ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE March 2020. Vol. 16(1):109-119
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

ASSESSMENT OF CALCIUM CARBIDE WASTE AND CALCINED CLAY AS STABILIZER IN FLEXIBLE PAVEMENT CONSTRUCTION

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ARTICLE INFORMATION

Submitted 15 June, 2019
Revised 27 November, 2019
Accepted 02 December, 2019

Keywords:
Weak subgrade soil
flexible pavement
calcium carbide waste
calcined clay.

ABSTRACT

Stabilization techniques have often been used globally to enhance properties of weak subgrade materials for flexible pavement construction. This study assessed the blend of calcium carbide waste (CCW) and calcined clay (CC) to serve as an effective stabilizer of Subgrade material (S) sourced from a section along Ota-Idiroko road. Subgrade material 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's limits 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. The OSLB was thereafter blended by weight with CC in the following percentage replacements 3, 6, 9, 12, 15 and 18% in order to activate the pozzolanic potentials of CC for strength enhancement. The resulting blends were subjected to Atterberg's limits, 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. The results showed that OSLB-CC blends reduced the Plasticity index from14.8 to 8.4 %, Maximum dry density from 1.82 to 1.54 Mg/m3, Optimum moisture content, 23.7 to 17.9 % and increased soaked CBR, 0 to 418.2% and UCS, 201.59 to 5660.84 kPa of natural subgrade respectively. Furthermore, the blends showed great improvement with reduction in PI less than standard value of 10% and increment in standard CBR and UCS values of 180% and 1700 kPa respectively for base course material. Therefore, stabilized blends at 7 days curing period could improve the natural subgrade to subbase and base for pavement construction.

1.0 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). Stabilization of soft subgrades with costly stronger materials like crushed rock is widely used, hence the need for cheaper alternative construction methods on soft subgrades (Cetin et al., 2010; Consoli et al., 2016; Quadri et al., 2019a; Quadri et al., 2019b). Clay stabilization using low-cost materials such as cement, lime, rice husk ash, cement kiln dust, calcined clay, steel slag or fly ash are better compared to crushed rock (Antonia, 2016). Steel slag, calcined clay, fly ash, rice husk ash amongst others are useful in many construction applications because they are pozzolanas (Quadri et al., 2019b).

Calcium carbide waste (CCW) is another form of industrial waste being used by researchers to improve properties of expansive soils (Krammart et al., 2004; Du et al., 2011; Quadri et al., 2019a). It is a by-product obtained from the acetylene gas (C_2H_2) production process, as shown in Equation 1 (Quadri et al., 2019b).

$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2 \quad (1)$$

CCW when mixed with certain pozzolans, which have high silicon dioxide (SiO_2) or aluminum oxide (Al_2O_3) content, could yield pozzolanic reactions, resulting in final products that are similar to those obtained from the cement hydration process (Wang et al., 2013).

Literature studies indicated that CCW can be reused as construction materials (Du et al., 2011). Jaturapitakkul et al. (2003) indicated that the compressive strength of mixture of CCW and rice husk ash was so high that the mixture could be used as cementitious material in mortar production. Krammart et al. (2004) used CCW as part of cement raw material, and found that the compressive strength of CCW cement mortars was close to that of the control cement. Fu and Fang (2004) investigated the potential use of mixture of CCW and fly ash as construction material for sub-base of municipal roads. It was concluded that CCW blends have the merits of low cost with high strength developed.

Agbede and Joel (2011) conducted a study on the effect of carbide CCW on the properties of Makurdi shale blended with 0 to 8% of CCW for use in brick production. Their study revealed that 4% CCW mix was suitable to stabilize the shale. It was concluded that the utilization of CCW to improve Makurdi shale has advantage of preventing the pollution of air and ground water. Du et al., (2011) used CCW and lime as binders to treat over-wetted clays being used as embankment filling material. It was concluded from their tests that CCW treated soils have better performance than that of lime treated soils and can be adopted as an alternative binder to treat over-wetted soils being used as highway embankment.

Joel and Edeh (2014) stabilized Ikpayongo laterite with cement and CCW. From the results, the use of mixture of 8% cement plus 10% CCW, 10% cement plus 10% CCW was recommended as best treatment for Ikpayongo laterite for use as base material. It was concluded that the use of CCW in the stabilization of soil will ensure economy in road construction, while providing an effective way of disposing CCW.

Darikandeh (2017) stabilized expansive soil by CCW-fly ash columns and reported that a significant reduction in the swell potential and swell pressure was observed at 62% (CCW: FA=20:80) and 68% (CCW: FA=20:80) respectively. Akinwumi et al. (2019) investigated CCW as a stabilizer for tropical sand used as pavement material. It was observed that increasing application of CCW generally reduced the soil's specific gravity, plasticity index and maximum dry unit weight. The authors concluded that the soil became more workable and its strength properties were improved by stabilization with an optimal application of 4% CCW. The subgrade characteristics of soil for use as earthwork materials for road construction were improved. Horpibulsuk et al. (2013) worked on strength development in silty clay stabilized with CCW and fly ash and observed that the soaked and unsoaked strengths depended mainly on the CCW and FA contents. The authors added that most of the ratios of soaked strength to unsoaked strength varied between 0.45 and 0.65 and proved that a mixture of CCW and FA could be used for soil stabilization instead of ordinary Portland cement.

Vichan and Rachan (2013) stabilized soft Bangkok clay using the blend of CCW and biomass ash with binders' contents ranging from 5 to 30%. The authors concluded that strength development ratio of stabilized clay with a CCW and BA mixture exceeded those of cemented clay and FA and BA blended cement admixtured clay after 28 days of curing due to the progress of the pozzolanic reaction. Bandyopadhyay et al. (2016) worked on stabilization of soil using ground granulated blast furnace (GGBS) and CCW. It was concluded that with increase of CBR (0.5, 0.7, 0.75, 0.8 and 1.0% of the weight of the soil), optimum moisture content (OMC) increased and maximum dry density (MDD) decreased which was due to the water absorbing nature of CCW. The UCS value increased when CCW percentage changed from 0.5 to 0.7% but decreased at 0.8 to 1.0%, hence it was tested for 0.75% and found that the value of UCS was 3.042 Kg/cm3 which was maximum. Also, maximum CBR in unsoaked condition was found to be 4.18% when soil sample was added with 0.75% CCW by weight. This study assessed CCW and calcined clay blend as an effective stabilizer for flexible pavement construction via Atterberg's limits, California bearing ratio and Unconfined compressive strength tests.

2. Materials and Methods

2.1 Sample Preparation

Subgrade material (S) was obtained from a section along Ota-Idiroko road (Latitude 60 40′ 53.082″ N and Longitude 30 9′ 11.172″ E) while CCW and raw clay were obtained from automobile workshops and Owode-Ketu in Ogun State respectively. The samples were air dried under the sun to remove moisture contents, ground to fineness using grinding machine and sieved through 425 µm sieve size. Particles with large surface area that would be very reactive to aid hydration or pozzolanic reaction after the raw clay had been calcined in a Kiln for 2 hours at a temperature of 700°C was used. These materials were subjected to Specific gravity, Particle size distribution and X-ray fluorescence tests according to BS 1377 (1990) to determine their properties.

2.1.1 Specific Gravity Test

A constant volume method was used by employing a 50cm^3 constant volume conical flask bottle with distilled water. 20g of dry mass each of these materials (Subgrade, CCW, and CC) was used as specified in BS 1377 (1990) using Equation 1.

$$G = \frac{Ms}{M1w} = \frac{M2-M1}{(M4-M1)-(M3-M2)} \quad (1)$$

where:

M1 (g) = mass of empty bottle

M2 (g) = mass of bottle + dry soil

M3 (g) = mass of bottle + soil + water

M4 (g) = mass of bottle + water

2.1.2 Particle Size Distribution Test

The subgrade sample was subjected to both wet sieving (sedimentation test) and dry sieving to evaluate percentages passing using different assemblage of sieves, percentage passing sieve No. 200 (75µm) as specified in BS 1377 (1990).

However, CCW and CC after being ground to fineness, were subjected to dry sieving to evaluate percentages passing different assemblage of sieves, most especially 425µm as specified in BS 1377 (1990).

2.1.3 X-Ray Fluorescence (XRF) Test

Firstly, the samples (Subgrade, CCW and CC) were crushed using an agate pestle and mortar, finely ground and sieved with a mesh size of 75μm to achieve homogeneity.

Afterwards, 15 to 20 g (this quantity makes up the thickness) and each sample was placed in a plastic sample holder with replaceable plastic support film for each sample analysed. This plastic support film was attached to the bottom of the sample holder, keeping the sample in the holder which served as a screen over the X-ray window for direct analysis of the sample and also provided a flat surface for the sample as rough surfaces could cause scattering of X-rays. An EDX3600B X-Ray fluorescence Spectrometer (Skyray Instruments, U.S.A) was used to determine the oxide compositions of materials (subgrade and additives) for classification.

2.2 Experimental Procedure

Firstly, subgrade was modified with calcium carbide waste (CCW) by weight using the following percentage 0, 4, 8, 12, 16 and 20%. The resulting blends were subjected to Atterberg's limits in order to determine the liquid limit (LL), plastic limit (PL) and plasticity index (PI) values of the blends. The LL and PI values alongside percentage of soil particles passing sieve No. 200 were used to classify subgrade according to American Association of Highway and Transportation Officials (AASHTO) system and Unified soil classification system. Also, from the PI values of the blends, the blend with the optimum PI reduction, tagged optimum subgrade lime blend (OSLB) was determined. The blend of S + 8% CCW which exhibited the optimum PI reduction (14.8 to 8.7%). The OSLB (S + 8% CCW) was thereafter blended by weight with CC using the following percentage; 3, 6, 9, 12, 15 and 18% respectively in order to activate the pozzolanic potentials of CC for strength enhancement. The blends were subjected to Atterberg's limits test to majorly determine their PI values, Compaction test to determine their optimum moisture contents (OMC) and maximum dry densities (MDD), Soaked and Unsoaked California bearing ratio (CBR) tests to determine their bearing capacities both in wet and dry states and Unconfined compressive strength (UCS) test to determine their compressive strengths. However, the specimens for strength test were moist cured for 0, 3, 7, 28, 56 and 90 days respectively in order to aid hydration or pozzolanic reaction which will in turn enhance strength developments of the blends. All tests were conducted according to BS 1377 (1990).

2.2.1 Atterberg's Limits Test

Subgrade sample was pulverized, sieved through sieve 425μm and consequently stabilized with CCW by weight of soil using the following percentage (0, 4, 8, 12, 16, and 20%) respectively. The blend of subgrade with 8% CCW (S + 8% CCW) which was singled out as the appropriate subgrade – lime (CCW) blend (OSLB) was blended with CC in the following percentage (3, 6, 9, 12, 15 and 18%) by mass of subgrade soil. The samples were subjected to Atterberg's limits test as specified in BS 1377 (1990) to evaluate PL and LL from where PI of each blend was derived using Equation 2.

$$PI = LL - PL \tag{2}$$

where:

PI = plasticity index (%)

LL = liquid limit (%)

PL = plastic limit (%)

2.2.2 Compaction Test

3000g each of the aforementioned blends was employed at varying moisture contents ranging from 100 to 500 ml at 100 ml interval using Proctol type of Compaction in accordance to BS 1377 (1990) where 27 blows were applied to sample at each layer of the mould to evaluate MDD and OMC of each blend.

2.2.3 California Bearing Ratio (CBR) Test

5000g each of the blends was produced at MDD and OMC applying 56 blows to sample per layer of CBR mould after which bearing capacity was determined with the aid of CBR machine in accordance to BS 1377 (1990).

2.2.4 Unconfined Compressive Strength (UCS) Test

Equation 3 was employed to determine the unconfined compressive strength (UCS) of each of the abovementioned blends in cylindrical shape of 120 mm x 100 mm after being produced at MDD and OMC and crushed with the aid of compression machine in accordance to BS 1377 (1990).

$$qu = \frac{P\,(1-\varepsilon)}{A} \tag{3}$$

where:

qu = Unconfined compressive strength (kN/m^2 or kPa)

P = Load that crushes cylindrical specimen to failure (kN)

ε = calculated strain from ratio of difference between length of cylindrical specimen before failure and length after failure to original length of cylindrical specimen before failure to

A = area of cylindrical specimen before failure (mm^2)

3. Results and Discussion

3.1 Physical and Index Properties

The Subgrade material as shown in Table 1 was classified as A-7-5 (fair to poor subgrade) and ML or OL (inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity) according to AASHTO classification and Unified soil classification system (USCS) respectively. The classifications were based on its LL, PI and percentage passing sieve No. 200 of 46, 14.8 and 64.21% respectively. Similarly, the fraction of silt-clay of Owode - Ketu raw clay with more than 35% passing sieve No. 200. According to USCS, the clay would be regarded as inorganic clay of low, medium and high plasticity (CL) since there are more than half of its material contents smaller than No. 200 sieve size. The Owode - Ketu material (raw clay) was regarded as a clayey soil according to USCS. It was observed that the percentages of particles passing sieve 425 μm of CCW and CC were 50.23 and 60.98% respectively.

CCW was found to be the least dense material with specific gravity of 1.81 as against 2.5 for CC and subgrade.

Table 1: Physical and Index Properties of Individual Materials

Property	Subgrade	CCW	Owode - Ketu Raw clay	CC
Plastic limit (%)	31.2	-	21	-
Liquid limit (%)	46	-	46	-
Plasticity index (%)	14.8	-	25	-
Clay content (<0.002mm)(%)	-	-	44.35	-
Silt content (0.002-0.06mm)(%)	-	-	35.84	-
Percentage passing sieve 425µm (%)	87.5	50.23	-	60.98
Percentage passing sieve 75µm (%)	61.21	-	80.19	-
AASHTO Classification	A-7-5	-	-	-
USCS Classification	ML or OL	-	CL	-
Specific gravity	2.5	1.81	-	2.5
Colour	Reddish brown	White	Darkish-grey	Darkish brown

3.2 X-Ray Fluorescence Test

The subgrade and CC were found to be pozzolanic materials and they belong to Class F according to ASTM: C618-08 standard. The standard stipulates that material whose 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.; However, the aggregation of the three (3) main oxides for subgrade and CC are 94.01 and 85.2% respectively; while their LOI are 3.10 and 2.20% respectively (Table 2).

However, from Table 2, the CCW contains 93.74% mass fraction of clincker 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.

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

Oxides	Percentage Oxide Contents of Materials		
	Subgrade	CC	CCW
SiO_2	49.57	58.86	0.83
Al_2O_3	28.86	16.23	0.71
Fe_2O_3	15.58	10.11	0.20
CaO	0.53	3.25	93.74
MgO	0.00	0.00	0.0
SO_3	0.41	7.81	0.7
Na_2O	0.00	0.0	0.0
K_2O	0.16	0.35	0.0
LOI	3.10	2.20	1.04

3.3 Atterberg's Limits Test

Figure 1 shows that the addition of CCW reduced the plasticity index of Subgrade from 14.8 to 8.7% with optimum reduction obtained at 8% CCW. Thus, referred to as optimum subgrade OSLB due to reduction in plasticity index and swell potential. This might be attributed to available calcium 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 similar to Ghobadi et al. (2014).

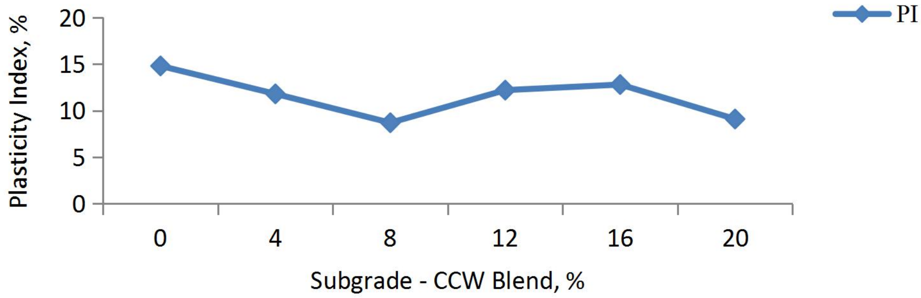

Figure 1: Plasticity Index values of Subgrade - CCW blend

The addition of CC at different variations (3, 6, 9, 12, 15 and 18%) to blend of 8% CCW-Subgrade (OSLB) increased its PI from 8.7 to 13.5% up to 15% CC while a sudden reduction was experienced at 18% CC (8.4%). However, all blends including OSLB reduced PI of Subgrade from 14.8 to 8.4% with optimum reduction at 18% CC (8.4%) as shown in Figure 2. According to Ghobadi et al. (2014), the addition of additives which led to reduction in PI might be attributed according to cation exchange that might have taken place or the ionic exchange between CCW and subgrade which resulted to flocculation and agglomeration of subgrade particles; hence reduction in swell potential and PI.

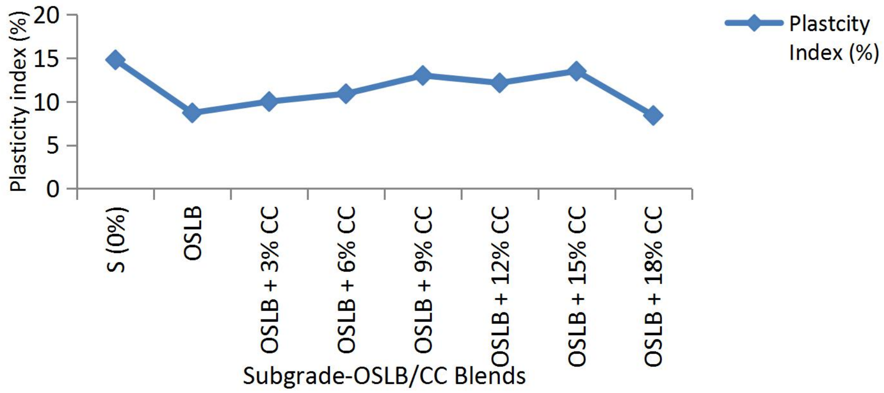

Figure 2: Plasticity index results of Subgrade-OSLB/CC Blends

3.4 Compaction Test

Figure 3 shows the addition of CC at different variations (3, 6, 9, 12, 15 and 18%) to blend of 8% CCW- Subgrade OSLB reduced its maximum dry density (MDD) from 1.6 to 1.54 Mg/m^3 except for 3% CC (1.66 Mg/m^3) where a slight increment was observed. However, all blends reduced MDD of subgrade from 1.82 to 1.54 Mg/m^3 with optimum reduction obtained at 18% CC.

This behavior in terms of reduction in MDD could be adduced to the fact that when a lime or pozzolan 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). The decrease in density could also be adduced to the specific gravity of CCW (1.81) which is less to that of Subgrade (2.50), a trend noted by Amadi (2010), Okonta and Govender (2011), Amadi (2013) and Eberemu et al. (2013).

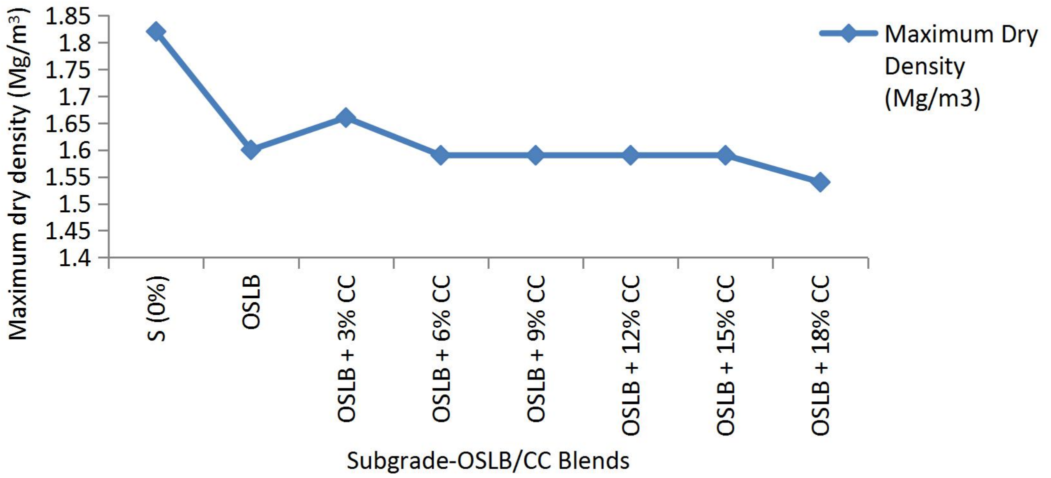

Figure 3: Maximum dry density results of Subgrade-OSLB/CC Blends

From Figure 4, the addition of CC at different variations (3, 6, 9, 12, 15 and 18%) to blend of 8% CCW - Subgrade (OSLB) increased its optimum moisture content (OMC) from 17.2 to 21.9%. However, all blends inclusive of OSLB reduced OMC of Subgrade from 23.7 to 17.2% with optimum reduction experienced at S + 8% CCW (OSLB). According to Osinubi (1998) and Al-Homidy et al. (2017), the addition of additives which led to reduction in OMC might be attributed to insufficiency of water in the mixtures, resulting in self-desiccation and consequently lower hydration.

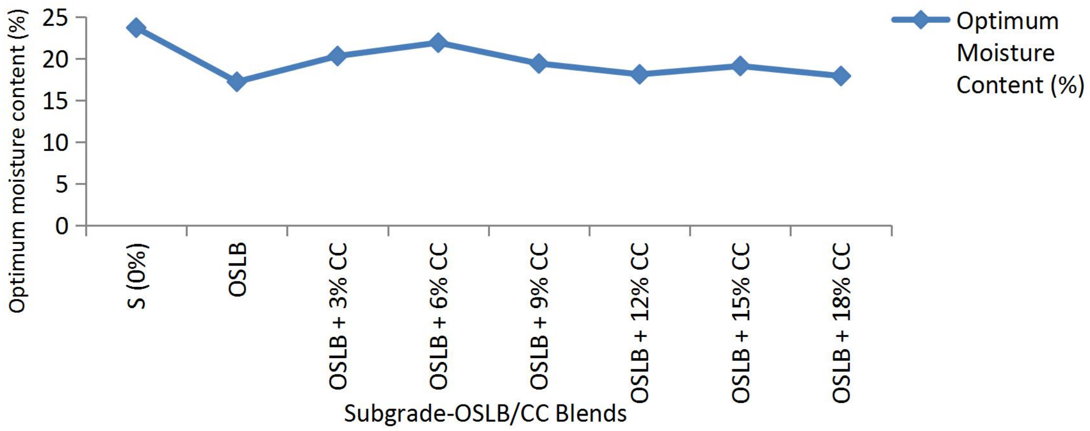

Figure 4: Optimum moisture content of Subgrade-OSLB/CC Blends

3.5 California Bearing Ratio Test

The CBR results of OSLB – CC blends (3, 6, 9, 12, 15 and 18% CC) addition to natural subgrade ranged from 1.12 to 530.3% and 0 to 418.2% 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%) and OSLB + 18% CC at 90 days curing period exhibited the least and highest CBR values for both unsoaked and soaked conditions respectively. However, for the purpose of pavement design, the soaked CBR results after 7 days moist curing ranged from 0 to 101.9% with the blends of S (0%) and OSLB + 18% CC exhibiting least and highest values respectively. All blends except OSLB + 3% CC (74.7% CBR) and OSLB + 6% CC (71.3% CBR) can be used as base course materials for lime-treated roads according to Nigerian General Specification for Roads and Bridges. The standard specifies a minimum conventional CBR values of 40, 80 and 100% to be met by soil materials for purposes of subbase, base course (for lightly trafficked roads) and base course (for heavily trafficked roads) respectively for lime-treated soils

Arid Zone Journal of Engineering, Technology and Environment, March, 2020; Vol. 16(1) 109-119. ISSN 1596-2490;
e-ISSN 2545-5818; www.azojete.com.ng

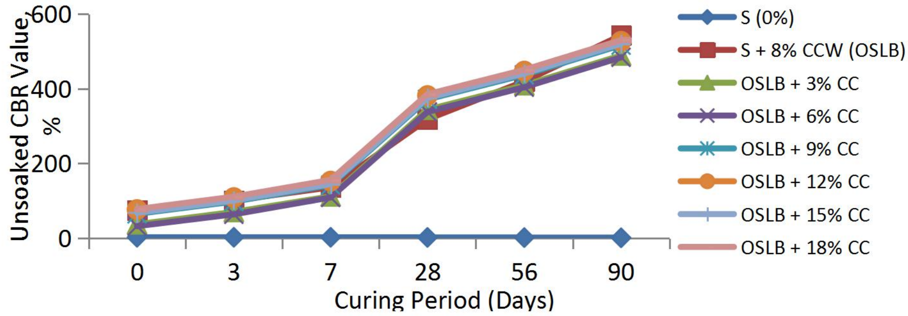

Figure 5: Unsoaked CBR Results of OSLB (Subgrade + 8% CCW) - CC Blends at varying Curing periods.

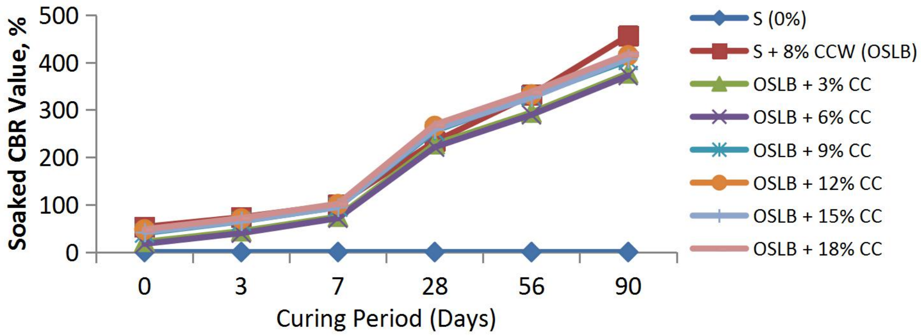

Figure 6: Soaked CBR Results of OSLB (Subgrade + 8% CCW) - CC Blends at varying Curing periods.

3.6 Unconfined Compression Strength (UCS) Test

Figure 7 shows the UCS results of OSLB – CC blends (3, 6, 9, 12, 15 and 18% CC) addition to subgrade which ranged from 201.59 to 5660.84 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 + 15% CC at 90 days moist curing exhibiting the least and highest values respectively. However, for the purpose of pavement design, the UCS results after 7 days moist curing ranged from 1934.32 to 3084.18 kPa with the blends of S (0%) and OSLB + 6% CC having the least and highest values respectively. However, all blends can be used as subbase and base courses for lime-treated and cement stabilized roads according to Nigerian General Specifications for Roads and Bridges. The standard specifies minimum conventional UCS values of 700, 1003 and 1700 kPa to be met by soil materials for purposes subbase, base course (for lime-treated roads) and base course (for cement stabilized roads) respectively.

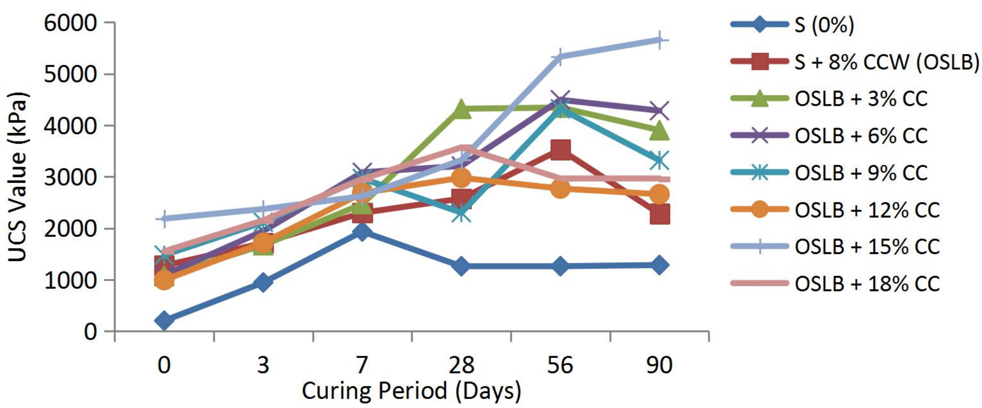

Figure 7: UCS Results of OSLB (Subgrade + 8% CCW) - CC Blends at varying Curing periods.

4.0 Conclusion

This study assessed Blend of Calcium Carbide Waste and Calcined Clay as Stabilizer in Flexible Pavement Construction. The blend of S + 8% CCW exhibited optimum PI reduction and was tagged OSLB when CCW was initially used to modify natural subgrade. All blends of OSLB-CC reduced PI, MDD and OMC of natural subgrade. Also, blends of OSLB-CC increased CBR (soaked and unsoaked) and UCS of natural subgrade with increase in curing period and increase in material addition; hence they can be used as subbase and base course materials for lime treated roads.

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