Investigating the Performance of Full Depth Reclaimed Surface-dressed Pavement Treated with Cement and Calcium Carbide Residue as Road Base

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Abstract

Investigation of performance of Full Depth Reclaimed Surface-dressed Pavement (FDRSP), treated with cement and Calcium Carbide Residue (CCR) as road base was undertaken. Wearing and base courses of a surface-dressed road was scarified and mixed to form the FDRSP, which was found to consist of 28.7 % Reclaimed Surface-dressed Pavement (RSP) and 71.3% soil from the natural base course. Laboratory tests were carried out to determine the most optimal of FDRSP/cement/CCR that will give a California Bearing Ratio (CBR) value of 150%, required for heavy traffic roads. The results showed that the original base course material of the road classified under A-2-5, but when mixed with Reclaimed Surface-dressed Pavement (RSP), the resulting material (FDRSP) classified under A-2-4 according to AASHTO soil classification system. 2% cement and 4% CCR, added to the FDRSP, satisfied the 150% CBR required for heavy traffic roads. From laboratory and field test results of the FDRSP/cement/CCR composites, soaking did not have adverse effect on the strength.

Keywords: Calcium carbide residue, California Bearing Ratio, Density, Reclaimed surface-dressed pavement, Stabilization, Road base.

Introduction

The rate of depletion of deposits of natural resources has become a global concern. This has prompted the concept of '*use and reuse*' of these resources, which is an aspect of the globally known concept of '*Sustainable Development Goals*'. Some of the deposits under this threat are those of lateritic soils. Good lateritic soil deposits were initially thought to be inexhaustible, but the current situation (especially in Minna, the capital city of Niger state and environs) have shown otherwise. Lateritic soil has been extensively used as sub-grade, sub-base and base courses for low to medium trafficked roads in Nigeria (Amu *et al*. 2010) and some other countries, where their deposit exists (Alhaji *et al*., 2019). Some of these soils performed well when used as sub-base and base course materials for roads, while others have been observed to fall short of the specifications for them to be used as such (Aginam *et al*., 2014; Oghenero *et al*., 2014 and Alhaji *et al*., 2014). In the later situation, the engineering properties of such soils are improved (Alhassan and Alhaji, 2007; Mu'azu, 2007; Osinubi *et al*., 2007; Alhassan, 2008a; Alhassan, 2008b; Osinubi and Mustapha, 2009; Eberemu *et al*., 2012; Sultan and Guo, 2016; Horpibulsuk *et al*., 2017; Alhaji and Alhassan, 2018, Suleiman *et al*., 2020 and Kanko *et al*., 2020) to make them fit for the intended use.

In most cases, lateritic soil materials that were initially found to be good for use as road bases become deteriorated with age while in service or during routine maintenance/reconstruction work. In such instances, and considering the current global trend, such materials are now being recycled and reused, thanks to utilisation of recycling/improvement techniques, using locally available and cheap additives. An example of these recycling/improvement techniques is the use of reclaimed pavement surface materials (eg Reclaimed Asphalt Pavement - RAP). In recent past, studies have been carried out on the possibility of using RAP for road pavement structures.

Mohammad *et al.* (2003) investigated the potential use of foamed asphalt treated RAP as a base course material instead of crushed limestone base and concluded that the foam asphalt showed higher in-situ stiffness than limestone base. In an attempt to reuse aged asphalt surface, Gregory and Halsted (2007), used Full Depth Reclamation (FDR) of RAP and the existing base and sub-base materials, mixed with small amount of cement to form new road base material that was considered excellent.

Edeh *et al*. (2012) investigated the possibility of using reclaimed asphalt pavement-lime stabilized clay as a highway pavement material, and obtained an unsoaked CBR of 36.56% and a 24hours soaked CBR of 34.23%, concluding that the material could be used for sub-grade and sub-base courses. A study aimed at increasing strength and reducing creep of RAP, by adding high quality aggregate and/or adding chemical stabilizer was carried out by Bleakley and Cosentino (2013), using Limerock Bearing Ratio (LBR) and creep tests to evaluate the strength and creep of the mixture respectively. Ochepo (2014) stabilized deficient lateritic soil using RAP and Sugarcane Bagasse Ash (SCBA) for pavement construction, and observed that the soil, stabilized with 6 and 8% SCBA gave a CBR value that was sufficient for the mixture to be used as subgrade and sub-base courses for road, while that treated with 10% SCBA gave CBR value that was sufficient for the mixture to be used as base course material.

Alhaji *et al.* (2014) worked on possible stabilization of A-6 lateritic soil using RAP without any chemical admixture, and reported minimal increase in Unconfined Compressive Strength (UCS) from 346kN/m^2 for the natural soil to 384 kN/m^2 at 40% soil mixed with 60% RAP, while the CBR increased marginally from 45.1% for natural soil to 48.6% at 40:60 mixtures. Alhaji and Alhassan (2018) also investigated the effect of RAP stabilization on the microstructure and strength of Black Cotton Soil (BCS), and reported optimal UCS value of 947kN/m^2 at optimal mixture of 30% RAP-70% BCS, representing 54.5% increase, maximum modulus of elasticity (E) of 42.52MPa at same mix ratio, representing 75.5% increase, reduction in free swelling of the compacted mixtures from 16.08% at 0% RAP to 0% at 80%, with 9.99% at optimal mixture of 30% RAP content, translating to 37.9% reduction in free swelling.

Mishra (2015) studied the use of RAP material in flexible pavements in which typical values of unit weight, natural moisture content, asphalt content, compaction densities and CBR values were reported, with the author concluding that 30% replacement of natural aggregate with RAP can successfully be used in base course. The use of geopolymer materials to stabilize RAP for road base courses was carried out by Avirneni *et al.* (2016), with the authors observing that Fly-Ash (FA) stabilization alone could not impact sufficient strength on the RAP-FA mixtures. They therefore concluded that 7 days UCS of the compacted RAP-FA blend at OMC met the strength requirement for base course specified by national road authority.

Alhaji and Alhassan (2018) worked on the microstructure and strength of RAP stabilized clay for road structure, with the result indicating CBR increased from 11% at 0% RAP-100% clay to 35% at 30% RAP-70% clay, after which the values reduced to 5% at 100% RAP- 0% clay. Suebsuk *et al*. (2014) studied effect of RAP on compaction characteristics and UCS of cement-treated soil–RAP mixtures, adopting porosity as a state parameter for assessing strength of the mixtures, with the results showing that as RAP content increases, OMC tended to decrease to an optimum soil-RAP ratio of 50/50. The asphalt fixation point was recorded to be at an asphalt content of 3.5% (50/50 soil-RAP ratio).

Kamel *et al*. (2016) evaluated the suitability of soil-RAP mixture for use as sub-bases, and from an extraction test observed the bitumen content of RAP to be 5.09% and maximum CBR to be 61.2% in a 50% soil-50% RAP mixture. Abukhettala (2016) also investigated the possibility of using RAP for road pavement structure. Rupnow *et al*. (2015) conducted a case study on the stabilization of a RAP-soil mixture with class C fly ash for use as a sub-grade., using Dynamic Cone Penetration (DCP) test to evaluate the strength gain in the field.

From the above review, it is evident that a lot have been done on the possibility of using RAP, either alone or mixed with additives, as road pavement structures. Study on the possibility of using Reclaimed Surface-dressed Pavement (RSP) material or Full Depth Reclaimed Surface-dressed Pavement (FDRSP) material, either alone or with additives have not received much attention in the literature. FDRSP material is obtained when surface-dressed layer together with the base course of a surface-dressed road are removed for reuse. This study is therefore aimed at investigating the possibility of using this FDRSP material together with cement and Calcium Carbide Residue (CCR) as road base.

Surface dressing is usually designed for light traffic roads, although it can be used on all types of roads. Reclaimed Surface-dressed Pavement (RSP) material is aged chippings embedded in bitumen, removed from road surfaces during maintenance or rehabilitation works on roads. These materials are usually carted away from site as waste. Physically, RSP also contains crushed gravel which can be used in mechanical stabilization. Due to high specific gravity of gravel compared to laterite, the combination of the two will result to increase in Maximum Dry Density (MDD) of the laterite gravel mixtures, improving the engineering properties of deficient soils. Incorporating cement and other additives to, especially Full Depth Reclaimed Surface-dressed Pavement (FDRSP) could further enhance attainment of desired properties of road bases.

Cement is a well-known conventional soil stabilization additive because of its cementitious property (Suebsuk *et al*., 2014; Alhassan and Alhaji, 2007; Osinubi and Mustapha, 2009; Alhaji *et al*., 2019; Alhaji *et al*., 2020). CCR is a by-product from acetylene gas production, which is used around the world for welding, lighting and metal cutting. CCR is obtained from a reaction between calcium carbide and water to form acetylene gas and calcium hydroxide in a slurry form, which mainly consists of calcium hydroxide $Ca(OH)_2$ along with silicon dioxide SiO_2, $CaCO_3$ and other metal oxides (Eqn. 1). The presence of natural pozzolanic materials in clayey soil, makes calcium hydroxide [$Ca(OH)_2$] a rich material that can be used to produce high strength geo-material (Gurugubelli *et al*., 2017). For environmental and economic impact, such waste materials can be utilized collectively with natural pozzolanic material in clay to form cementitious material. Calcium carbide residue production is described in the following reaction equation:

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \qquad (1)$$

From the Equation (1), Kumrawat and Ahirwar (2014) stated that 64g of calcium carbide (CaC_2) will produce 26g of acetylene gas (C_2H_2) and 74g of Calcium carbide residue (CCR) as $Ca(OH)_2$. Jaturapitakkul and Roongreung (2003) and Horpibulsuk *et al*. (2014) used CCR, blended with pozzolanic materials such as fly ash and Rice Husk Ash as an alternative to Ordinary Portland cement, to form cementing agent for manufacturing concrete and masonry units. Latifi, *et al*. (2018), Suleiman *et al*. (2020) and Kanko *et al*. (2020), stabilised deficient soils with CCR, and reported decrease in MDD with increase in dosage of the CCR, while OMC was observed to increase with increase in CCR. A similar trend of MDD and OMC with increase in CCR was earlier reported by Du *et al*. (2011).

Materials and Methods

Materials

The materials used in this study were Full Depth Reclaimed Surface-dressed Pavement (FDRSP), Portland cement and Carbide Residue (CCR).

Full depth reclaimed surface-dressed pavement

The full depth reclaimed surface-dressed pavement used in the study was obtained by mechanically scarifying a surface dressed road. This material was obtained from Morris road, Minna, Niger State, Nigeria. The road was constructed to serve as entrance access to Morris Fertilizer Company, but has since gone bad, due to the heavy trucks plying the road and lack of routine maintenance. As of the time of this study, the road was being rehabilitated. Because of the relative difficulty in obtaining only Reclaimed Surface-dressed Pavement (RSP) material as compared to RAP, Full Depth Reclamation (FDR) method was employed. This is because asphalt pavement surface have defined separation from the road base, while surface-dressed pavement have no such because of the embedment of chippings, over time, into the bitumen/road base layers, resulting from vehicular loads. The resulting Full Depth Reclaimed Surface-dressed Pavement (FDRSP) was found to consist 28.7 % Reclaimed Surface-dressed (RSP) material and 71.3% soil from the base course.

Cement

The Portland cement (Dangote brand) used for the study was procured from a cement vendor at Minna building materials market. The cement was properly stored under dry condition.

Calcium carbide residue

The Calcium Carbide Residue (CCR) used in the study was obtained from panel beaters in Minna. The collected CCR was air dried and milled to fine particles passing through BS sieve No. 200 (75µm) before use.

Test location

The laboratory aspect of this study was carried out in Civil Engineering Laboratory of Federal University of Technology, Minna, Niger State, Nigeria, while the field (in-situ) test was carried out on an access road to Morris Fertilizer Company, Minna, Nigeria.

Methodology

Laboratory tests

The materials were manually mixed to allow for uniformity in the samples. Samples were taken from each of the stockpiled materials and carried to Civil Engineering laboratory for tests, which includes particle size analysis, Atterberg limits, compaction test and California Bearing Ratio tests. These tests were carried out in accordance with BS 1377 (1990) and BS 1924 (1990) for unstabilised and stabilized materials respectively. Considering the nature of the resulting composite material, and in an attempt to use less energy during field densification, West African Standard (WAS) compaction, as described in Nigeria General Specification (1997) was employed. CBR tests, at Optimum Moisture Content (OMC) were carried out on the FDRSP mixed with 0, 2, 4, and 6% cement and CCR, by dry weight of the FDRSP. Uunsoaked and 24hour soaked CBR tests were carried out on the compacted mixtures after 7 days curing. Based on the nature of the traffic being experienced by the road (Fig. 1), unsoaked CBR value of 150% (Overseas Road Note 31, 1993) for heavy traffic roads was used to select the optimal percentage combination of FDRSP/additives that will be used for the field test. Based on this, 2% cement/4% CCR was chosen, together with that containing 0% additive and 2% cement, so as to provide basis for comparison.

Fig. 1: Nature of traffic on the road

Field tests

The field tests were carried out on a section of the road. Adopting the test method used by Alhaji *et al*, (2019), the width of the test section of the road was 7.5m, while the length was 15.0m. The test section of the road was mechanically scarified to depth of 30cm using ripper (Fig. 2), with lumps of the soil-RSP mixture properly pulverized, in preparation for addition of cement and CCR. The 15.0m length of the test section was divided into three sections of 5.0m each. To effectively study the effect of these additives on the reclaimed pavement, the first test section consisted of the reclaimed pavement (FDRSP) only, the second section consisted of the reclaimed pavement (FDRSP) + 2% cement, while the third section consisted of reclaimed pavement (FDRSP) + 2% cement + 4% CCR. Fig. 3 shows a sketch of test sections of the road and the test points.

The test section of the road was cleared and cleaned of any possible organic matters or other impurities, before the mechanical scarification and crumbling of the lumps were carried out. The test sections were then demarcated using pegs, into three sections of 5m length each. On the second and third sections, the additives were added and properly mixed, making sure that each of the sections was consisted of only the additives intended. After adding and properly mixing the FDRSP-cement and FDRSP-cement-CCR mixtures at the respective sections, compaction was carried out using sheep-foot (Fig. 4) and smooth drum vibrating rollers. During the compaction, in-situ density determination using sand replacement method (Fig. 5) was carried out intermittently to determine the maximum in-situ density, which eventually became constant with further compaction. Average of three in-situ density tests were performed after 1, 7, 28, 60 and 90 days of compaction. Dynamic Cone Penetration (DCP) tests (Fig. 6) were also conducted at three positions on each of the three sections, after 1, 7, 14, 28, 60 and 90 days of compaction. Data from the DCP test were used to compute CBR of the road base, with the aid of an empirical relationship developed by TRL (2014).

Fig. 2: Scarification of the test sections using ripper

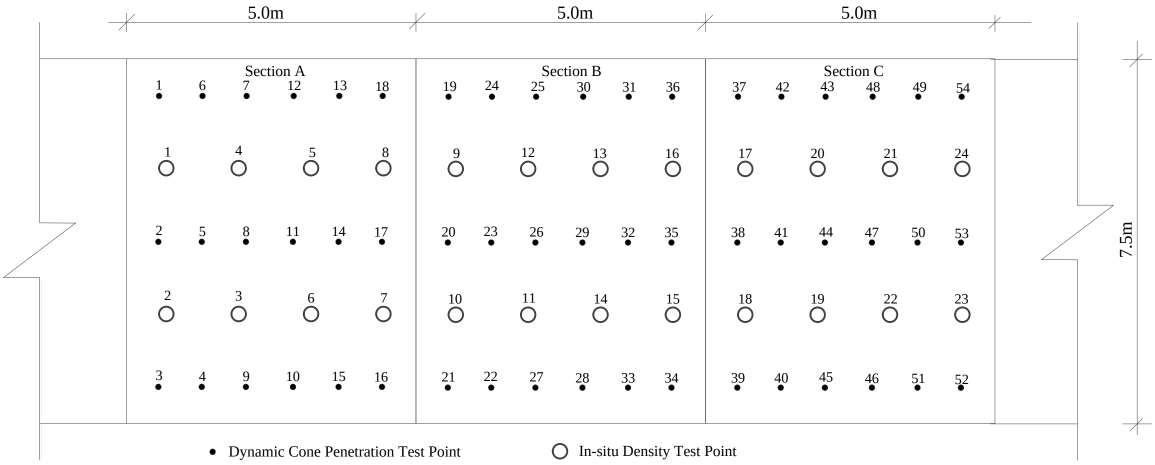

Fig. 3: Schematic diagram of the test section of the road showing the test points

Fig. 4: Compaction of the test sections using sheep-foot roller

Fig. 5: Determination of in-situ density of the test sections

Fig. 6: Dynamic cone penetration test to estimate CBR of the test sections

Results and Discussion

Laboratory Results

Results of index properties of the initial base soil and FDRSP are presented on Table 1. From the table the initial base course material of the road classified under A-2-5 and SC according to American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) respectively. On the other hand, FDRSP classified under A-2-4 and GC, according to AASHTO and USCS respectively. This indicates that the surface-dressed material improved both grading and consistency of the original base course material, by changing it from clayey sand (SC) to clayey gravel (GC) and reducing the PI from 9.26 to 6.49%. This improvement is evident in the MDD and OMC of the resulting FDRSP. The plasticity characteristics of the mixtures have been provided in previous study by Saidu (2021).

Variation of compaction characteristics of the FDRSP material with dosage of the additives

Variations of compaction characteristics (MDD and OMC) of the FDRSP with varied dosage of the additives are presented on Figs. 7 and 8 respectively. The result indicates gradual increase in MDD of the FDRSP material with increase in cement content. This is expected, as cement with higher specific gravity and fineness fills the voids in the FDRSP, resulting to a more compact and dense material. At constant cement content, the MDD of the mixtures was observed to decrease with increase in CCR. The decrease in MDD with increase in CCR is as a result of the lower specific gravity (2.21) being contributed to the mixture by the CCR.

Table 1: Geotechnical properties of Initial base material and FDRSP

Property	**Existing base**	**FDRSP**
Fraction passing BS No 200 sieve (%)	26.6	14.7
Liquid limit (%)	57.84	40.10
Plastic limit (%)	48.58	33.49
Plasticity index (%)	9.26	6.49
USCS	SC	GC
AASHTO classification	A-2-5	A-2-4
MDD (g/cm^3)	1.92	2.20
OMC (%)	17.0	10.0
Unsoaked CBR (%)	75	111
Soaked CBR (%)	37	78

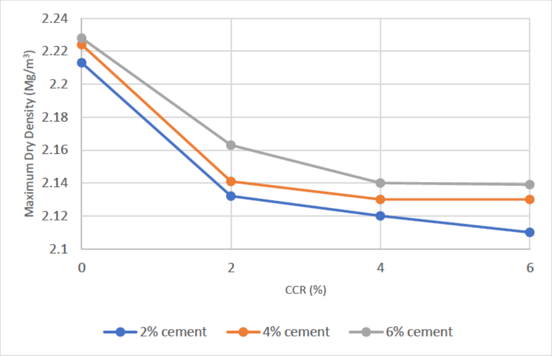

Fig. 7: Variations of maximum dry density with dosage of the additives

Reference to OMC (Table 1) of the untreated FDRSP, initial decreased in the value was observed on addition of 2% cement, but with subsequent increase in the cement content, the OMC gradually increased. The initial decrease in OMC with first dosage of cement is attributed to the consistency of the fines in the FDRSP, as cement modifies the consistency. The subsequent increase in OMC observed, with increase in cement content is attributed to hydration reaction of the cement and subsequent reaction of the CCR, which require water to proceed. This observed tends in variation of MDD and OMC with increase in CCR is similar to those reported by Latifi *et al*. (2018) and Du *et al*. (2011).

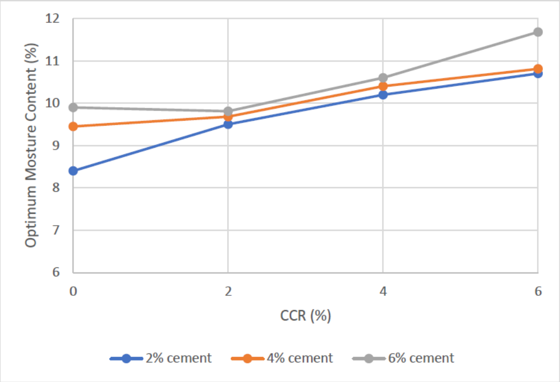

Fig. 8: Variations of optimum moisture content with dosage of the additives

Effect of the additives on CBR of the mixtures

Variation of laboratory soaked and unsoaked CBR of the FDRSP with changes in dosage of the additives are presented on Table 2. From the table, it is observed that both soaked and unsoaked CBR value of the FDRSP increased with increase in cement content. This is expected, as more cement means more binding material in the mixture. On the other hand, at constant percentage of cement, CBR values of the mixtures increased to their maximum values at 4% CCR, after which the values decreased at 6% CCR. Observation of the soaked and unsoaked CBR values indicated that the mixtures still maintained comparatively high strength even after 24hours soaking. This is attributed to the hardened mass that resulted from the cementitious compounds from cement and the subsequent CCR reactions, and the waterproofing properties of the bitumen present in the FDRSP. Similar trend of soaked CBR values was reported by Edeh *et al*. (2012) for clay-RAP-lime composite. Based on the unsoaked minimum CBR value of 150% for base course of heavy traffic roads, the optimal percentage combination for stabilization of the FDRSP with cement and CCR for use as base course material, for heavy traffic roads will be 2% cement and 4% CCR. This is the combination with with least cement content that gave the required strength. Therefore, the performance of this mixture was studied on the field.

Table 2: Variation of laboratory CBR of the FDRSP with changes in dosage of the additives

Cement (%)	CBR (%)							
	Unsoaked	Soaked	Unsoaked	Soaked	Unsoaked	Soaked	Unsoaked	Soaked
	0% CCR		2% CCR		4% CCR		6% CCR	
2	123	111	136	124	159	147	107	91
4	165	151	192	176	270	248	175	155
6	231	213	296	266	320	285	281	241

Field Results

Field densities

During compaction, the test was routinely conducted on the three sections of the road until three consecutive trials gave consistent results. This was repeated after 1, 7, 14, 28, 60, and 90 days. Summary of the results are presented on (Table 3). From the table, it is observed that the dry densities of the three sections changes throughout the 90 days of the study. The rate of increase in the densities was more pronounced in section B, section A has recorded the least rate of increase in the densities. In all the sections, more than 95% of the laboratory densities were achieved after 14 days, while more than 100% was achieved after 28 days, as compared to about 90% that was achieved before exposure of the test sections of the road to traffic. Alhaji *et al*. (2019) recorded 99.8 and 98.8% for lateritic soil/RAP/cement and lateritic soil/RAP mixtures respectively, after 60 days. The relatively early attainment of laboratory density is attributed to the nature traffic the road was exposed to, after the compaction.

Table 3: Summary of the field densities for the three sections of the road

Test Section	**Density (Mg/m^3) After**					
	1 day	7 days	14 days	28 days	60 days	90 days
A	2.180	2.194	2.198	2.210	2.215	2.223
B	2.191	2.211	2.234	2.258	2.261	2.262
C	2.080	2.108	2.118	2.120	2.123	2.130

Field CBR

The field CBR of the compacted surfaces was determined using the Dynamic Cone Penetration (DCP) test data with the help of the empirical relation, developed by Transport Research Laboratory-TRL (2014).

$$Log\ (CBR) = 2.48 - 1.057(PI) \qquad (1)$$

Where PI, is the penetration index

Variation of CBR with days of exposure to traffic is presented on Fig. 9.

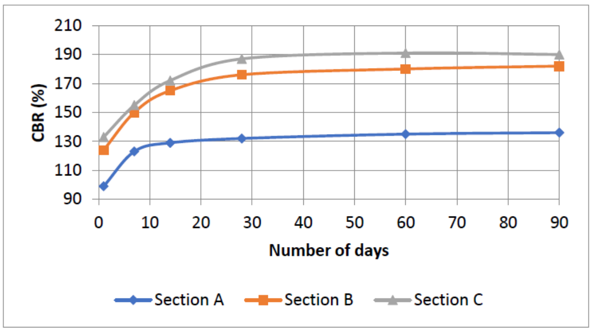

Fig. 9: Variation of In-Situ CBR values with number of days

From the figure, it is observed that the CBR of section A is generally less than those of sections B and C. The relatively higher strength (CBR), recorded from these sections in comparison to section A, is as a result of the cementation, resulting from reactions of the additives (cement and CCR). At 7 days after compaction, the CBR values of sections A and B were generally more than 100% of the laboratory CBR, while that of section C was 98%. This tremendous increase in CBR values of the test sections is as a result of the combined effect of stabilisation reaction and the nature of traffic the road is exposed to. This road, being access road to entrance to Morris Fertilizer Company, Minna, is plied by heavy and articulate vehicles, transporting raw materials and products, in and out of the company. After 14 days, only marginal increase in CBR was noticed in section A, which could be attributed to the marginal increase in density of the section. Sections B and C recorded relatively noticeable increase in CBR up to 28 days, after which the increase became marginal to 90 days.

Conclusion

The following conclusions were drawn from the study:

i. The initial lateritic soil that constituted the base course of the road classified under A-2-5. When this soil was mixed with RSP, the resulting material (FDRSP) classified under A-2-4 according to AASHTO soil classification system.

ii. Field CBR results of the compacted FDRSP/2% cement/4% CCR used in sections C, after 14 days of exposure to traffic was 172%, which was higher than the laboratory 159%.

iv. The field CBR result of the FDRSP used in section A, after 7 days was 129% as against the 111% laboratory value.

v. Due to the cementitious properties imparted to the composite mixtures, soaking did not have adverse effect on strength.

vi. From the study FDRSP treated with 2 and 4% cement and CCR respectively can be used as base course for heavy traffic roads.

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