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EVALUATION OF BLENDS OF CALCIUM CARBIDE WASTE AND IRON SLAG DUST AS STABILIZER IN FLEXIBLE PAVEMENT CONSTRUCTION

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ABSTRACT

Stabilization techniques have often been used globally to enhance properties of weak subgrade materials for flexible pavement construction. This study evaluated the blends of calcium carbide waste (CCW) and iron slag dust (ISD) as an effective stabilizer. Subgrade material sourced from a section along Ota-Idiroko road was initially modified with CCW in different percentage replacements by weight (0, 4, 8, 12, 16 and 20%) and the resulting blends were subjected to Atterberg limit test to determine the blend with optimum plasticity index reduction which would be tagged optimum subgrade lime blend (OSLB). The blend of S + 8% CCW was tagged OSLB because it exhibited optimum plasticity index reduction (14.8 to 8.7%). The OSLB was thereafter blended by weight with ISD in the following percentage replacements (3, 6, 9, 12, 15 and 18%) in order to activate the pozzolanicity of ISD for strength enhancement. The resulting blends were subjected to Atterberg limit, Compaction, California bearing ratio (CBR) and Unconfined compressive strength (UCS) tests with the strength specimens cured for 0, 3, 7, 28, 56 and 90 days. Results showed that OSLB-ISD blends increased Plasticity index of OSLB (8.7 to 13.1%), reduced Maximum dry density to 6% ISD (1.66 to 1.52 Mg/m^3) and Optimum moisture content to 9% ISD (17.2 to 14.5%). Increases in 7 days soaked CBR between 3 to 9% ISD (100.1 to 141.5%) and UCS between 9 to 18% ISD (2298.02 to 3096.27 KPa) were observed. The CBR and UCS results showed that the stabilized blends at 7 days curing upgraded natural subgrade to subbase and base for pavement construction.

Keywords: *weak subgrade soil, flexible pavement, calcium carbide waste, iron slag dust*

INTRODUCTION

Construction of roadways over soft subgrade is one of the most frequent problems for highway construction in many parts of the world (Antonia, 2016). A common approach to soft subgrades is the removal of soil and its replacement with stronger materials like crushed rock which are costly in nature, hence the need for alternative construction methods on soft subgrades (Cetin *et al.,* 2010; Consoli *et al.,* 2016). Soft subgrade stabilization with materials such as cement, lime, rice husk ash, cement kiln dust, steel slag, calcium carbide waste, calcined clay or fly ash has a lower cost to crushed rock (Antonia, 2016).

Modifications in soil's engineering properties are attributed to cation exchange, flocculation, and pozzolanic reaction (Athanasopoulou and Kollaros, 2011). Ultimate cured strength development is gradual but may continue for several years (Mahmoudi *et al.,* 2014; Al-Kiki *et al.,* 2011). Carbonation reactions are harmful to the long-term strength and durability of the lime-stabilized soil. Using sufficient amount of lime (to provide enough alkalinity) compaction of the soil to high density and prompt placement after mixing lime with soil can minimize potential carbonation problems (Antonia, 2016).

The effect of lime on soil's plasticity is immediate. Calcium ions from the lime replace other exchangeable ions, causing flocculation and reduction of the samples plasticity, making them more friable and easily workable (Buhler, 2007).

When lime is added to clay soil, it must first satisfy the affinity of the soil for lime, that is, ions are absorbed by clay minerals and are not available for pozzolanic reactions until this affinity is satisfied (Sajja and Chakravarthi, 2014; Consoli *et al.,* 2014). Because this lime is fixed in the soil and is not available for other reactions, the process has been referred to as lime fixation (Antonia, 2016). Soils that react with lime to produce substantial strength increase (greater than 3.5 kg/cm^3 following 28-day curing at 23^{o}C) are termed as reactive (Toohey *et al.,* 2013). This terminology does not imply that lime modification does not take place (Antonia, 2016).

Steel slag, calcined clay, fly ash, rice husk ash amongst others are useful in many construction applications because they are pozzolanas, meaning they are siliceous or alumino-siliceous materials which on their own possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (ASTM, 2003).

Calcium carbide waste (CCW) is a by-product of acetylene production process that contains calcium hydroxide, has been used for soil stabilization owing to its rich calcium oxide or calcium hydroxide content (not less than 90%)(Horpibulsuk *et al.,* 2013; Kampala & Horpibulsuk, 2013). Engineering characteristics of calcium carbide waste stabilized clay was evaluated by Horpibulsuk *et al.,* (2013) and Kampala & Horpibulsuk (2013) to ascertain the performance in fill and pavement applications. They confirmed that the calcium carbide waste is more effective than the lime stabilization in terms of engineering, economical, and environmental perspectives. Steel slag is a by-product of steel making from separation of molten steel from impurities which has been used for soil stabilization (Abiola *et al.,* 2016). Akinwumi (2012) utilized steel slag in improving the plasticity, UCS and drainage characteristics of lateritic soil. The study showed that the improvement of the soil was limited to application of 8% steel slag.

The use of CCW and steel slag as a soil stabilizing agent is beneficial for improving the engineering properties of the soil, while at the same time it provides an opportunity for the utilization of an industrial waste that will otherwise require costly disposal (Zhang *et al.,* 2016). This study evaluated blends of calcium carbide waste and iron slag dust as an effective stabilizer for flexible pavement construction via Atterberg limit, California bearing ratio and unconfined compressive strength tests.

MATERIALS AND METHODS

Subgrade material was sourced from a section along Ota-Idiroko road at a coordinate of Latitude 60 40' 53.082" N and Longitude 30 9' 11.172" E while Calcium carbide waste and Iron slag dust were sourced from Automobile Workshop and Federated Steel Company, Ota respectively; after which they were air dried, ground to fineness and sieved through 425µm sieve. These materials were subjected to specific gravity, particle size distribution and X-ray fluorescence tests to determine their properties. Firstly, subgrade was modified with CCW by weight in 0, 4, 8, 12, 16 and 20% replacements and the resulting blends were subjected to Atterberg limit test to determine the blend with the optimum plasticity index reduction which was tagged as optimum subgrade lime blend (OSLB). Consequently, the blend of S + 8% CCW exhibited the optimum plasticity index reduction (14.8 to 8.7%). The OSLB (S + 8% CCW) was thereafter blended by weight with iron slag dust (ISD) in the following percentage replacements (3, 6, 9, 12, 15 and 18%) respectively in order to activate the pozzolanic potentials of ISD for strength enhancement. The blends were subjected to Atterberg limit, compaction, California bearing ratio (CBR) (soaked and unsoaked) and Unconfined compressive strength (UCS) tests according to BS 1377 (1990).

However, the specimens for strength test were moist cured for 0, 3, 7, 28, 56 and 90 days respectively.

RESULTS AND DISCUSSION

Physical and Index Properties

The Subgrade material as reflected in Table 1 was classified as A-7-5 (fair to poor subgrade), ML or OL (inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity), MI or OI (inorganic silts / silty sands or organic clays of medium plasticity) according to AASHTO classification, Unified system of soil classification.

The most dense material used for this research is iron slag dust (ISD) (3.3) followed by subgrade (2.5) while the least dense is calcium carbide waste (CCW) (1.81).

Table 1: Physical and Index Properties of Individual Materials

Property	Subgrade	CCW	ISD
Plastic limit (%)	31.2	-	-
Liquid limit (%)	46	-	-
Plasticity index (%)	14.8	-	-
Clay content (<0.002mm)(%)	56.3	2.975	6.75
Silt content (0.002-0.06mm)(%)	61.21	2.975	6.75
Percentage passing sieve 425μm (%)	87.5	50.23	83.5
Percentage passing sieve 75μm (%)	61.21	-	-
AASHTO Classification	A-7-5	-	-
USCS Classification	ML or OL	-	-
IS Classification	MI or OI	-	-
pH	5.8	13.5	10.0
Specific gravity	2.5	1.81	3.3
Colour	Reddish brown	White	Black

X-Ray Fluorescence Test

The subgrade and iron slag dust (ISD) have been found to be pozzolanic materials and they belong to Classes F and C respectively as according to ASTM: C618-08 standard. The standard stipulates that material whose aggregation aggregation of the main oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) is in excess of 70% and having Loss on Ignition (LOI) of maximum of 6% is a class F pozzolana; while material whose aggregation of main oxides is in excess of 50% but not up to 70% and having LOI of maximum of 10% is a class C pozzolana. In the same vein, material whose aggregation of main oxides is in excess of 70% and having Loss on Ignition (LOI) of maximum 10% is a Class N pozzolana. However, the aggregations of the three (3) main oxides for subgrade and iron slag dust (ISD) are 94.01 and 67.96% respectively; while their LOI are 3.10 and 1.60% respectively (Table 2). However, the Table also shows that calcium carbide waste (CCW) contains 93.74% mass fraction of clinker or quick lime (CaO) which makes it a potent binding material/binder with tendency to undergoing hydration reaction when mixed with water just as in the case of cement. The subgrade material can also be classified as a laterite and not a lateritic or non-lateritic material owing to its silica sesquioxide ratio which is 1.11 as revealed by XRF results (Table 2). According to Martin and Doyne (1927, 1930) and Winterkorn and Chandrasekharan (1951) material with a silica sesquioxide ratio of less than 1.33 is laterite, between 1.33 and 2 is lateritic material and above 2 is non-lateritic material.

Silica Sesquioxide ratio of subgrade,

$$\frac{S}{R} = \frac{SiO2}{Al2O3 + Fe2O3} = \frac{49.57}{.86 + 15.58} = 1.11 < 1.33$$

However in contrast, the Silica Sesquioxide ratio according to AFCAP (2013)

$$= \frac{\frac{SiO2}{molecular\ mass}}{\frac{Al2O3}{molecular\ mass} + \frac{Fe2O3}{molecular\ mass}}$$

Therefore, the Silica Sesquioxide ratio ($\frac{S}{R}$) of subgrade according to AFCAP=

$$= \frac{\frac{49.57}{60.08}}{\frac{28.86}{101.96} + \frac{15.58}{159.69}} = \frac{0.825}{0.283 + 0.0975} = \frac{0.825}{0.3805} = 2.168 > 2$$

These results suggest that the subgrade material according to AFCAP (2013) could be classified as a non-laterite owing to its Silica Sesquioxide ratio of 2.168 which is greater than 2 and 1.33 which are boundaries for lateritic material (between 1.33 and 2) and laterite (less than 1.33)

Table 2: The oxide compositions of individual materials according to XRF test

Oxides	Percentage Oxide Contents of Materials		
	Subgrade	ISD	CCW
SiO_2	49.57	23.93	0.83
Al_2O_3	28.86	6.57	0.71
Fe_2O_3	15.58	37.46	0.20
CaO	0.53	12.9	93.74
MgO	0.00	0.0	0.0
SO_3	0.41	5.29	0.7
Na_2O	0.00	0.0	0.0
K_2O	0.16	0.45	0.0
LOI	3.10	1.60	1.04

Atterberg Limits

From Figure 1, it could be seen that the addition of calcium carbide waste (CCW) reduces the plasticity index of Subgrade across board (from 14.8 to 8.7%) with optimum reduction experienced at 8% CCW addition. This might be might be attributed according to Ghobadi *et al.,* (2014) and Wubshet and Tadesse (2014) to the calcium available for cation exchange to take place or the ionic exchange between lime and clay minerals of the soil which led to flocculation and agglomeration of clay particles which in turn reduced the plasticity.

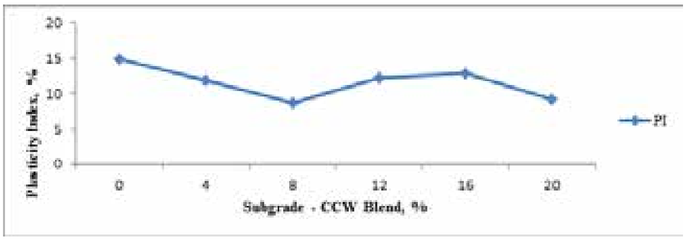

Figure 1: Plasticity Index values of Subgrade - CCW blend

From Figure 2, the addition of ISD at different variations (3, 6, 9, 12, 15 and 18%) to blend of 8% CCW - Subgrade (OSLB) increased the plasticity index across board from 8.7 to 13.1% with optimum increment experienced at 9% ISD.

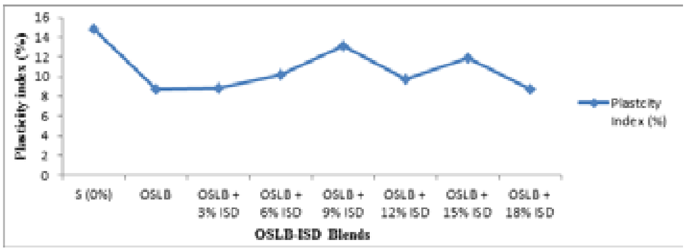

Fig. 2 Plasticity index results of Subgrade – OSLB/ ISD Blends

Compaction Test

As shown in Figure 3, the addition of ISD at different variations (3, 6, 9, 12, 15 and 18%) to blend of 8% CCW- Subgrade (OSLB) reduced the maximum dry density (MDD) from 1.66 to 1.52 Mg/m3 (between 3 to 6% ISD) with optimum reduction experienced at 6% ISD (1.52 Mg/m3) and subsequently increased it to 1.76 Mg/m3 (between 9 to 18% ISD) with optimum increment at 15% ISD. The increment could be attributed to the specific gravity of ISD (3.3) while the reduction experienced with these additives could be as a result of the fact that ISD and CCW being very fine materials, dislocated the granular structure of the Subgrade causing the particles of soil to float in CCW - ISD and thus reducing the MDD, such trend earlier reported by (Ahmed, 1995; Abdullah, 2009; Al-Homidy, 2013; Al-Homidy and Abd El Aal, 2017).

This behavior in terms of reduction in MDD could be adduced to the fact that when a lime or pozzolant is added or mixed with a highly plastic soil in the presence of water, hydration reaction takes place leading to flocculation and agglomeration of particles where the number of free clay and silt present in the soil would be reduced leading to formation of coarser particles which occupy less place, hence the reduction in density. (Eberemu *et al.,* 2013).

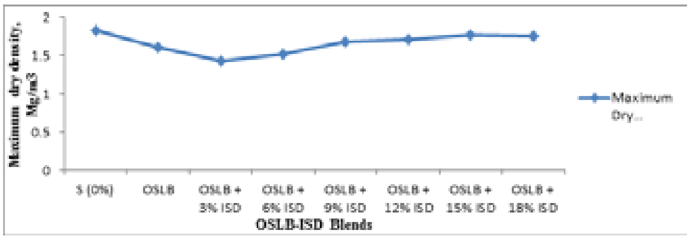

Fig. 3 Maximum dry density results of Subgrade-OSLB/ISD blends

The addition of ISD at 3, 6, 9, 12, 15 and 18% to blend of 8% CCW- Subgrade (OSLB) reduced the optimum moisture content (OMC) from 17.2 to 14.5 % (between 3 to 9% ISD) with optimum reduction experienced at 9% ISD (14.5 %) and consequently increased it to 20.3% (between 12 to 18% ISD) with optimum increment at 18% ISD (Figure 4). The addition of additives which led to reduction of OMC might be attributed according to Osinubi (1998) and Al-Homidy *et al.,* (2017) to insufficiency of water in the mixtures, resulting in self-desiccation and consequently lower hydration. It is known according to them that if no water movement to and from the resulting paste is permitted, the reaction of hydration use up the water until too little is left to saturate the soil surfaces and the relative humidity with the paste decreases. This means that this particular Subgrade soil can be stabilized with these additives (CCW - ISD blends) with less water requirement.

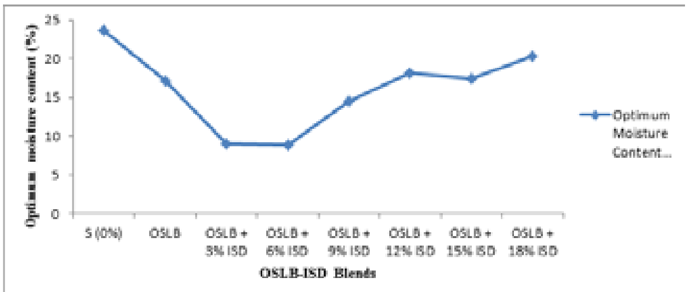

Fig. 4 Optimum moisture content results of Subgrade-OSLB/ISD blends

California Bearing Ratio Test

The CBR results of Optimum Subgrade Lime Blend (OSLB; S + 8% CCW) – Iron Slag Dust (ISD) blends (3, 6, 9, 12, 15 and 18% ISD) to natural subgrade ranged from 2.52 to 587.1% and 0 to 551.7% for both unsoaked and soaked conditions for varying curing periods (0, 3, 7, 28, 56 and 90 days) as captured in Figures 5 and 6 respectively. The blends of S (0%) at 0 curing day and OSLB + 3% ISD at 90 days curing period exhibited the least and highest values for both unsoaked and soaked conditions. However, for the purpose of pavement design, the soaked CBR results of the blends after 7 days moist curing ranged from 0 to 141.5% with blends of S (0%) and OSLB + 3% ISD having least and highest values respectively as captured in Figure 5. The Nigerian General Specifications for Bridges and Road works state that a minimum conventional CBR values of 40, 80 and 100% are to be met by soil materials for purposes of being used as subbase, base course (for lightly trafficked roads) and base course (for heavily trafficked roads) respectively for lime-treated soils while a minimum CBR value of 180% is recommended for a base course for cement stabilized materials. However, all blends can be used as subbase materials for lime-treated lightly trafficked roads while all the blends except OSLB + 18% ISD (68.6% CBR) can be used as base course materials for lime-treated lightly trafficked roads. Only blends of OSLB, OSLB + 3% ISD, OSLB + 6% ISD and OSLB + 9% ISD can be used as base course materials for lime-treated heavily trafficked roads owing to their CBR values of 100.1, 141.5, 112.4 and 122.9% respectively.

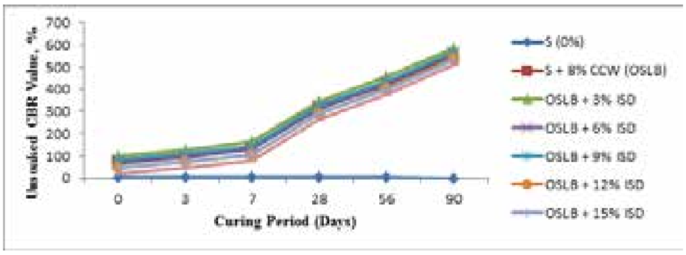

Figure 5: Unsoaked CBR Results of Subgrade-OSLB/ ISD Blends at varying Curing periods.

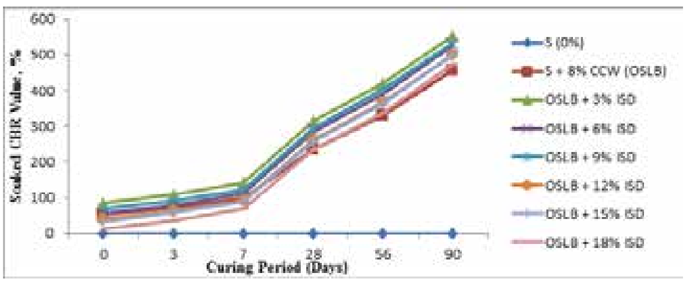

Figure 6: Soaked CBR Results of Subgrade- OSLB/ ISD Blends at varying Curing periods.

Unconfined Compression Strength (UCS)

Figure 7 shows the UCS results of Optimum Subgrade Lime Blend (OSLB; S + 8% CCW) – Iron Slag Dust (ISD) blends (3, 6, 9, 12, 15 and 18% ISD) to natural subgrade which ranged from 201.59 to 3, 684.49 KPa for varying curing periods (0, 3, 7, 28, 56 and 90 days) with the blends of S (0%) at 0 day moist curing and OSLB + 18% ISD at 90 days moist curing exhibiting the least and highest values respectively. However, for the purpose of pavement design, the UCS results of the blends after 7 days moist curing ranged from 1211.03 to 3096.27 KPa with blends of OSLB + 3% ISD and OSLB + 18% ISD having least and highest values respectively. The Nigerian General Specifications for Bridges and Road works state that a minimum conventional UCS values of 700, 1, 003 and 1, 700 KPa are to be met by soil materials for purposes of being used as subbase, base course (for lime-treated roads) and base course (for cement stabilized roads) respectively. However, all blends can be used as subbase and base courses for lime-treated roads while all blends except the blend of S + 3% ISD (1211.03 KPa UCS) can be used as base course for cement stabilized road.

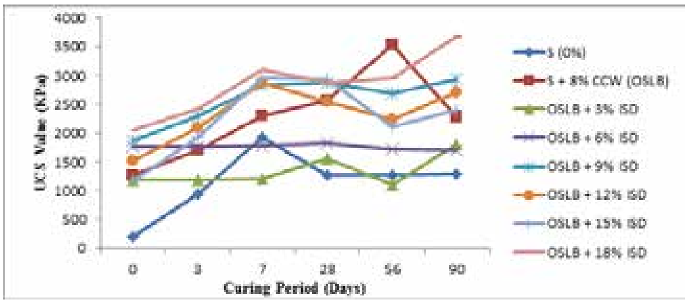

Figure 7: UCS Results of Subgrade-OSLB/ISD Blends at varying Curing periods.

CONCLUSION

The research revelaed that the Subgrade soil was classified as A-7-5 (fair to poor subgrade) and ML or OL according to AASHTO and Unified systems of soil classification. The subgrade and iron slag dust were also classified as classes F and C pozzolanas owing to aggregations of main oxides (SiO_2 + Al_2O_3 + Fe_2O_3) in excess of 70 and 50% respectively. The Subgrade material was classified as laterite owing to its silica sesquioxide ratio of 1.11 which is less than 1.33. The Subgrade has also been classified as non-lateritic material owing to its silica sesquioxide ratio of 2.168 which is greater than 2. The blend of S + 8% CCW was found to be the optimum subgrade lime blend (OSLB) because it exhibited optimum plasticity index reduction (14.8 to 8.7%). It is clear that all blends of OSLB-ISD increased plasticity index of OSLB across board with optimum increment at OSLB + 9% ISD (13.1%). Also, all blends of OSLB-ISD increased maximum dry density 1.66 to 1.76 Mg/m^3) except 3 and 6% ISD. An increment was observed in optimum moisture content between 12 to 18% ISD (17.2 to 20.3%) of natural subgrade. There was also an increase in 7 days CBR (soaked) between 3 to 9% ISD and UCS between 9 to 18% ISD. All blends of OSLB-ISD met the specification for sub-base and base course materials for pavement construction for CBR and UCS results according to Nigerian General Specification for Roads and Bridges.

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