

Effect of Reclaimed Asphalt Material on The Compaction and California Bearing Ratio of Lateritic Soil for Pavement Applications

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Abstract

Pavement recycling is an effective practical process for conserving the diminishing supply of construction material and reducing the cost of preserving existing pavement networks. This study investigates the effect of grinding and blending Reclaimed Asphaltic Material (RAM) with virgin lateritic soil aggregate to yield a base/sub-base material suitable for pavement construction in Nigeria, and aims to establish the optimum RAM percentage that produces base or sub-base quality material at reduced cost without compromising pavement performance. Two materials were investigated: an untreated lateritic soil (control) obtained from a borrow pit in Ogbomoso North Local Government, and RAM collected from an old pavement in Ogbomoso South Local Government. A total of seven mixtures were prepared, comprising the untreated control and six RAM-treated blends at 5, 10, 15, 20, 25 and 30% RAM by dry weight. Sieve analysis, moisture content, specific gravity, Atterberg limit, compaction and California Bearing Ratio (CBR) tests were carried out on untreated soil sample to determine its suitability for the pavement layers in accordance with BS 812 and BS 1377, while compaction and California Bearing Ratio (CBR) tests were only carried out on the soil sample combined with RAM. Results showed that aggregate blends containing RAM and lateritic soil in soil-to-RAM ratios ranging from 90:10 to 70:30 (i.e., 10-30% RAM by dry weight of the lateritic soil) are suitable for use as sub-base and base course material respectively, with RAM acting mainly as a mechanical blending agent rather than a chemical stabilizer. Addition of RAM increased the maximum dry density from 1.76 to 2.25 g/cm³ before decreasing to 2.22g/cm³ at West African Standard (WAS) compaction and from 1.82 to 2.37 g/cm³ before decreasing to 2.34g/cm³ at AASHTO compaction, while the optimum moisture content showed an overall decreasing trend. Unsoaked CBR increased from 57% to 94% (WAS) before decreasing to 92% and from 72% to 97% (AASHTO) decreasing to 95%, and soaked CBR increased from 18% to 34%(WAS) decreasing to 31%. This study contributes new laboratory evidence, specific to Nigerian lateritic soil, on how RAM dosage affects compaction and bearing-ratio behaviour, and recommends RAM-lateritic soil blending as a cost-effective, sustainable alternative for sub-base and base course pavement construction.

Keywords: Reclaimed asphalt pavement (RAP); lateritic soil; mechanical blending; pavement subbase; base course; compaction; California Bearing Ratio; sustainable pavement materials.

Introduction

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 potentially improve certain 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. Pavement recycling is reportedly limited in Nigeria; as a research motivation, this research aims to provide insights into sustainable practices that could reduce costs and environmental impact while improving road

quality (Nicholls, 2019). Although RAP/RAM blending with various aggregates has been investigated elsewhere, few studies have systematically quantified how RAM dosage affects the compaction behaviour and California Bearing Ratio of Nigerian lateritic soils across a full dosage range; this study addresses that specific gap. It was hypothesized that (i) increasing RAM content would increase the maximum dry density and reduce the optimum moisture content of the lateritic soil, (ii) both soaked and unsoaked CBR values would improve with increasing RAM content, and (iii) the liquid limit and plasticity of the blend would decrease with increasing RAM content.

Recent studies continue to explore complementary approaches for improving lateritic soil performance in road pavement construction. Ajayi *et al.* (2024) evaluated laterite derived from sedimentary rock and confirmed its suitability for subgrade and sub-base applications after appropriate treatment. Similarly, Subair (2025) reported that stabilizing lateritic soil with a combination of palm kernel shell ash and egg shell ash markedly improved its California Bearing Ratio, rendering it suitable as a sub-base material. Stevens *et al.* (2026) demonstrated that combining bitumen emulsion with iron ore tailings enhanced the strength and durability of lateritic clay soil for pavement sub-base construction, while Yusuf *et al.* (2026) showed that cold-mix reclaimed asphalt pavement incorporating treated crumb rubber reduced binder demand by up to 30% and improved moisture and rutting resistance. These recent findings reinforce the relevance of combining reclaimed and waste materials with lateritic soils for sustainable pavement construction, and underscore the continuing need for locally specific data, such as that generated in this study.

Materials and Methods

The methodology adopted for this study covered the sourcing and characterization of the lateritic soil and reclaimed asphaltic material (RAM), the blending of RAM with the soil at varying dosages, and the geotechnical tests carried out on the natural and RAM-blended soil samples.

Materials

Lateritic Soil

The lateritic soil used for this study was obtained at a depth of 1.2 m from a borrow pit at Ogbomoso North Local Government Area, Ogbomoso, Oyo State, Nigeria. The site lies within a basement-complex geological setting (granite/gneiss/schist parent rock) at an elevation of approximately 300-400 m above sea level, under a tropical wet/dry climate. The soil samples were collected in properly covered sacks, transported to the laboratory, and air-dried prior to testing.

Reclaimed Asphaltic Material (RAM)

The reclaimed asphaltic material (RAM) was obtained from an old, milled pavement surface at the Seminary area, Ogbomoso South Local Government Area, Oyo State, Nigeria, and was transported to the laboratory in polythene bags to minimize moisture loss. The RAM was milled to reduce its particle size, after which its bitumen content was extracted and its particle size distribution determined to establish the proportion of mineral filler present. The material was found to contain 8.8% bitumen, 11.8% mineral filler (passing the BS No. 200 (0.075 mm) sieve), and 79.4% aggregate, and was classified as AASHTO A-3 (granular). The bitumen content falls within the typical range (5-10%) reported for asphalt mixtures, while the filler content is below the 35% maximum-passing-No.200 limit specified by the Federal Ministry of Works and Housing (FMWH), confirming the material's suitability for use in road construction.

Chemical and Mineralogical Characterization

The chemical compositions of the lateritic soil and RAM were determined at the National Agency for Science and Engineering Infrastructure Centre of Excellence in Nanotechnology and Advanced Materials (NASeni CoEx-NA), Akure, Nigeria, using a Skyray EDX 3600B Energy Dispersive X-ray Fluorescence (XRF) Spectrometer. Mineralogical characterization was carried out by X-ray Diffraction (XRD) analysis

using a Rigaku D/Max-111C X-ray diffractometer (Rigaku International Corp.), while the surface morphology of the natural soil was examined using Scanning Electron Microscopy (SEM).

Sample Preparation and RAM Blending

Seven mixtures were prepared for testing: an untreated (natural) lateritic soil control and six RAM-blended samples, in which RAM was added to the lateritic soil at 5, 10, 15, 20, 25 and 30% by dry weight. Sieve analysis, specific gravity, moisture content, Atterberg limit, compaction, CBR and Unconfined Compressive Strength (UCS) tests were carried out on the untreated soil to establish its baseline geotechnical properties, in accordance with BS 812-102 (1984), BS 812-103.1 (1985) and BS 1377 (1990); sieve analysis followed BS 812-103.1 (1985), moisture content, specific gravity and Atterberg limits followed BS 1377:1990 Part 2, and UCS followed BS 1377-7:1990 Section 7.2, with specimens cured for 7 days prior to testing. As the study was specifically concerned with the effect of RAM content on the compaction and load-bearing behaviour of the lateritic soil, only the compaction and CBR tests were repeated on each of the six RAM-blended samples, following BS 1377:1990 Part 4 (unsoaked CBR, Section 7.2.4; soaked CBR, Section 7.3, with specimens soaked in water for 72 hours and drained for 15 minutes prior to testing).

Compaction Test

For the compaction test, 6 kg of air-dried soil was pulverized and passed through the 4 mm sieve into a mixing pan. The mass of the soil sample and the empty compaction mould (excluding the collar) were recorded, and an initial water content of 4% was assumed for the first trial. The corresponding mass of water to be added was calculated using Equation (1):

$$\text{Water to be added (g)} = \frac{\text{Soil mass (g)} \times \text{Water content (\%)}}{100} \quad (1)$$

The calculated water was added to the soil and mixed thoroughly with a trowel until a uniform colour was obtained. The mould was assembled onto its base, and the moistened soil was compacted in five equal layers, each receiving 10 blows (27 blows per layer for CBR specimens) from a 4.5 kg rammer falling freely from a height of 450 mm, in accordance with British Standard procedure. Blows were applied at a uniform rate not exceeding 1.5 seconds per drop, with the rammer providing uniform coverage of the specimen surface, until the final compacted layer extended slightly above the collar joint. The collar was then carefully removed, and the compacted soil was trimmed level with the top of the mould, with any dislodged soil replaced. The mould and its compacted content were weighed, and the wet mass of the soil obtained by subtracting the mass of the mould and base. The compacted soil was extruded using a mechanical extruder, and moisture content samples were taken from the top and bottom of the specimen and oven-dried to determine the water content. The procedure was repeated with the water content increased by 2%, until the maximum dry density and optimum moisture content of the soil were established (Plate 1).



Plate 1: Compaction Test Setup

California bearing ratio

The CBR test was carried out in accordance with BS 1377 (1990) to determine the influence of RAM content on the load-bearing capacity of the lateritic soil.

Test material was passed through the 19 mm sieve for fine-grained soils, or the 37.5 mm sieve for coarse material; any material retained on the 19 mm sieve was replaced with an equal mass of material passing the 19 mm sieve and retained on the 4.75 mm sieve.

Samples were statically compacted to their respective maximum dry density and optimum moisture content. In this approach, the mass of wet soil required to attain the specified density in the test mould (volume 2,250 cm³; 152 mm internal diameter × 127 mm height, per BS 1377 Part 4) was calculated using Equations (2)-(4):

$$\text{Weight of dry soil, } W \text{ (g)} = 2250 \times MDD \quad (2)$$

$$\text{Weight of wet soil (g)} = \left(1 + \frac{m}{100}\right) \times W \quad (3)$$

$$\text{Weight of water (g)} = \text{Weight of wet soil} - \text{Weight of dry soil} \quad (4)$$

Where MDD is the maximum dry density (g/cm³) and m is the optimum moisture content (%) obtained from the compaction test. The calculated mass of oven-dried soil was thoroughly mixed with the corresponding mass of water. The empty mass of the mould and base plate (with the extension collar removed) was recorded as m₁, and the moist soil was placed into the mould in five layers, each compacted with a spacer disc between the platens of a compression testing machine until the top of the spacer disc was flush with the top of the mould (Plate 2). The load was sustained for about 30 seconds before being released.

The mould was then removed from the machine, the spacer disc taken out, and the mould with its compacted soil weighed (m₂). The extension collar was replaced, and two further specimens were prepared following the same procedure for each RAM dosage.



Plate 2: CBR Test Setup

Three specimens were prepared and tested per RAM dosage level, and RAM-treated specimens for the Unconfined Compressive Strength test were cured for 7 days prior to testing.

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 for the untreated lateritic soil and the compaction and CBR test results for lateritic soil stabilized with Recycled Asphaltic Materials (RAM) at 5,10,15,20,25 and 30%.

Characterization of Lateritic Soil

Table 1 and 2 give 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%. The soil recorded a Liquid Limit of 56.0%, Plastic Limit of 38.0% and Plasticity Index of 18.0%, consistent with the A-7-6 classification.

Table 1: Physical Properties of the Lateritic Soil.

Physical Properties	Quantities /Values
Percentage Passing No. 200 sieve (%)	39
Natural Moisture Content (%)	1.8
AASHTO Classification	A-7-6
Specific Gravity	2.67
Colour	Brown
Liquid Limit (%)	56.0
Plastic Limit (%)	38.0
Plasticity Index (%)	18.0

Table 2: 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
Unsoaked CBR at BS (%)	34
Soaked CBR at BS (%)	6
Unsoaked CBR at WAS (%)	57
Soaked CBR at WAS (%)	18
Unsoaked 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 Fig 1

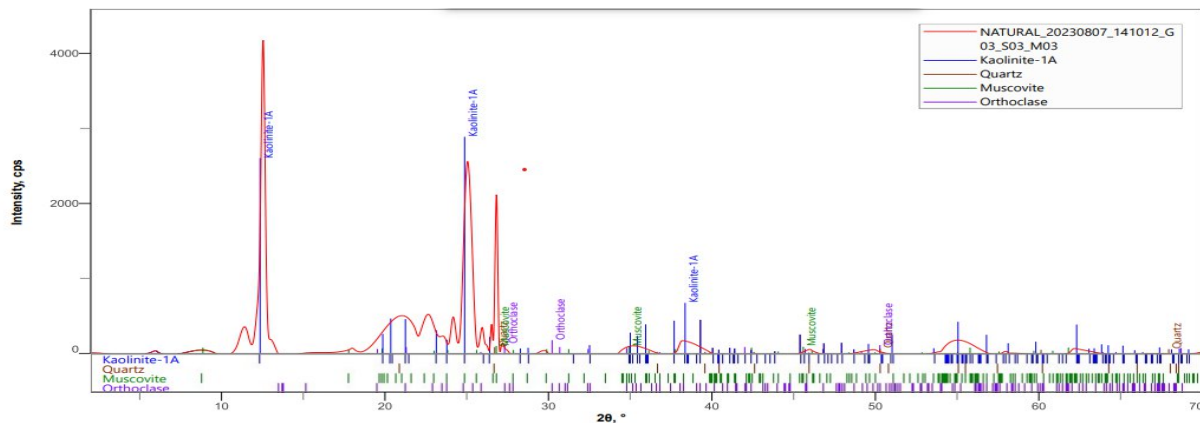


Figure 1: XRD result of the lateritic soil

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.

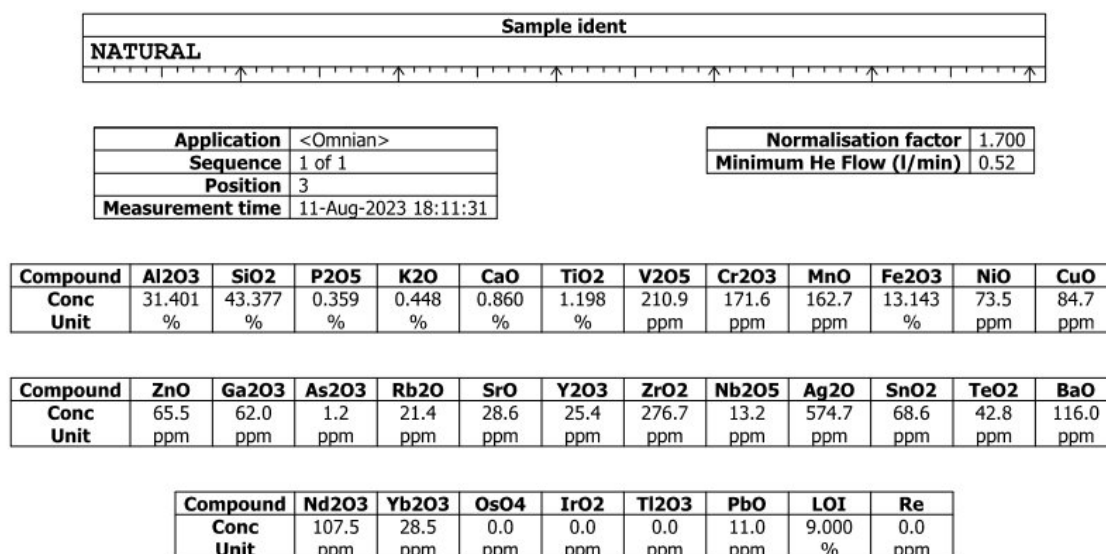


Figure 2: XRF result of the lateritic soil

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 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, 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.

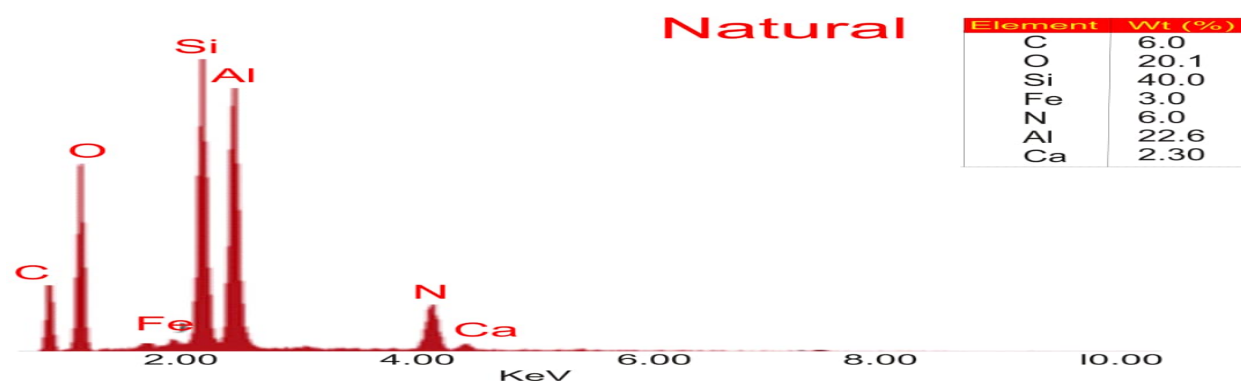
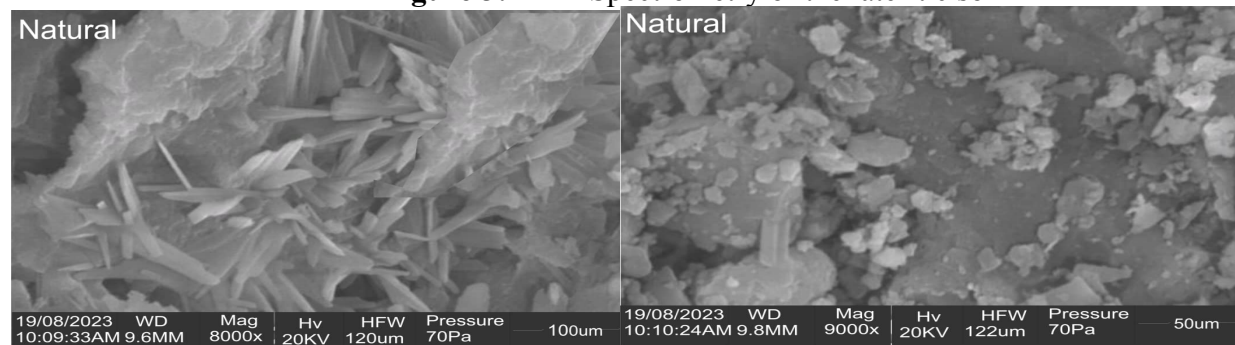


Figure 3: EDX Spectrometry of the lateritic soil



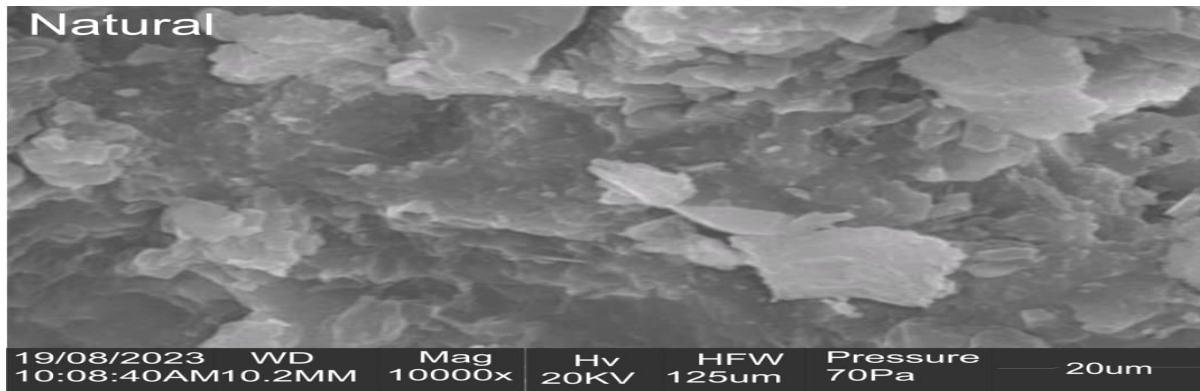


Figure 4: SEM images of the lateritic soil

Compaction test

The compaction characteristics of the lateritic soil-RAM blends were evaluated at British Standard (BS), West African Standard (WAS) and AASHTO compaction energies, representing sub-grade, sub-base and base course design conditions respectively. The untreated soil recorded a Maximum Dry Density (MDD) of 1.72, 1.76 and 1.82 g/cm³ and an Optimum Moisture Content (OMC) of 12.43%, 11.78% and 9.80% at BS, WAS and AASHTO energies respectively (Table 2). As shown in Figure 5, incorporating RAM into the lateritic soil produced a consistent increase in MDD at WAS compaction, rising from 1.76 g/cm³ for the untreated soil to a peak of 2.25 g/cm³ at 25% RAM, a 27.8% improvement, before falling slightly to 2.22 g/cm³ at 30% RAM. The corresponding OMC fell overall from 11.78% to 10.10% at 30% RAM, although a small rise to 12.20% was recorded at 5% RAM before the downward trend resumed. A similar pattern was observed at AASHTO compaction energy (Figure 6): MDD increased from 1.82 g/cm³ for the untreated soil to a peak of 2.37 g/cm³ at 25% RAM, a 30.2% gain, before declining marginally to 2.34 g/cm³ at 30% RAM. OMC decreased overall from 9.80% to 9.00% at 30% RAM, with a similar non-monotonic rise to 10.20% recorded at 5% RAM. The improvement in MDD is attributable to the mechanical, rather than chemical, action of RAM within the soil matrix. RAM is a well-graded granular material (AASHTO A-3, with 79.4% aggregate content) coated with a thin residual bitumen film; when blended with the fine-grained lateritic soil (39% passing the No. 200 sieve), the coarser RAM particles occupy the voids between the finer soil particles, improving the overall particle-size gradation and packing density of the mixture. This densification effect is consistent with the mechanical blending mechanism that RAM is understood to provide in this study, and mirrors the improvement in packing density typically achieved when a coarser granular fraction is introduced into a fine-grained soil matrix (Das, 2000).

The general reduction in OMC with increasing RAM content is attributed to the lower water affinity of the RAM particles: the residual bitumen coating renders the RAM aggregate largely hydrophobic, so a smaller volume of water is required to bring the blend to its optimum compaction moisture as more of the fine, more absorptive lateritic soil fraction is displaced. The brief rise in OMC recorded at 5% RAM under both compaction energies is likely a threshold effect, in which the small quantity of RAM initially disrupts the soil's natural fabric before enough RAM is present to establish the denser, less water-demanding granular skeleton observed at higher dosages. Beyond the 25% RAM dosage, MDD at both WAS and AASHTO compaction energies declined slightly (to 2.22 g/cm³ and 2.34 g/cm³, respectively, at 30% RAM), even though OMC continued to fall. This indicates that an optimum RAM content exists near 25%, beyond which the excess residual bitumen coating on the additional aggregate particles begins to lubricate inter-particle contacts and interfere with effective compaction, offsetting the densification benefit of the extra granular material. This is consistent with the 5-25% RAM dosage range adopted for the treated blends in this study, beyond which excess bitumen coating is expected to reduce shear and bearing performance.

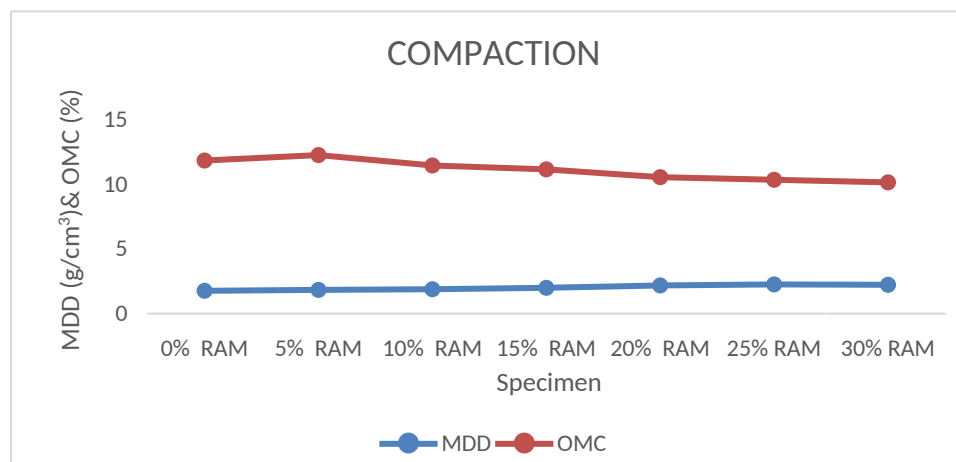


Figure 5: Compaction characteristics (Maximum Dry Density and Optimum Moisture Content) of the lateritic soil-RAM blend at West African Standard (WAS) compaction energy.

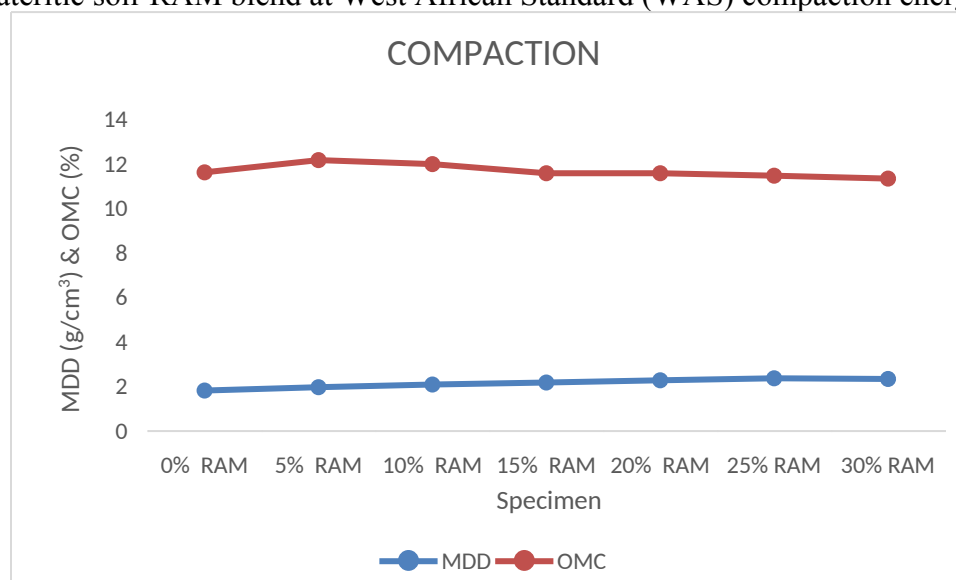


Figure 6: Compaction characteristics (Maximum Dry Density and Optimum Moisture Content) of the lateritic soil-RAM blend at AASHTO compaction energy.

California Bearing Ratio

The California Bearing Ratio (CBR) test, a key index of subgrade and pavement layer strength, was carried out on the untreated soil and each RAM-blended mixture at WAS (unsoaked and soaked) and AASHTO (unsoaked) compaction energies. As presented in Figures 7 and 8, CBR increased consistently with RAM content up to 25% RAM across all three testing conditions, before declining slightly at 30% RAM. At WAS compaction (Figure 7), the unsoaked CBR of the untreated soil (57%) rose progressively with RAM addition to 63%, 70%, 78%, 88% and 94% at 5%, 10%, 15%, 20% and 25% RAM respectively, before falling slightly to 92% at 30% RAM, an overall improvement of up to 64.9% relative to the untreated soil. The four-day soaked CBR followed the same trend, rising from 18% for the untreated soil to a peak of 34% at 25% RAM (an 88.9% improvement), before declining to 31% at 30% RAM. At AASHTO compaction (Figure 8), unsoaked CBR increased from 72% for the untreated soil to 77%, 86%, 88%, 94% and 97% at 5%, 10%, 15%, 20% and 25% RAM respectively, a 34.7% improvement at the 25% optimum, before decreasing to 95% at 30% RAM.

As with the compaction results, the improvement in CBR is attributed principally to the mechanical densification and improved particle interlock provided by the coarser, well-graded RAM aggregate rather than to any pozzolanic or cementitious binding action, consistent with RAM's role as a mechanical blending

agent for this soil. The angular aggregate skeleton contributed by RAM increases the internal friction and load-transfer capacity of the soil-RAM matrix, while the residual bitumen film coating the RAM particles may additionally provide a degree of particle-to-particle adhesion at contact points, further restraining lateral deformation under the penetration load. The decline in CBR beyond 25% RAM mirrors the decline observed in MDD at the same dosage, reinforcing the conclusion that an excess of bitumen-coated aggregate beyond the optimum begins to reduce inter-particle friction and offsets the strength gained from densification. These results were benchmarked against the Federal Ministry of Works and Housing (FMWH, 1997) minimum unsoaked CBR requirements of 30%, 70% and 80% for sub-grade, sub-base and base course materials respectively. At WAS compaction, unsoaked CBR reached the 70% sub-base threshold at 10% RAM (70%) and exceeded it comfortably from 15% RAM upward (78-94%), supporting the 15-25% RAM dosage range recommended for sub-base application. At AASHTO compaction, unsoaked CBR met the 80% base-course threshold from 10% RAM upward (86-97%), consistent with the 10-25% RAM dosage range recommended for base course construction. Soaked CBR values (22-34%) are, as expected, well below these unsoaked-based thresholds, since the FMWH limits cited apply specifically to unsoaked conditions; nonetheless, the consistent upward trend in soaked CBR with RAM content confirms that a meaningful part of the bearing-capacity improvement is retained even after prolonged saturation, an important consideration for pavements exposed to Nigeria's wet season.

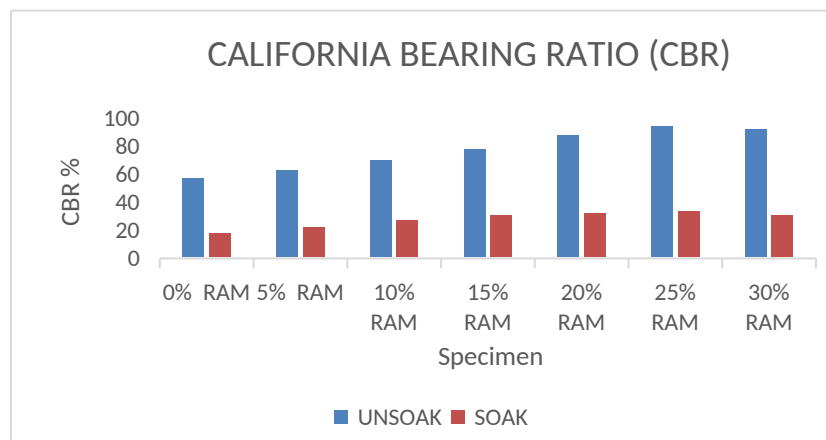


Figure 7: Unsoaked and soaked California Bearing Ratio (CBR) of the lateritic soil-RAM blend at West African Standard (WAS) compaction energy.

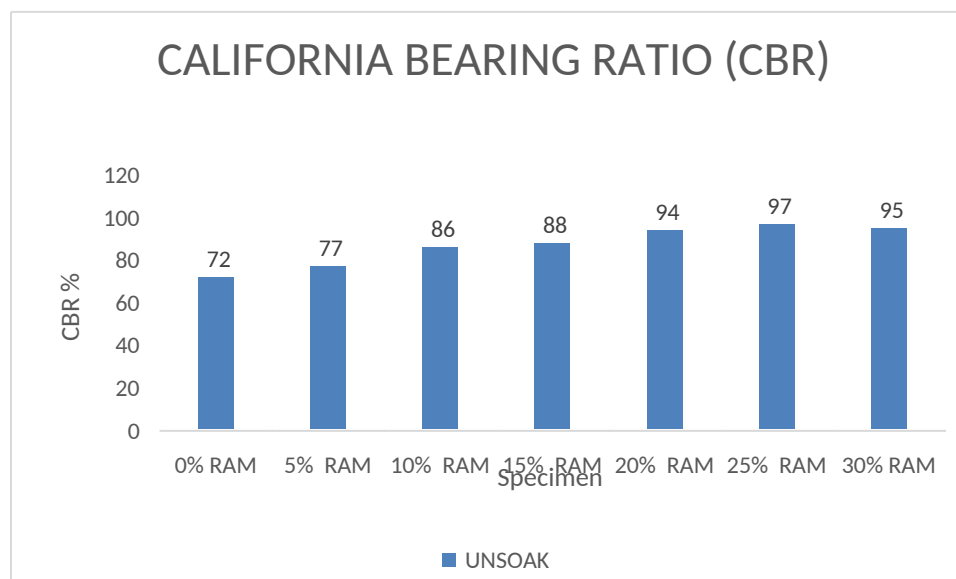


Figure 8: Unsoaked California Bearing Ratio (CBR) of the lateritic soil-RAM blend at AASHTO compaction energy.

Conclusion

The natural lateritic soil, which originally failed to meet the Nigerian General Specification (FMWH, 1997) requirements for sub-base or base course construction, was significantly improved through mechanical blending with Recycled Asphalt Material (RAM). Compaction, bearing capacity, and overall strength parameters improved consistently with increasing RAM content, evidenced by Maximum Dry Density increases of 4–49% under West African Standard (WAS) and 14–55% under AASHTO compaction energies, along with substantial enhancements in both unsoaked and soaked California Bearing Ratio (CBR) values. Furthermore, 7-day cured shear stress and shear strength increased by up to 70% and 123% respectively, confirming that RAM functions effectively as a mechanical aggregate replacement to transform non-compliant lateritic soil into a technically sound pavement material. Based on the compaction and CBR test performance, a RAM replacement level of 15% to 25% by dry weight is recommended for lateritic soil intended for highway sub-base applications, while a 10% to 25% replacement level is recommended for base course construction depending on the specific properties of the natural lateritic material. Although literature benchmarks suggest potential project cost savings of 15% to 30% through RAM reuse, project-specific financial evaluations under local Nigerian conditions are recommended to substantiate direct economic claims. Overall, highway authorities and site engineers should adopt RAM partial aggregate replacement as a sustainable, eco-friendly pavement construction strategy that reduces reliance on virgin aggregates while effectively mitigating local asphalt waste management challenges.

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