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Mechanical Characterization of Lateritic Soil Stabilized with Recycled Asphaltic Materials for Road Construction

[1]Ibitoye B.A., *[1]Onadiran S.O., Subair S. O., Hassan D. E., Fakorede V., Ige J. A.

Department of Civil Engineering, LAUTECH, Ogbomoso, Oyo State, Nigeria.
[2]Department of Civil Engineering, Kwara State University, Malete Kwara State Nigeria

*Corresponding Author's E-mail: soonadiran@lautech.edu.ng Tel: 07037571549

Abstract

Pavement recycling is an effective practical process to conserve the diminishing supply of construction material and to help reduce the cost of preserving the existing pavement network in the country. In the U.S. the asphalt pavement industry recycles roughly 73 million tons of material yearly. This research study addresses the effect of grinding and blending recycled asphaltic materials (RAM) with Virgin aggregate in order to yield a base/sub-base material to be used in pavement construction in Nigeria. It also aims at finding the optimum RAM percentage to be added to a virgin aggregate in order to produce a base or sub-base quality and material with cheaper cost without affecting the pavement performance.In this research study. two types of pavement materials were investigated. The first material is a lateritic soil (Control) extracted from a site. The second material is a recycled asphaltic material {RAM} collected from an old pavement. A total of five different mixtures were prepared using different percentages of the two material types. This research showed that. based on the CBR strength testing results, aggregate blends containing RAM and lateritic soil are only suitable to function as a sub-base and base course material at 90:10 to 75:25 respectively, as sub-base and base course material with the RAM acting as a stabilizer, continuous adding of RAM to the laterite increases the maximum dry density thereby reducing the optimum moisture content, the plasticity and liquid limit also reduces as more RAM were added to the mixture.

Keywords: Pavement Recycling, Recycled Asphaltic Materials (RAM), Base/Sub-base Material, Lateritic Soil, California Bearing Ratio (CBR), Pavement Performance.

Introduction

Asphalt has been a vital material in road construction for centuries, initially used in shipbuilding and later in road paving (Roberts, Mohammad, and Wang, 2018). With rapid urbanization and increased traffic volumes, there is growing pressure to develop sustainable solutions for road construction. The demand for new roads and the maintenance of aging infrastructure have resulted in the depletion of natural resources and rising asphalt costs (Darcy et al., 2016). Moreover, many roads are approaching or exceeding their design life, requiring extensive rehabilitation.

Recycling asphalt pavement offers an environmentally sustainable alternative, reducing the need for new materials and minimizing waste (Lee et al., 2015). Recycled Asphaltic Materials (RAM) can be combined with local aggregates, such as lateritic soil, to improve the material properties for use in road construction, particularly for sub-base and base courses (Prof. Tom Mathew, 2019). This study explores the feasibility of using RAM in lateritic soil stabilization to enhance road pavement performance in Nigeria. Given the limited use of pavement recycling in Nigeria, this research aims to provide insights into sustainable practices that could reduce costs and environmental impact while improving road quality (Nicholls, 2019).

Materials and Method

The methodology adopted in carrying out the study is discussed under two sub headings of Materials and methods for the tests carried out.

Materials
The following materials were used in the experimental design.

Soil
The soil samples were obtained at a depth of 1.2 m at a borrow pit at Ogbomosho North Local Government, located in Ogbomosho, Oyo state. The samples were collected in sacks, properly covered and kept in the laboratory. The lateritic soil was dried before subjecting to test.

Reclaimed Asphaltic Material (RAM)
The Reclaimed asphaltic material (RAM) was collected from seminary area, Ogbomosho South Local Government. The soil samples were taken in polythene bags to prevent loss of moisture to the atmosphere. Before anything was done on the collected RAM, it was first milled to smaller sizes and then the bitumen content was derived. Particle size analysis was done to know the amount of mineral filler present in the RAM.

Method
The chemical compositions of the laterite soil and Reclaimed asphaltic material (RAM) were examined at a National Agency for Science and Engineering Infrastructure NASENI Centre of Excellence in Nanotechnology and Advanced Material (NASENI CoEx-NA), Akure, Nigeria using Sky ray EDX 3600B Energy Dispersive X-ray Fluorescence (XRF) Spectrometer.

For stabilised lateritic soil samples, reclaimed asphaltic material (RAM) was introduced in incremental order of 5, 10, 15, 20 and 25% by dry weight in the soil samples. The following experiments were conducted; Sieve Analysis, Moisture Content Test, Specific Gravity Determination Test, Atterberg Test (Liquid and Plastic Limit), Compaction Test and California Bearing Ratio (CBR). The tests were carried out in accordance with the procedural steps in BS 812-102 (1984), BS 812-103.1 (1985) and BS 1377 (1990) on both natural stabilised lateritic soil samples.

Compaction test
A sufficient quantity of air-dried soil in large mixing pan was obtained, pulverized and run through the 4 mm sieve. Using the balance, it was possible to weigh the soil sample and the base of the compaction mould (without the collar) and record the results. And the following formula was used to determine how much initial water to add:

(a) Consider the first test's water content to be 8%.

(b) compute water to add from the following equation: 100 water to add in mm = soil mass in grams 8 where “water to add” and the “soil mass” are in grams.

Water was measured, add it to soil, and then mix it thoroughly into the soil using the trowel until the soil gets a uniform colour. The compaction moulds were assembled to the base and some soil was placed in the mould and compact in the number of equal layers specified by British standard. The drops were applied at a uniform rate not exceeding around 1.5 seconds per drop, and the rammer provided a uniform coverage of the specimen surface. The last compacted layer of dirt was extended just above the collar joint once the soil had completely filled the cylinder. The collar was removed with care and the compacted soil was being trim off using the trowel. Soil that fell out during the trimming process was replaced. The compacted soil was weighed while it’s in the mould and to the base, and the mass was recorded. The wet mass of the soil was determined by subtracting the weight of the mould and base. The soil was removed from the mould using a mechanical extrudes and soil moisture content samples were taken from the top and bottom of the specimen. The moisture cans were filled with soil and the water content was determined. The soil sample was placed in a large tray, broken up until it visually resembled it would flow through a #4 sieve, and then re-mixed with 2 percent more water depending on the initial sample mass.


California bearing ratio

The lateritic soil was modified with Reclaimed asphaltic material (RAM) by 5, 10, 15, 20 and 25% to determine their influence on both the index and geotechnical properties of the tested soil. The CBR test was determined by means of standard procedures on BS1377 (1999). The material used in the above methods pass through 19 mm sieve for fine grained soils and 37.50 mm sieve for coarse materials up to 37.50 mm. The material retained on 19 mm sieve was replaced by an equal amount of material that passes through 19mm sieve and retained on 4.75 mm sieve.

Static Compaction approach involved calculating the mass of wet soil at the necessary moisture content to produce the specified density when compacted in a typical test mould, as shown below

Volume of mould = 2250cc.
Weight of dry soil (W) = 2250 x MDD.
Weight of wet soil = 1 + ---------- x W.
Weight of water = Weight of wet soil – Weight of dry soil.
m = OMC obtained from the laboratory compaction test.
Oven dried soil sample of calculated weight and thoroughly mix with water as obtained from the above equation was taken. The empty weight of the mould with base plate (with extension collar removed) was recorded as m_1. The correct mass of the wet soil was placed into the mould in five layers and each layer was compacted with the spacer disc as shown in Plate 3.6. The mould was compact by pressing it in between the platens of the compression testing machine until the top of the spacer disc comes flushed with the top of the mould. The load was held for about 30 seconds and then released.

The mould was removed from the compaction testing machine. The spacer discs were also being removed and weigh the mould with compacted soil (m_2). The extension collar of the mould was replaced. Two more specimens in the same procedure as described above was prepared.

Result and Discussion

This section discusses the results obtained from the various tests carried out. The Summary of the test results which includes sieve analysis test, Compaction test, Atterberg Limit test, California bearing ratio(CBR) and Unconfined compressive strength test (UCS); chemical analysis tests and the soil stabilization with Recycled Asphaltic Materials (RAM) at 5,10,15,20 and 25%.

Characterization of Lateritic Soil

Table 3.1 gives a summary of the geotechnical properties of the Lateritic soil. This soil has a natural moisture content of 1.8%. And according to AASHTO soil classification system, this soil is classified as A-7-6. It shows that the soil is a clay which has the percentage passing the BS No. 200 sieve (0.075 mm) to be 39%.

Table 3.1: Mechanical Properties of the Lateritic Soil.

Mechanical Properties	Quantities /Values
Optimum moisture content at BS (%)	12.43
Maximum dry density at BS (g/cm^3)	1.72
Optimum moisture content at WAS (%)	11.78
Maximum dry density at WAS (g/cm^3)	1.76
Optimum moisture content at AASHTO (%)	9.80
Maximum dry density at AASHTO (g/cm^3)	1.82
Unsoacked CBR at BS (%)	34
Soacked CBR at BS (%)	6
Unsoacked CBR at WAS (%)	57
Soacked CBR at WAS (%)	18
Unsoacked CBR at AASHTO(%)	72
Unconfined Compressive Strength UCS(Kpa)	116

Characterization of natural soil using X-ray diffraction (XRD)

The phase analysis of the laterite was determined using a Rigaku D/Max-111C X-ray diffractometer developed by the Rigaku int. Corp. The XRD profile of the laterite shows it has broad peaks, these peaks have noticeable widths on both sides and it has a composition of Kaolinite,Quartz, Muscovite and Orthoclase, which is represented in Fig4.3.

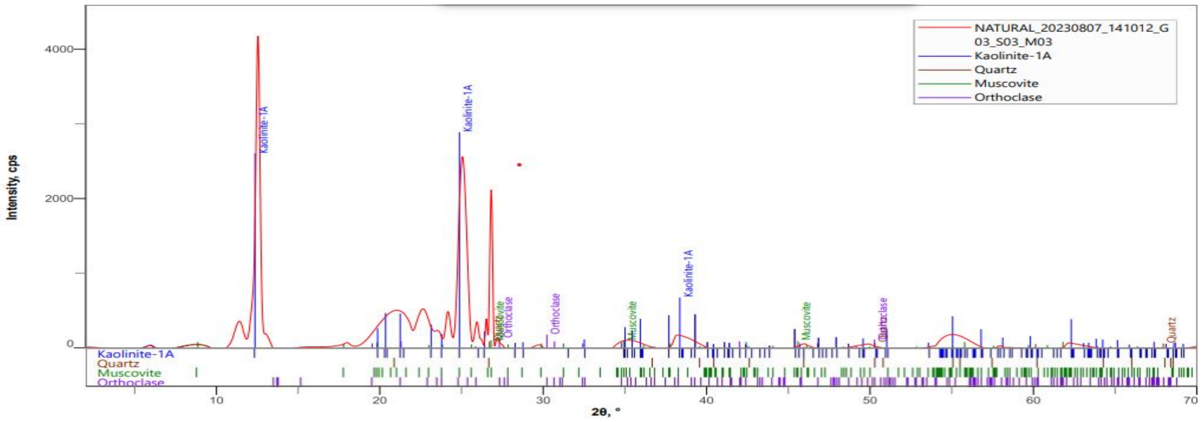

Fig 3.1: XRD result of the lateritic soil

Characterization of natural soil using X-ray Fluorescence (XRF)

The phase analysis of the laterite was determined using a Rigaku D/Max-111C X-ray spectrometer developed by the Rigaku int. Corp. The elemental composition of the laterite is shown in Fig 3.2.

Sample ident
NATURAL

Application	<Omnian>
Sequence	1 of 1
Position	3
Measurement time	11-Aug-2023 18:11:31

Normalisation factor	1.700
Minimum He Flow (l/min)	0.52

Compound	Al2O3	SiO2	P2O5	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	Fe2O3	NiO	CuO
Conc	31.401	43.377	0.359	0.448	0.860	1.198	210.9	171.6	162.7	13.143	73.5	84.7
Unit	%	%	%	%	%	%	ppm	ppm	ppm	%	ppm	ppm

Compound	ZnO	Ga2O3	As2O3	Rb2O	SrO	Y2O3	ZrO2	Nb2O5	Ag2O	SnO2	TeO2	BaO
Conc	65.5	62.0	1.2	21.4	28.6	25.4	276.7	13.2	574.7	68.6	42.8	116.0
Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm

Compound	Nd2O3	Yb2O3	OsO4	IrO2	Tl2O3	PbO	LOI	Re
Conc	107.5	28.5	0.0	0.0	0.0	11.0	9.000	0.0
Unit	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm

Fig 3.2: XRF result of the lateritic soil

3.1.3 Characterization of Natural Soil using Scanning Electron Microscope (SEM)

The chemical composition of the natural soil sample was obtained using EDX analysis, which is a non-destructive test that provides information about the elemental composition of the tested materials. EDX analysis was used to verify the surface elements as shown in Figure 4.3.

The elemental analysis of the natural soil sample as determined by EDX analysis is composed mainly of 20.1% Oxygen and 40.0% Silicon. The SEM image provides information regarding the natural soil sample structure such as shape. As can be seen from Figure 4.4, the natural soil sample particles are generally irregular in shape. Arshad *et al.,* (2020) observed that the microstructure of lateritic soil through the use of SEM indicating that the particles are generally irregular in shape.

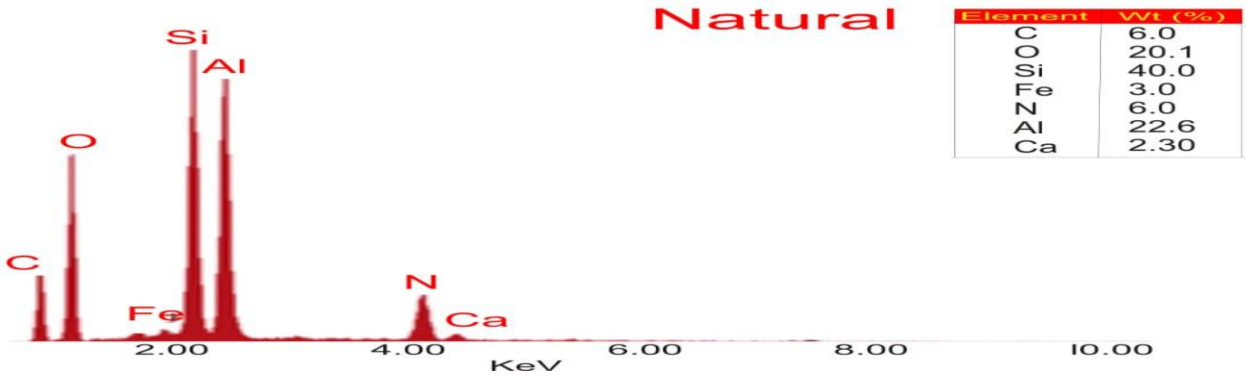

Fig 3.3: EDX Spectrometry of the lateritic soil

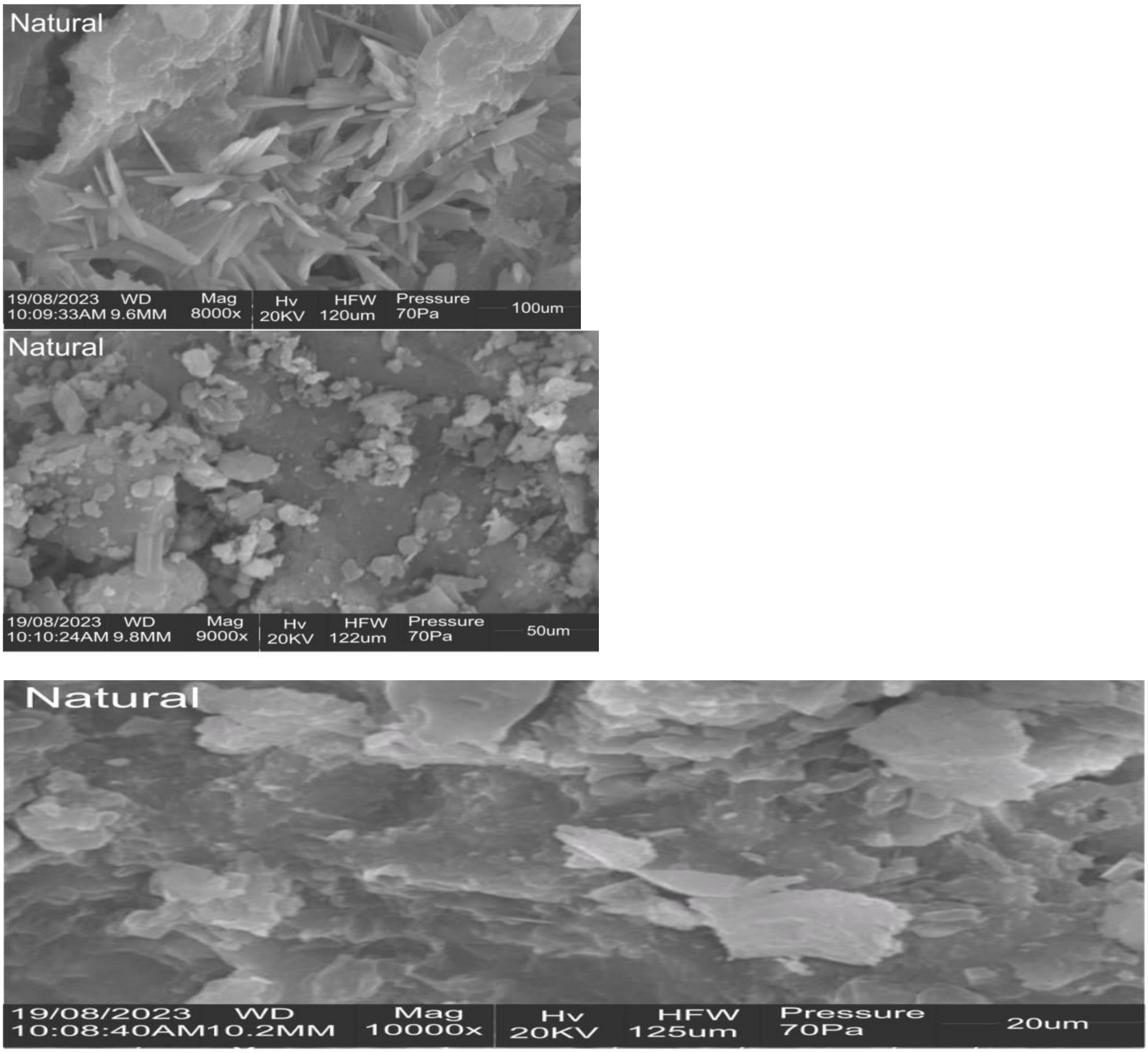

Fig 3.4: SEM images of the lateritic soil

Compaction test

The compaction test was carried out by using British Standard (BS), West African Standard (WAS) and Association of American State Highway and Transport Officials method of testing civil Engineering materials for sub-grade, sub-base and base course respectively. The un-stabilized maximum dry density (MDD) for the sample are 1.72 g/cm3, 1.76 g/cm3 and 1.82 g/cm3 with Optimum Moisture Content(OMC) 12.43%,11.78% and 9.80% for sub-grade, sub-base and base course respectively. The addition of RAM at 5,10,15,20 and 25% by weight of sample generally increased the MDD and decreased the OMC virtually for sub-grade, sub-base and base course respectively. The summary of the test results for both MDD and OMC obtained for the sub-base material are shown in Table 4.4 increased from 1.76g/cm^3 to 2.25g/cm^3 and decreased of OMC from 11.78% to 10.30%.

The summary of the test results for both MDD and OMC obtained for the base material are shown in Table 3.2 increased from 1.82g/cm^3 to 2.37g/cm^3 and decreased of OMC from 9.80% to 9.10%. The Compaction results for the natural soil samples which produced Maximum Dry Density (MDD) and Optimum moisture content (OMC).The Maximum Dry Density (MDD) and Optimum moisture content (OMC) for the soil samples used with RAM at 5,10,15,20 and 25%.The Maximum Dry Density (MDD) at WAS compaction ranges from 1.76 to 2.25g/cm^3 and 10.30 to 11.78% of OMC shown in table 4.4 below and The Maximum Dry Density (MDD) and Optimum moisture content (OMC) for the soil samples used with RAM at 5,10,15,20 and 25% at AASHTO compaction ranges from 1.82 to 2.37g/cm^3 and 9.10 to 9.80% of OMC shown in table 3.2.1 below.

The reduced in OMC is probably due to low water absorbed of RAM. An increased in MDD is general indication of soil improvement, however the addition of RAM increased the MDD which revealed the opinion of Das (2000).

Table 3.2: Summary of Compaction test results (MDD and OMC) for natural soil sample with RAM at 5,10,15,20 and 25% at WAS compaction test.

Percentage of RAM (%)	Maximum Dry density MDD (g/cm^3)	Optimum Moisture Content OMC(%)
0	1.76	11.78
5	1.83	12.20
10	1.88	11.40
15	1.99	11.10
20	2.17	10.50
25	2.25	10.30

The Maximum Dry Density (MDD) at WAS compaction ranges from 1.76 to 2.25g/cm^3 and 10.30 to 11.78% of OMC

The Maximum Dry Density (MDD) and Optimum moisture content (OMC) for the soil samples used with RAM at 5,10,15,20 and 25% at AASHTO compaction ranges from 1.82 to 2.37g/cm^3 and 9.10 to 9.80% of OMC.

Table 3.2.1: Summary of Compaction test results (MDD and OMC) for natural soil sample with RAM at 5,10,15,20 and 25% at AASHTO compaction test.

Percentage of RAM (%)	Maximum Dry density MDD (g/cm^3)	Optimum Moisture Content OMC(%)
0	1.82	9.80
5	1.97	10.20
10	2.09	9.40
15	2.18	9.90
20	2.28	11.00
25	2.37	9.10

The Maximum Dry Density (MDD) and Optimum moisture content (OMC) for the soil samples used with RAM at 5,10,15,20 and 25% at AASHTO compaction ranges from 1.82 to 2.37g/cm^3 and 9.10 to 9.80% of OMC.

California Bearing Ratio

The CBR values of the lateritic soil samples increased considerably with RAM stabilization.

The addition of RAM at 5% to 25% for the sub-base material (WAS) unsoaked condition increased the CBR values for;

i. RAM at 5% from 57% to 63%
ii. RAM at 10% from 57% to 70%
iii. RAM at 15% from 57% to 78%
iv. RAM at 20% from 57% to 88%

RAM at 25% from 57% to 94%

The addition of RAM at 5% to 25% for the sub-base material (WAS) soaked condition increased the CBR values for;

i. RAM at 5% from 18% to 22%
ii. RAM at 10% from 18% to 27%
iii. RAM at 15% from 18% to 31%
iv. RAM at 20% from 18% to 32%
v. RAM at 25% from 18% to 34%
vi. RAM at 25% from 57% to 94%

Also, the addition of RAM at 5% to 25% for the base material (AASHTO) un-soaked condition increased the CBR values for;

RAM at 5% from 72% to 77%

i. RAM at 10% from 72% to 86%
ii. RAM at 15% from 72% to 88%
iii. RAM at 20% from 72% to 94%
iv. RAM at 25% from 72% to 97%

The above results show that the load bearing capacity of the sub-base and base materials increased considerably with the addition of both RAM as presented in Figures 4.14 and 4.15. The CBR recommended for soils for use as sub-grade, sub-base, and base materials according to the Federal Ministry of Works and Housing, FMWH (1997) is 30%, 70%, and 80%, respectively, for unsoaked soils. The CBR value of RAM-Stabilized soil for sub-base material shows that addition of RAM from 10% to 25% are suitable for use as sub-base materials having CBR values greater than 70% while the sample tested as base material are suitable for use as base materials having CBR values greater than 80%. However, CBR value of RAM-Stabilized soil are suitable for use as sub-base and base course materials.

Table 3.3: Summary of California Bearing Ratio test results (CBR) for the natural soil sample with RAM 5,10,15,20, and 25% at both soaked and un-soaked conditions.

Percentage of RAM (%)	Un-soaked CBR values(%)	Soaked CBR values(%)
0	57	18
5	63	22
10	70	27
15	78	31
20	88	32
25	94	34

The California Bearing Ratio (CBR) for un-soaked and soaked conditions values for the RAM 5,10,15,20, and 25% at both soaked and un-soaked conditions for the sub-base materials using WAS compactive energy ranges from 22 to 48 for un-soaked and 2.0 to 14 at soaked condition

Table 3.3.1. Summary of California Bearing Ratio test results (CBR) for the natural soil sample with RAM 5,10,15,20, and 25% at unsoaked conditions.

Percentage of RAM (%)	Un-soaked CBR values(%)
0	72
5	77
10	86

15	88
20	94
25	97

The California Bearing Ratio (CBR) values for the soil with RAM at 5,10,15,20, and 25% at un-soaked conditions for the base materials using AASHTO compactive energy ranges from 72 to 97%.

Conclusion

From the results of the various tests performed, the following conclusions can be drawn:

i. The natural soil, which do not even meet the requirements of the Nigerian General Specification (1997) for use as a sub-base and base material, became improved by RAM stabilization such that it satisfies their requirements for use as a sub-base and base material.

ii. Shear stress and shear strength for cured and uncured samples of the lateritic soil increased by 14% to 70% and 17% to 123% for the cured and uncured shear stress and shear strength respectively. while the bearing capacity for both soaked and unsoaked conditions strength increased by 11% to 65% for the unsoaked CBR at WAS compaction, by 22% to 89% for the soaked at WAS compaction and by 7% to 35% for the unsoaked at AASHTO compaction. shows that RAM improved CBR and UCS of the lateritic soil.

iii. It was noticed that the increase in the RAM content the geotechnical properties of the soil increases, Maximum Dry Density increased by 4% to 49% at WAS compaction and increased by 14% to 55% at AASHTO compaction, Shear stress, Shear strength, CBR increases

iv. It is clear from the above investigation results that between15% to 25% replacement of natural aggregate can be successfully done in sub-base and between 10% to 25% replacement for the base course of flexible pavements respectively base on the types of lateritic materials, resulting in material cost savings ranges from 15% to 30% of total project cost (source ; Federal Highway Administration), 20% to 40% of material cost (source; Asphalt Recycling and Reclaiming Association) and 10% to 25% of construction costs (source; Nigerian Journal of Technology).

v. Above all the problem of disposal of RAM wastes can be easily solved and adverse effect on environment may be avoided by using the RAM materials in flexible pavement construction

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