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COMPARATIVE EFFECTS OF SELECTED WASTES ON THE INDICES AND STRENGTH PROPERTIES OF LATERITE SOIL

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Abstract

This study carried out comparative analyses of the potentials of induction furnace slag (IFS), rice husk ash (RHA) and saw dust Ash (SDA) on the geotechnical properties of the A-7-6 and CL classified laterite soil obtained from Imota, Lagos State. By these classifications, the laterite soil is a poor subgrade material that requires stabilization before it could be utilized for engineering applications. Moreover, IFS, RHA and SDA are agro-industrial waste materials, whose poor disposal systems pose serious concerns to the environment. As one of the sustainable ways of reusing these wastes, the laterite soil was treated with 0-10% of these wastes by mass of the soil sample. The impacts of these admixtures on the grain size distribution, specific gravity, Atterberg limits, compaction, uniaxial compressive strength (UCS) and California bearing ratio (CBR) were determined based on relevant standard procedures. The study revealed that the percentage of specimen passing 0.075 mm sieve increased with increase in admixture contents. However, the specific gravity of the soil decreased with the addition of RHA and SDA but increased significantly with IFS treatment. The plasticity index of the stabilized samples reduced with increasing IFS content, while it increased with RHA and SDA additions. UCS values increased from 108.90 kPa for the natural soil to 150.90 kPa, 146.57kPa and 121.52 kPa at 10% addition of IFS, RHA, and at 8% SDA, respectively. The CBR increased from 63.38% for the natural soil to 157.19%, 98.98% and 88.94%, and from 9.12% to 38.59%, 24.74% and 14.13%, for IFS, RHA, and SDA, respectively under unsoaked and soaked conditions, respectively at 10% stabilization. The research findings indicate that IFS have significant impacts on soil properties than RHA and SDA, and the addition of 4% IFS makes this soil a suitable material for both subgrade and sub-base road courses.

1.0 INTRODUCTION

Lateritic soil is a chemically weathered residual soil, formed by the process of decomposition of Ferro-Alumino Silicate minerals and the permanent deposition of Sesquioxides (Iron and Aluminium Oxides) within the soil profile [1]. Due to this high Sesquioxide contents, lateritic soil has a granular microstructure and low compressibility [2]. Lateritic soil is commonly utilised in civil engineering works in many parts of Nigeria due to its availability and cost effectiveness [3]. It constitutes the significant portion of materials for the construction of embankments, earthen dams, engineered landfills, and subgrade, sub-base, and base profiles of highways, plastering and brick moulding for buildings [4-7]. Lateritic soils are weak soils and need enhancement of their engineering

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properties prior to being utilised for construction works [8].

A popular means of enhancing soil properties is chemical stabilisation through the addition of cement and lime. Latest developments in cement chemistry coupled with the need to minimise carbon footprints of construction has led to the substitution of cement with other cementitious materials, especially wastes from agricultural and industrial processes [9-12]. Induction furnace slag (IFS) is generated during heating and melting of metals or alloys at high temperatures in an induction furnace. It is a byproduct of the interaction between the molten metal and other substances such as fluxes and oxides used in the induction process. It is a crystalline, granular, and glassy material of varying colour and texture depending on the melted metal or alloy. It may contain contaminants, hence appropriate disposal or effective handling is essential to lessen its environmental impact. When processed properly, it can be incorporated into the production of concrete in a similar manner like ground granulated blast-furnace slag (GGBFS), because of its high silica content and potential pozzolanic nature [13, 14].

Rice husk ash (RHA) the residual ash from the combustion of the outer protective layers of rice grains, a byproduct of rice processing, and a common agricultural waste product which is generated to the tune of about 2 million tons annually in Nigeria. RHA has been extensively used as partial replacement for cement in concrete mixes; it has a high silica content, finer particles, and exhibits strong pozzolanic reactivity [15-17]. Saw dust ash (SDA) is a byproduct from the combustion of sawdust, another waste material from wood processing. It can be reused in the production of wood-based products like particleboard, fibreboard, or cardboard. More than a million metric cube of sawdust were produced in Nigeria in 2010, a significant amount of it ends up improperly disposed, constituting environmental nuisance and contaminating both soil and water [18, 19].

In this research, the effects of IFS, RHA, and SDA on index and strength properties of lateritic soils taken from Imota, Lagos state, Nigeria are examined. The physical properties of the lateritic soil sample were determined, the effects of varying percentages of IFS, RHA, and SDA on geotechnical parameters such as particle size distribution, Atterberg limits, moisture-density curve, isotropic compression, and California Bearing Ratio (CBR) of the lateritic soil were investigated.

2.0 METHODOLOGY

2.1 Materials

Lateritic soil sample was collected by using bulk disturbed sampling method from a borrow pit at a depth of 1.5 m in Imota [6° 39' 23" N, 3° 47' 43" E], Lagos State, Nigeria. The samples were sealed in polythene sacks and transferred to the geotechnical laboratory of the Department of Civil Engineering, University of Lagos (UNILAG), Lagos, Nigeria, for experimental tests. IFS was collected from the Nigeria foundries limited, Ota, Ogun State, Nigeria. This material was crushed and grinded to reduce the particle size to pass 0.425mm diameter sieve before it was used in this research. The rice husk was collected in its natural form from rice mills industry in Lagos, and then burnt into ash at 550°C in the laboratory. The saw dust was obtained from sawmill in Lagos and was also burnt into ashes in a furnace at 600°C in the laboratory.

2.2 Experimental Tests and Methods

The soil sample was tested for specific gravity, Atterberg limits and Sieve Analysis. IFS, SDA, and RHA were added at ratios 2, 4, 6, 8, and 10% by weight of the samples and the tests repeated. Compaction, CBR, and Unconfined Compressive Strength (UCS)] tests were performed on the lateritic soil and varying mixes of IFS, SDA, and RHA. All tests were carried out according to the relevant sections of 1377-2;2022 [20].

3.0 RESULTS AND DISCUSSION

3.1 Chemical Composition of the Laterite Soil, FSS, RHA and SDA

Table 1 presents the results of the chemical analyses conducted on the laterite soil sample, IFS, RHA, and SDA. These results reveal that the sum of Silica, Alumina and ferrite present in the IFS, RHA, and SDA are 77.74%, 83.97% and 73.08% respectively. These values are higher than the minimum of 70% recommended for good pozzolanic material by BS 8615 [21, 22]. Likewise, the SiO_2 contents for the materials exceeds the minimum 25% specified, the reactive CaO contents of 5.54%, 1.55% and 9.66% for IFS, RHA and SDA, respectively are lower than 10%, the 5.0% specified limit for Alkali content (sodium oxide equivalent i.e., $Na_2O + 0.658\ K_2O$) was also met by the three materials [21, 22]. Hence, IFS, RHA and SDA are good pozzolanas. Their corresponding CaO to silica ratios are 0.12, 0.02 and 0.15, respectively. The silica ratio of the natural soil as determined from Table 1 is 0.27. This lower value of 0.27 shows that the soil is a laterite soil as the silica ratio falls between 0 and 1.33 specified for laterite soil by [23]. The higher sesquioxide (Al_2O_3 and Fe_2O_3) value in the soil is an indication of higher proportion of clay minerals in the soil, which has high tendency of swelling-shrinkage behaviours of the soil. Without stabilization, this soil is therefore structurally unstable to resist traffic loadings and surface distortions [24].

Table 1: Chemical constituents of laterite soil, IFS, RHA and SDA

Oxide composition	Laterite soil	IFS	RHA	SDA
SiO_2	15.87	44.62	81.20	65.80
Al_2O_3	39.56	10.09	1.51	5.21
Fe_2O_3	20.08	23.03	1.27	2.07
CaO	9.15	5.54	1.55	9.66
MgO	11.20	1.60	2.30	4.10
MnO	0.03	9.70	-	-
Na_2O	0.001	0.39	0.14	0.05
K_2O	0.12	0.31	2.04	2.40
P_2O_5	0.001	0.07	6.45	-
SO_3	-	0.32	0.17	1.10
L.O.I	0.03	9.95	-	4.28
Silica Ratio	**0.27**	-	-	-
$SiO_2 + Al_2O_3 + Fe_2O_3$		**77.74**	**83.97**	**73.08**

3.2 Geotechnical Properties of the Laterite Soil

Table 2 presents the geotechnical properties of the laterite soil specimen. The percentage of the soil passing sieve size 0.075 mm was 43.02%, which is higher than the maximum percentage finer of 35% specified for particle distribution by the Nigerian Federal Ministry of Works Specification [25]. Thus, the natural soil specimen requires stabilization before it could be suitable for road applications. The results of Atterberg limits of the natural soil showed the LL, PL, and PI of 43.35%, 23.38% and 19.97% respectively. From these results, the laterite soil can be grouped as an A-7-6 (poor subgrade material) soil and *CL* (inorganic clay with low plasticity) in line with AASHTO and USCS classification systems.

It is obvious from these results that the soil sample is a poor subgrade soil which requires stabilization or modification before it could be used as a competent material for road layers. Figure 1a, 1b and 1c show the particle size gradation plots for the laterite soil mixed with varying percentages of IFS, RHA, and SDA, respectively. From the plots, the percentage passing sieve 0.075 mm generally increased with the increasing contents of the three binders, and these trends were more evident for the induction furnace slag and rice husk ash. These results clearly show that as the binders' contents increased, the soil-binder mixtures become finer, and these behaviours could be advantageous in filling the pour spaces and enhancing the inter particle bonds between the binders and the soil.

Table 2: Geotechnical properties of the laterite soil

Properties	Results
Percentage finer (0.075 mm sieve)	43.02
LL (%)	43.35
PL (%)	23.38
PI (%)	19.97
Specific gravity	2.51
AASHTO classification	A-7-6
USCS classification	CL
Initial water content	8.39
MDD (g/cm^3)	1.55
OMC (%)	17.7
CBR (Soaked, %)	9.12
CBR (Unsoaked, %)	63.38
UCS (kPa)	108.90

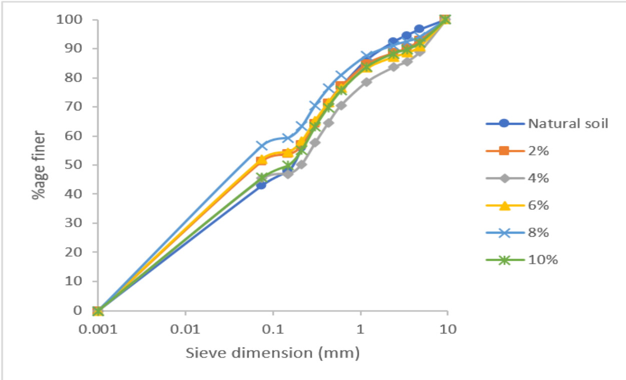

Figure 1a: Effect of IFS addition on soil gradation

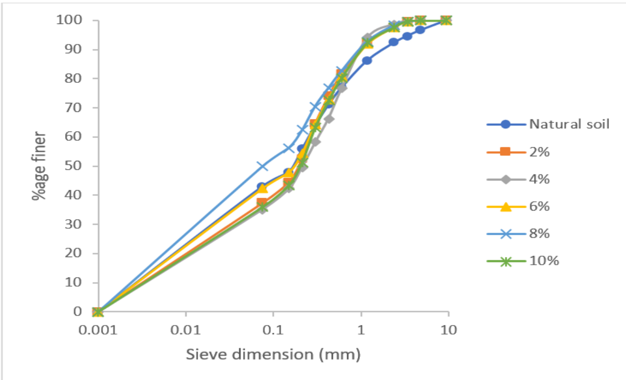

Figure 1b: Effect of RHA addition on soil gradation

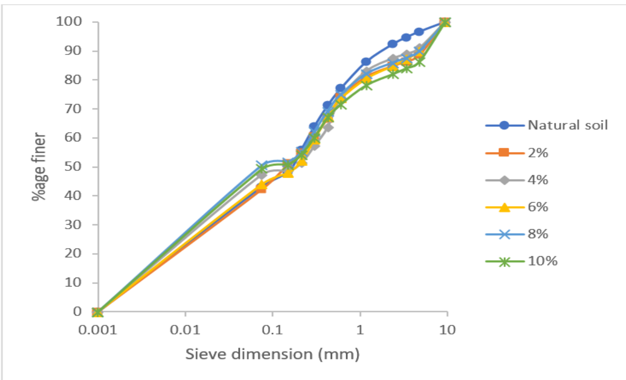

Figure1c: Effect of SDA addition on soil gradation

3.3 Effect of the Selected Binders on Specific Gravity (SG)

The influence of varying percentages of IFS, RHA, and SDA on the specific gravity (SG) of the laterite soil sample is presented in Figure 2. The SG of the laterite sample, IFS, RHA, and SDA are 2.51, 3.58, 2.20 and 2.35, respectively. The Figure shows a significant increase in the SG with the addition of IFS from 2.51 for the natural soil to 2.83 at 10% addition, which represents about 12.7% in specific gravity. However, the addition of the RHA and SDA to the laterite soil reduced the SG of the soil from 2.51 to 2.24 and 2.4 at 10% addition of RHA and SDA, respectively. This increased SG value for IFS stabilized soil could be due to higher specific gravity of the induction furnace slag when compared with those of RHA and SDA. These findings suggest that induction furnace slag can be effectively utilized to enhance the specific gravity and density of the laterite soil.

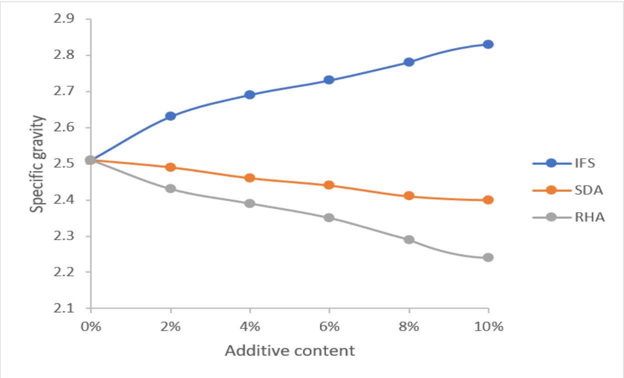

Figure 2: Influence of IFS, RHA, and SDA on the SG of the laterite soil

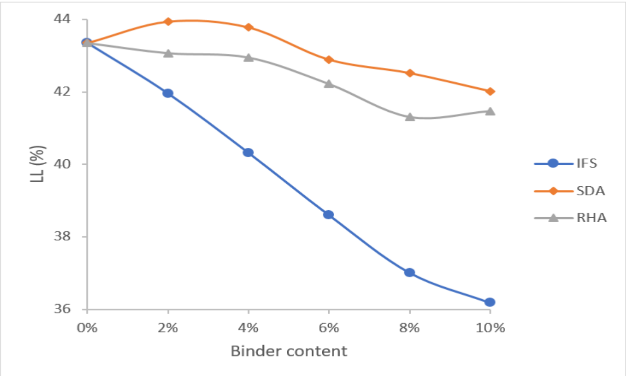

Figure 3a: Influence of IFS, RHA, and SDA on liquid limit of the laterite soil

3.4 Influence of the Admixtures on Consistency Limit

The effect of increasing percentages of IFS, RHA, and SDA on the Atterberg limits of the laterite soil is presented in Figure 3(a-c). From Figure 3a, the liquid limit (LL) decreased from 43.35% for the natural soil to 36.18%, 41.47% and 42.02% at 10% addition of IFS, RHA, and SDA, respectively. These results show that IFS can be used to lower the liquid limit of the laterite soil. Figure 3b reveals an increase in the plastic limit (PL) as the percentages of the three binders increased from 0-10%, even though the highest values were observed to be between 2% and 4%. The effects of IFS, RHA, and SDA on the plasticity index (PI) of the soil are shown in Figure 3c. The addition of IFS continuously reduced the PI from 19.97% to 12.4% at 0% and 10% IFS additions, respectively. However, the addition of RHA and SDA slightly decreased the plasticity index from 19.97% for the natural soil to 19.2% and 17.67% at 8% of RHA and SDA, respectively.

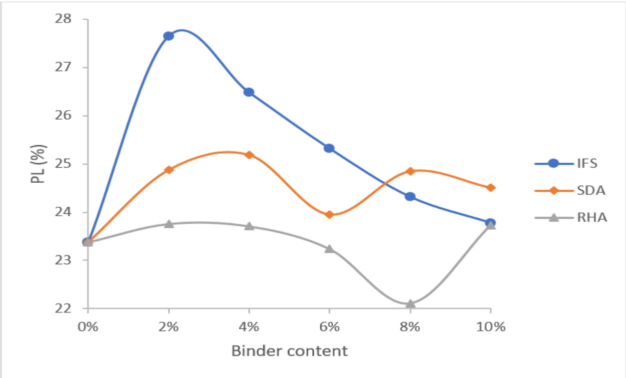

Figure 3b: Influence of IFS, RHA, and SDA on plastic limit of the laterite soil

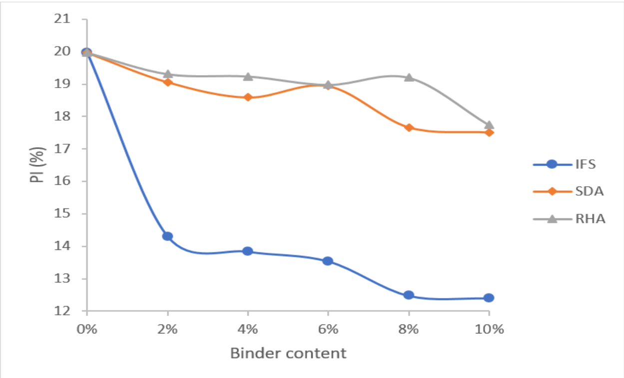

Figure 3c: Influence of IFS, RHA, and SDA on plasticity index of the laterite soil

The significant decline in PI with the addition of IFS can be linked to the higher specific gravity of the IFS, which caused a decrease in clay content of the sample, thereby increasing the workability of the soil [26-28]. The variations of the laterite soil under the influence of IFS, RHA, and SDA on the relationship between the LL and PI index are shown in Figure 4. The results show that the soil type, which is low plasticity clayey soil (*CL*), remained unchanged with the addition of SDA and RHA. However, the stabilization of natural soil with IFS changed the soil type from clay soil with low plasticity (*CL*) to low plasticity silty soil (*ML*), which thereby makes the soil to be more workable.

This reveals that IFS can be effectively used to improve the plasticity of the laterite soil, due to the reduction in the thickness of double layer when the slag is in contact with water, leading to flocculation and agglomeration of the clay particles, hence the agglomeration modified the clayey soil to silty soil [29].

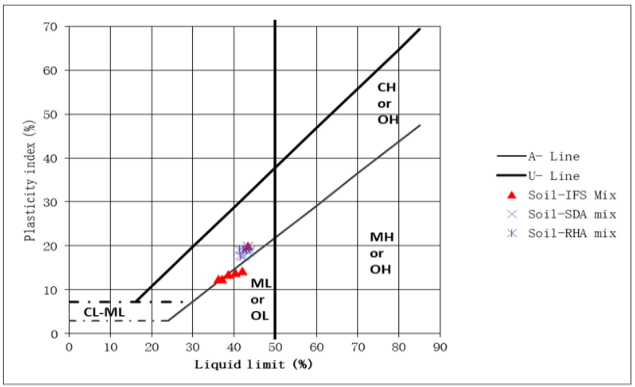

Figure 4: Classification of laterite soil stabilized with some selected admixtures on plasticity chart

3.5 Influence of the Selected Binders on Compaction Parameters

The effects of increasing percentages of IFS, RHA, and SDA on the maximum dry density (MDD) and optimum moisture content (OMC) of the laterite soil are shown in Figure 5. The MDD for soil stabilized with IFS increased from 1.55 – 1.83 g/cm^3 with increasing slag content from 0 – 6%, the MDD value was reduced beyond 6% addition and fell to 1.75 g/cm^3 at 10% IFS. For samples treated with 0 – 10% RHA, the MDD values increased continuously from 1.55 to 1.75 g/cm^3. The addition of SDA to the laterite soil also improved the soil dry density from 1.55 to 1.66 g/cm^3 but fell with further addition of SDA. These results revealed that MDD increased with increasing contents of these admixtures from 0-6%. However, the impact of IFS is more significant than those of RHA and SDA due to its higher specific gravity.

The increase in MDD values could be attributed to the pozzolanic reactions of the admixtures with the laterite soil in the presence of lime which caused the agglomeration of soil and formation of larger soil particles with increased weight that resulted in higher density. Figure 5b shows the behaviour of the OMC with the addition of IFS, RHA, and SDA. The OMCs became lower at higher MDD values and vice versa for all the three admixtures. This behaviour was also observed by [19, 24]. These studies attributed the decrease in OMC to water consumption due to hydration process during soil mixing and compaction.

The results of this study clearly show that the IFC can be utilized in enhancing the compaction parameters of this laterite soil. This observation agrees with the previous findings [28, 30].

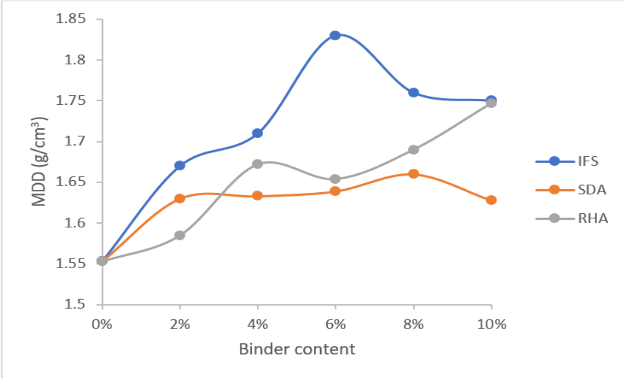

Figure 5a: Influence of the selected binders on MDD of the laterite soil

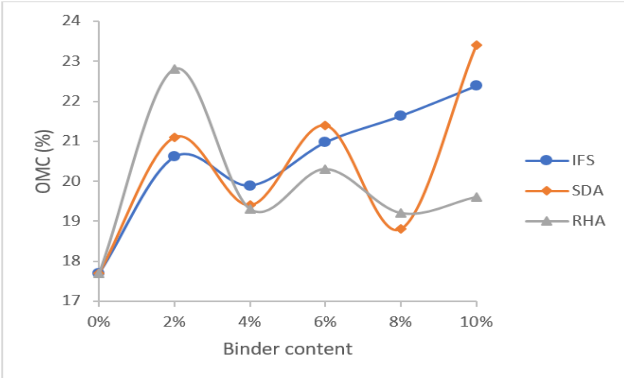

Figure 5b: Influence of the selected binders on OMC of the laterite soil

3.6 Influence of the Binders on California Bearing Ratio (CBR)

The influence of increasing percentages of IFS, RHA, and SDA on soaked and unsoaked CBR of Imota laterite is presented in Figure 6. The CBR increased from 63.38% for the natural soil to 157.19%, 98.98% and 88.94% at 10% stabilization for IFS, RHA, and SDA, respectively under unsoaked conditions. For the soaked soil conditions, the corresponding CBR values also increased from 9.12% to 38.59%, 24.74% and 14.13%, respectively. These results show a general increase in the CBR of the laterite soil, as the volume of the IFS, RHA and SDA increased for both soaked and unsoaked soil conditions, even though the rate of increase was more significant with the addition of IFS when compared with those of RHA and SDA due to its higher specific gravity. The increase in CBR of the stabilized soil is due to the increase in inter-particle cohesion and zeolite crystallization resulting from the pozzolanic reactions of the silicates, aluminates, and alkali ions [31-33]. The CBR of the unsoaked samples are higher than those of soaked ones due to increased shear strength of dry samples when compared to that of the soaked specimens.

According to the Nigerian General Specification for Roads and Bridge Works [25], the minimum soaked CBR values recommended for subgrade and subbase road layers are 6% and 30%, respectively. Therefore, the laterite soil treated with IFS from 2% addition to soil satisfies the required specification for its application for both subgrade and subbase material for light and heavy traffic roads. However, those stabilized with RHA and SDA can only be utilized as subgrade materials. The findings clearly show that the application of these waste materials for soil stabilization would not only ameliorate their environmental hazards but also enhance the strength characteristics of the laterite soil. By this application, the quantity of cement and other expensive stabilizers currently used for soil improvement will be significantly reduced.

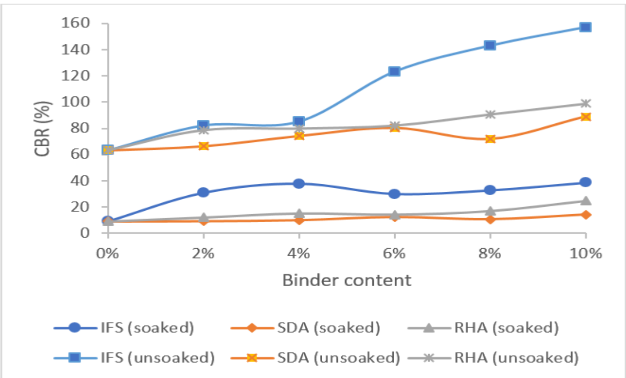

Figure 6: Influence of the three binders on CBR of the laterite soil

3.7 Influence of the three binders on unconfined compression strength (UCS)

The impacts of increasing percentage replacements of the laterite soil with IFS, RHA, and SDA on the UCS of the laterite-binder mixtures are presented in Figure 7. The UCS values increased from 108.90 kPa for the natural soil to 150.90 kPa, 146.57kPa and 117.06 kPa at 10% addition of IFS, RHA, and SDA, respectively. It is evident from the results that the soil strength generally increased with increasing percentage replacements of soil with IFS, RHA, and SDA, with highest strengths observed for IFS and RHA at 10% replacement, except for SDA at 8% addition. The increase in soil strength of 39%, 35% and 12% was observed with the addition of IFS, RHA, and SDA, respectively, when compared to that of the natural laterite soil. The increase in UCS value of the IFS, RHA and SDA stabilized soil samples is due to increased inter particle cohesion and zeolite crystallization resulting from the pozzolanic reactions of the silicates, aluminates, and alkali ions [29, 30]. These observations agree with the findings of the earlier researchers [24, 33]. Unlike the observation by Yadu and Tripathi [34], which reported a decreased in soil strength beyond 9% addition of granulated steel slag, the findings of this study show a continuous increase in UCS value up to 10%. The difference in these findings could be because of the variations in the compositions of the steel slag used. Although, the result of this study is consistent to the previous works that reported increase in strength beyond 9% stabilization with steel slag [30, 35].

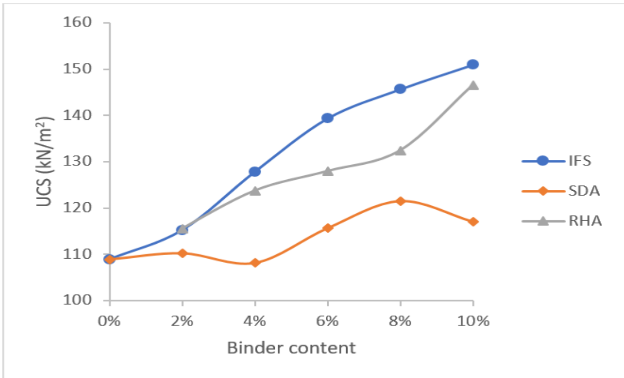

Figure 7: Impact of the binders on UCS of the laterite soil

4.0 CONCLUSIONS

Comparative study on the stabilization of laterite soil with induction furnace slag, rice husk ash and saw dust ash had been conducted, with the following conclusions observed from the work:

i. The oxide composition of the laterite showed aluminium oxide as the dominant oxide, with a silica ratio of 0.27. The sum of silica, alumina and ferrite present in the IFS, RHA and SDA are 77.74%, 83.97% and 73.08% respectively. These values are higher than a minimum of 70% recommended for good pozzolanic material by ASTM C618. Hence, these materials are good pozzolans.
ii. The laterite soil is classified as A-7-6 soil and CL (low plasticity clay) according to AASHTO, and USCS classification and hence, the soil is a poor subgrade material.
iii. The findings showed that liquid limit and plasticity index of the stabilised laterite soil decreased with increasing contents of IFS, RHA, and SDA, which thereby improved the workability of the laterite soil.
iv. Stabilizing the soil with these admixtures enhanced the compaction characteristics of the soil. The results revealed that MDD increased with increasing contents of the three admixtures from 0-

6%. However, the impact of IFS was more significant than those of RHA and SDA due to higher specific gravity of the slag. This suggests that IFS can be effectively utilized in increasing the dry density of the laterite soil.

v. Treatment of the poor laterite soil with IFS, RHA and SDA was found to have improved the soaked and unsoaked CBR and UCS from 0-10% additions of the stabilizers. The laterite soil treated with IFS from 2% addition to the soil satisfies the required specification for its application as both the subgrade and subbase materials for light and heavy traffic roads in accordance with Nigerian General Specifications for Highways and Bridges. However, those stabilized with RHA and SDA can only be utilized as subgrade materials.

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