% SS / 2% cement and 20% SS / 2% cement, respectively. However, the soaked CBR values for WAS and AASHTO compactions increased with both increase in steel slag and cement contents. The CBR for WAS compaction increased from 10% and 24% for 0% SS / 0% cement and 0% SS / 6% cement to 38% and 56% at 15% SS / 6% cement and 20% SS / 6% cement. The same trend of increase in CBR values with steel slag and cement was also observed under AASHTO compaction. The decreased in soaked CBR under BSL compaction with increase in steel slag could be as a result of more voids presence that allowed for higher penetration of water in BSL compared to WAS and AASHTO, thereby causing reduction in soil strength. The soaked CBR value for all three energy levels was lower than that of unsoaked CBR due to the ingress of water into the slag-cement-soil mixtures which weakened it and reduced its strength.

Effects of steel slag, cement and compactive effort on the soaked and unsoaked California ratios (CBRs) of the soil were examined using ANOVA at 5% level of significance and results of the examination are presented in Table 6. Results indicate steel slag (P-value = 0.015164982 < 0.05), cement (P-value = 0.023650812 < 0.05) and compactive efforts (P-value = 0.001506938 < 0.05) as having statistically significant effects on the unsoaked CBR of the lateritic soil. The influence of compactive effort on the MDD was the highest, followed steel slag while the impact of cement was the lowest. However, for soaked CBR, the compactive effort (P-value = 0.000545962 < 0.05) was the most significant, followed by that cement (P-value = 0.011798285 < 0.05) while that of steel slag (P-value = 0.037198396 < 0.05) was the lowest.

Impacts of steel slag content, cement content, plasticity index, compactive efforts, MDD and OMC on the unsoaked and soaked CBR was analysed using regression analysis, and the outcome of the analysis is as presented in Figures 7 and 9. For unsoaked CBR, it is observed from the result that steel slag content, cement content, plasticity index, compactive efforts, MDD and OMC had the most significant effect on the CBR of the lateritic soil with positive coefficient. The value of the coefficient of correlation (R^2) of 85.4% is an indication of a strong relationship between unsoaked CBR and the parameters in equation (3). The regression model in equation (3) indicates a strong correlation between the observed unsoaked CBR values (Figure 9, a-c) from the laboratory test and the predicted values from the model with coefficient of determination with R^2 values of 0.86, 0.90 and 0.95 for BSL, WAS and AASHTO compaction energy, respectively. The result of the regression analysis on the soaked CBR showed the steel slag content, cement content, plasticity index, compactive efforts and OMC as the parameters that had a very significant effect. The value of the coefficient of correlation (R^2) of 64% for soaked CBR is lower than that of the unsoaked CBR, even though it’s also evidence of strong relationship between the soaked CBR and the parameters in equation (4). Figure 10 also showed a strong the observed and predicted soaked CBR of the various energy levels except that of BSL compaction.

$$\text{Unsoaked CBR} = 20.125\text{MDD} + 2.3\text{OMC} + 0.628\text{SS} + 3.19\text{C} + 16.36\text{CE} - 1.20\text{PI} - 15.11 \tag{3}$$

$$\text{Soaked CBR} = -41.10\text{MDD} + 2.640\text{MC} + 0.80\text{SS} + 3.10\text{C} + 19.30\text{CE} - 0.66\text{PI} + 65.67 \tag{4}$$

where SS are Steel slag, C are cement, CE are Compactive effort, PI are Plasticity index.

Table 6. Influence of compactive effort, Cement, SS and PI on CBR of the soil using ANOVA at 5% significant level.

CBR	Source of variation	Standard Error	P-value	Lower 95%	Upper 95%	Remark
Unsoaked	SS*	0.435837554	0.015164982	0.219438589	1.96704196	Significant
	C*	0.806528396	0.023650812	0.261129965	3.495114118	Significant
	CE*	4.425671994	0.001506938	5.925912288	23.67178852	Significant
Soaked	SS	0.494038068	0.037198396	0.064959972	2.045933352	Significant
	C	0.914229916	0.011798285	0.550035995	4.215877241	Significant
	CE	5.01666371	0.000545962	8.384039655	28.49964999	Significant

* *SS = Steel slag, C = Cement, CE = Compactive effort*

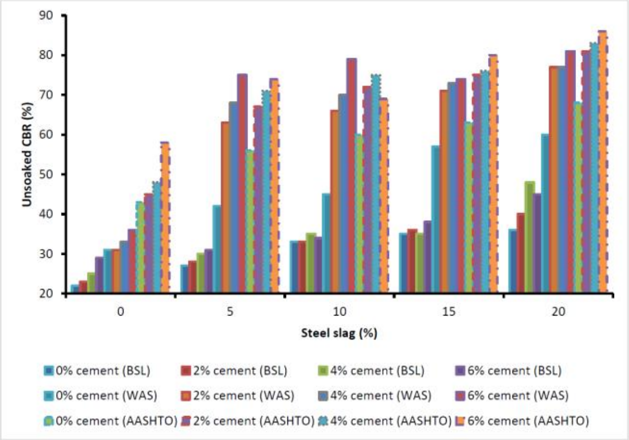
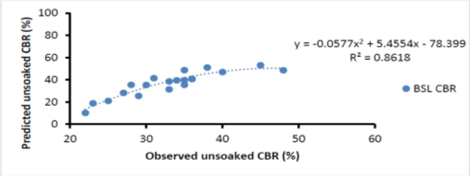
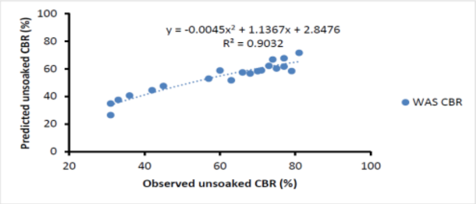


Fig. 6. Impact of compactive effort, steel slag and cement on the unsoaked CBR.

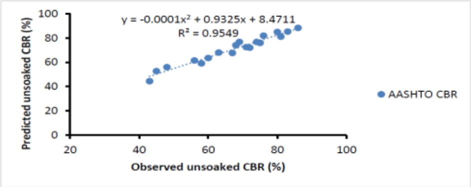


(a) Unsoaked CBR for BSL Compaction

(b)



(c) Unsoaked CBR for WAS Compaction



(d) Unsoaked CBR for Modified AASHTO Compaction

Fig. 7. Observed and predicted unsoaked CBR values for various compactive efforts.

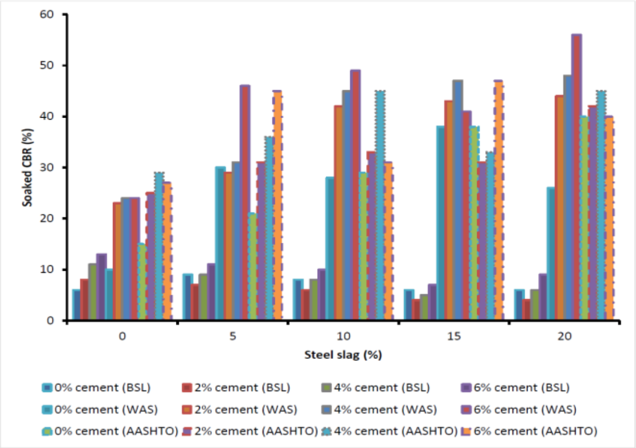
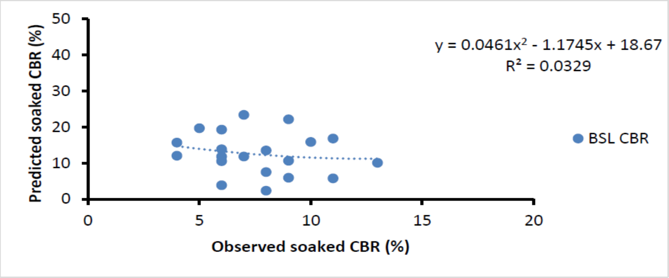
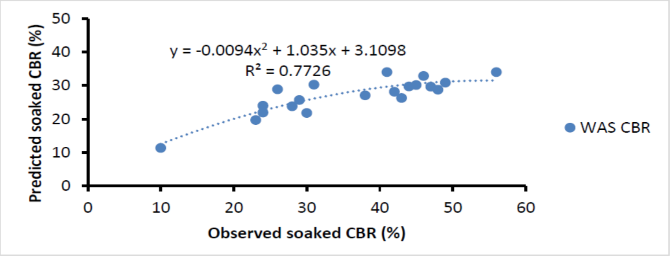


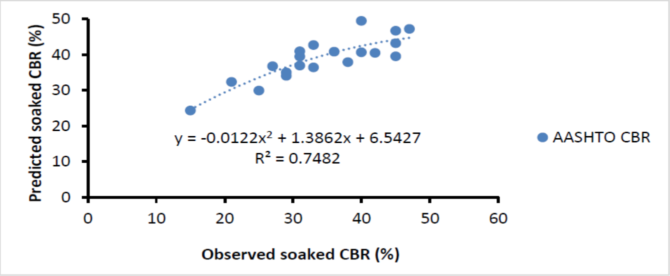
Fig. 8. Impact of compactive effort, steel slag and cement on the soaked CBR values of the lateritic soil.



(a) Soaked CBR for BSL Compaction



(b) Soaked CBR for WAS Compaction



(c) Soaked CBR for Modified AASHTO Compaction

Fig. 9. Observed and predicted soaked CBR values for various compactive efforts:
a) Ssoaked CBR for BSL compaction; b) soaked CBR for WAS compaction; c) soaked CBR for modified AASHTO compaction.

4. CONCLUSIONS

Based on the results of the oxide composition of the additives (steel slag (SS) and ordinary Portland cement) and various geotechnical tests conducted on the lateritic soil classified as A-6 (9) and SC (Clayey sand or clay-sand mixtures) in conformity with USCS and AASHTO soil classification systems respectively, the following conclusions were made:

(i). The result of the oxide composition on the two additives showed that the summation of ($SiO_2 + Al_2O_3 + Fe_2O_3$) for steel slag was 97.06%, which is more than 70%, and the loss on ignition of the slag of 0.002 was also less than 6% recommended for class F pozzolanic material by ASTM C618-12 [41]. This steel slag can therefore be categorized as Class F pozzolan.

(ii). The liquid limit (LL) and plasticity index (PI) of the soil decreased significantly with the increasing contents of the steel slag and cement, but plastic limit increased as the two additives increased. The result of the 2-way analysis of variance showed that steel slag and cement have statistically significant effects on the consistency of the lateritic soil. However, the impact of steel slag that is a waste material is quite significant than cement. This shows that steel slag can be sustainably used to improve workability of this soil.

(iii). The soil maximum dry density (MDD) increased significantly with increasing contents of steel slag and cement. The MDD values for BSL, WAS and Modified AASHTO ranged from 1.73 - 1.93 g/cm^3, 1.77 - 2.10 g/cm^3 and 1.92 - 2.20 g/cm^3, respectively. This implies a 11.56%, 18.64% and 14.58% increase in the MDD of the soil under BSL, WAS and modified AASHHTO, respectively. The increase in the values of MDD is as a result of densification of the lateritic soil mass due to rise in compaction energy. ANOVA and Regression analyses of MDD values showed that compactive effort has the most significant effect followed by the steel slag while cement showed the least effect on MDD of the lateritic soil.

(iv). The optimum moisture content (OMC) decreased with an increase in compactive effort, as well as increasing steel slag and cement contents. The OMC values for BSL, WAS and Modified AASHTO decreased from 12.4 - 9.25%, 11.8 - 8.8% and 11.4 - 8.4%, respectively. The decreased in OMC as the compactive efforts increased is as a result of reduction of voids present in the soil due to increase in the density of the soil. Results of ANOVA and regression analyses also revealed that compactive effort, cement, steel slag had significant effect on the optimum moisture content.

(v). California bearing ratio (unsoaked and soaked) increased as the compacting efforts, steel slag and cement increased from BSL compaction to Modified AASHTO compaction, which is an indication that the denser the soil as a result of larger compactive effort the higher the strength of the soil.

(vi). It is very clear from the results that the stabilized soil (at 5% Steel slag / 2% cement contents and beyond) satisfies the requirement to be used as sub-base course based on the recommendation of Gidigasu and Dogbey [51], which proposed a minimum CBR value of 20-30% for sub-base course and 60-80% for base course of flexible pavement when compacted at optimum moisture content and 100% West African standard.

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