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PERFORMANCE EVALUATION OF FULL DEPTH RECLAIMED SURFACE-DRESSED PAVEMENT TREATED WITH CEMENT AND CALCIUM CARBIDE RESIDUE AS ROAD BASE

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ABSTRACT
Performance evaluation 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 FDRSP, which was found to consist of 28.7 % Reclaimed Surface-dressed (RSP) and 71.3% soil from the base course. Laboratory tests were carried out to determine the most economic mixture of FDRSP/cement/CCR that will give a Californian 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 density results for the FDRSP, FDRSP/cement mixture and FDRSP/cement/CCR mixtures, it was observed that more than 95% density can be achieved after 14 days exposure to the traffic load. Field CBR results of the compacted FDRSP/2% cement/4% CCR agreed with the laboratory CBR after 14 days of exposure to traffic load on the road, while the field CBR result of the section with only FDRSP agreed with laboratory value after 7 days, after which the value became higher than the laboratory value.

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

1.0 INTRODUCTION

The rate at which deposits of natural resources are depleting 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*. Some of the deposits under this threat are those of lateritic soils. Good lateritic soil deposits were initially thought to be inexhaustible, but their current situation (especially in Minna, the capital city of Niger state and environs) have shown that nothing can be farther from the truth as that. 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 road structures, 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) 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, curtesy of utilization 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 24 hour 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 A-7-6 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 346 kN/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 stabilization alone could not impact sufficient strength on the RAP-VA 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 has 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 pavement structure.

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 of roads. These materials are usually carted away from site as waste products. 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 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 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, metal cutting and for fruit ripening. 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 without Ordinary Portland cement, to form cementing agent for manufacturing concrete and masonry units. Latifi, *et al.* (2018), stabilsed clays with up to 15% 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).

2.0 MATERIALS AND METHODS

2.1 Materials

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

2.1.1 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 by the state Government. Because of the relative difficulty in obtaining only Reclaimed Surface-dressed Pavement (RSP) material as compared to RAP (asphalt pavement surface is laid as a blanket on road base course, making the layer have a defined separation from the road base, while surface-dressed pavement consist of a thin layer of bitumen with aggregates spread, that have over the time, embedded into the bitumen/road base layers as a result of vehicular loads), Full Depth Reclamation (FDR) method was used, giving rise to Full Depth Reclaimed Surface-dressed Pavement (FDRSP), which was found to consist of 28.7 % Reclaimed Surface-dressed (RSP) material and 71.3% soil from the base course.

2.1.2 Cement

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

2.1.3 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 grinded to fine particles passing through BS sieve No. 200 (75µm) before use.

2.2 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.

2.3 Methodology

2.3.1 Laboratory tests

Substantial quantity of the Full Depth Reclaimed Surface-dressed Pavement (FDRSP) material was collected from Morris road, Minna, Niger State. Substantial quantities of cement and CCR were also collected, and taken to Civil Engineering laboratory for tests. These 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 grain size analysis, Atterberg limits, Proctor compaction test and California Bearing Ratio tests. These tests were carried out in accordance with BS 1377 (1990). Compaction and CBR tests were carried out on the reclaimed pavement (FDRSP) material mixed with 0, 2, 4, and 6% cement and CCR, by dry weight of the FDRSP. Using compaction characteristics, obtained from compaction test, unsoaked CBR test was carried out on compacted mixtures after 7 days curing. Based on the nature of the traffic being experienced by the road (Figure 1), CBR value of 150% for heavy traffic roads was used to select the optimal percentage combination of FDRSP/additives that will be used for the filed 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.

Figure 1: Nature of traffic on the road

2.3.2 Field Tests

The field test was 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 (Figure 2), with lumps of the soil-RSD 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 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. Figure 3 shows a sketch of test sections of the road and the test points.

The test section of the road was cleared of organic and 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 (Figure 4) and smooth drum vibrating rollers. During the compaction, in-situ density determination using sand replacement method (Figure 5) was carried out intermittently to determine the maximum in-situ density, which eventually became constant with further compaction. The pegs and lines used in demarcating the sections were left standing throughout the test. Average of three in-situ densities was performed after 1, 7, 28, 60 and 90 days of compaction. Dynamic Cone Penetration (DCP) tests (Figure 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. The field CBR was evaluated using the DCP test results on the compacted surfaces with the aid of an empirical relationship developed by TRL (2014).

Figure 2: Scarification of the test sections using ripper

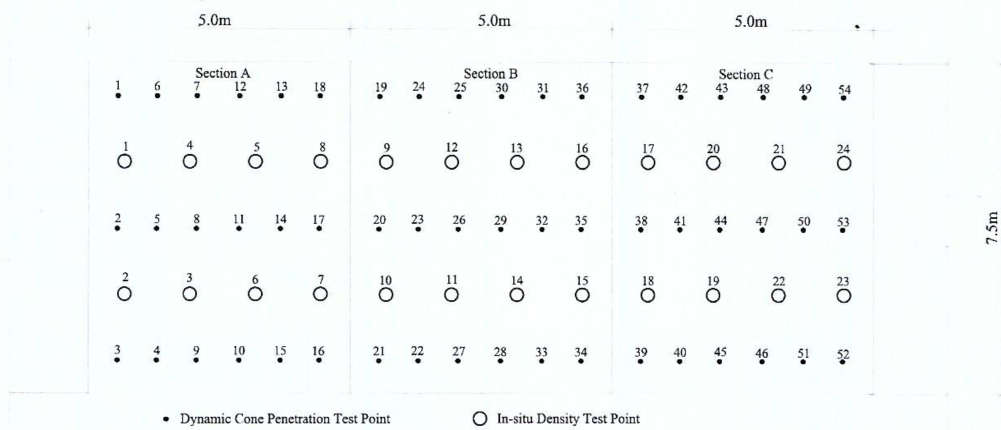

Figure 3: Schematic diagram of the test section of the road showing the test points

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

Figure 5: Determination in-situ density of the test sections

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

4.0 RESULTS AND DISCUSSION

4.1 Geotechnical Properties from Laboratory Results

4.1.1 Index properties of initial base Soil and FDRSP

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.

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
CBR	75	111

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

Variation of compaction characteristics of the FDRSP with varied dosage of the additives is presented on Table 2. 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 FDRSP, this results to a more compact and dense material. OMC of FDRSP initially decreased on first dosage of cement, but with subsequent increase, the OMC gradually increased. The initial decrease in OMC with first dosage of cement is as a result of the consistency of the fines in the FDRSP. The subsequent increase in OMC with increase in cement content is attributed to hydration reaction of cement, which requires water to proceed. At constant cement content, the MDD of the mixtures is observed to decrease, while the OMC increased. The decrease in MDD with increase in CCR is a result the lower specific gravity being contributed to the mixture by the CCR. 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).

Table 2: Variation of compaction characteristics of the FDRSP with changes in dosage of the additives

Cement (%)	Compaction Characteristics							
	0 % CCR		2 % CCR		4 % CCR		6 % CCR	
	MDD	OMC	MDD	OMC	MDD	OMC	MDD	OMC
2	2.213	8.40	2.132	9.68	2.12	10.2	2.110	10.70
4	2.224	9.45	2.141	9.60	2.13	10.4	2.130	10.81
6	2.228	9.90	2.183	9.81	2.14	10.60	2.139	11.68

4.1.3 Effect of Additive Dosages on CBR Value

Variation of laboratory CBR of the FDRSP with changes in dosage of the additives is presented on Table 3. From the table, it is observed that 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 of the mixture initially increased to their maximum value at 4% CCR, after which the value decreased at 6% CCR. Based on the value of CBR for heavy traffic roads (150%), the optimal percentage combination for stabilization of the

FDRSP with cement and CCR for use as base material for heavy traffic roads will be 4% cement and 2%CCR. Therefore the performance of this mixture was studied on the field.

Table 3: Variation of laboratory CBR of the FDRSP with changes in dosage of the additives

Cement (%)	CBR (%)			
	0% CCR	2% CCR	4% CCR	6% CCR
2	123	136	159	107
4	165	192	270	175
6	231	296	320	281

4.2 Field Results

4.2.1 Field densities

Sand replacement method of in-situ density determination was used in accordance with BS 1377 (1990). During compaction, the test was routinely conducted on the three sections of the road until three consecutive trials gave very close results. This was repeated after 1, 7, 14, 28, 60, and 90 days. Summary of the results are presented on (Table 4). 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. 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 4: 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

4.2.2 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).

$$Log\ (CBR) = 2.48 - 1.057(PI) \tag{1}$$

Where PI, is the penetration index

Variation of the CBR with days after compaction is presented on Figure 7.

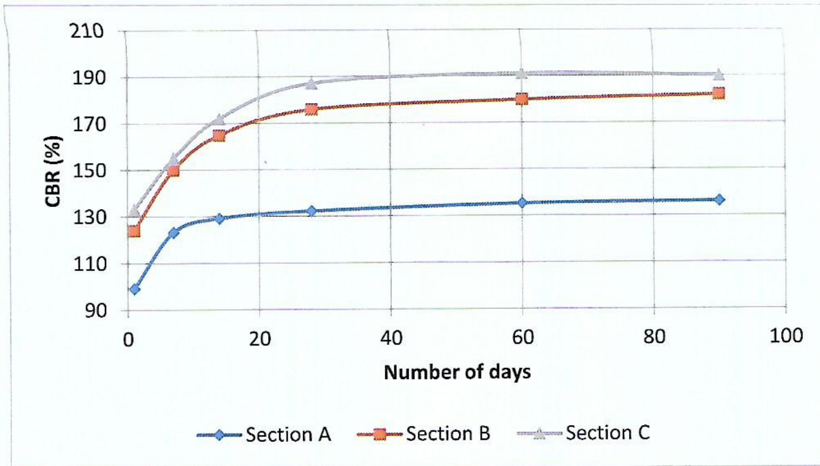

Figure 7: Variation of In-Situ CBR values with the number of days

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 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.

5. 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. 2% cement and 4% CCR, added to FDRSP satisfied the 150% CBR required for heavy traffic roads.

iii. Field CBR results of compacted FDRSP/2% cement/4% CCR used in sections C agreed with the laboratory CBR after 14 days of exposure to traffic on the road.

iv. The field CBR result of the FDRSP used in section A agreed with laboratory value after 7 days, after which the value became higher than the laboratory value.

v. From laboratory and field density results for the FDRSP, FDRSP/cement mixture and FDRSP/cement/CCR mixture, it was observed that more than 95% density can be achieved after 14 days exposure to traffic load.

vi. Further study is suggested using cement and pozollanic material (especially those from agricultural waste, eg Rice Husk Ash-RHA and SCBA) instead of CCR (lime) for longtime strength development.

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