

Comparative Evaluation Of Reclaimed Asphalt (Ra) And Laterite As Sub-Base Materials For Flexible Pavement Construction

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ABSTRACT : The continued dependence on lateritic soil for sub-base construction in Nigeria has intensified borrow-pit quarrying, land degradation and the depletion of natural aggregate reserves, while large volumes of reclaimed asphalt (RA) generated during road rehabilitation remain underutilised. This study presents a comparative laboratory evaluation of RAP and laterite as sub-base materials for flexible pavements. RAP was obtained from milled stockpiles of the Keffi–Maraba Expressway expansion project, and laterite was sampled at a depth of 1.0 m from a borrow pit in the North Bank area of Makurdi, Benue State. Both materials were characterised through natural moisture content, particle-size distribution, Atterberg limits, modified Proctor compaction and California Bearing Ratio (CBR) tests under soaked and unsoaked conditions, in accordance with BS 1377 (1990), the relevant ASTM standards and the Federal Ministry of Works and Housing (FMWH, 1997) specification. One-way analysis of variance (ANOVA) with Levene's test for homogeneity of variance was used to assess statistical significance. RAP recorded a very low natural moisture content of 1.65% against 56.38% for laterite ($p < 0.001$). Both materials were well-graded gravels (USCS "GW"; AASHTO A-1-a), with coefficients of uniformity of 23.7 (RAP) and 12.4 (laterite) and fines contents below 3%, and both compacted to a comparable maximum dry density of about 1.70 g/cm³ (RAP at $\approx 8\%$ and laterite at $\approx 9\%$ optimum moisture content; $p = 0.859$). Laterite was of medium plasticity (LL = 37%, PL = 12.9%, PI = 24.1%), whereas RAP was non-plastic. Laterite recorded higher CBR values (39% unsoaked, 33% soaked) than RAP (26% unsoaked, 21% soaked); the difference was statistically significant ($F = 27.17$, $p < 0.002$, $\omega^2 = 0.766$). On soaked CBR, laterite satisfied the 30% minimum requirement for sub-base, while unbound RAP fell marginally short and would require blending with natural aggregate or chemical stabilisation to comply. RAP nevertheless offers superior moisture stability and substantial environmental benefits through waste diversion and aggregate conservation. The study concludes that RAP is a technically viable and environmentally sustainable sub-base alternative for low- to medium-traffic roads when appropriately processed, and recommends blended RAP–laterite or stabilised RAP systems for routine adoption.

KEYWORDS: Reclaimed asphalt pavement, Laterite, Sub-base, California Bearing Ratio, Compaction, Sustainable pavement, Geotechnical properties

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I. INTRODUCTION

The sub-base is a critical layer in flexible pavement systems, providing structural stability, distributing traffic-induced stresses and protecting the subgrade from premature failure (Arulrajah, Disfani & Horpibulsuk, 2012). In tropical regions such as

Nigeria, lateritic soil a reddish, iron- and aluminium-rich residual soil has long been the preferred sub-base material owing to its wide availability, low cost and acceptable geotechnical performance when

properly compacted (Gidigas, 1976; O'Flaherty, 2002).

However, the extensive quarrying of laterite has produced significant environmental consequences, including deforestation, loss of arable land, soil erosion and elevated carbon emissions from haulage and earthmoving operations (Nwaiwu & Uzodinma, 2020). At the same time, Nigeria generates large quantities of construction and demolition waste annually, a substantial proportion of which including reclaimed asphalt (RA) recovered during resurfacing and reconstruction is landfilled or indiscriminately dumped (Tam & Tam, 2006). These twin pressures have motivated a global search for reclaimed and recycled materials capable of substituting, wholly or partly, for natural sub-base aggregates (Arulrajah, Piratheepan, Bo & Disfani, 2013).

RA consists of aggregate particles coated with aged bitumen, recovered by milling existing asphalt layers. Internationally, RA has been used successfully in unbound and stabilised sub-base and base applications, offering reduced demand for virgin aggregate, lower landfill burden and competitive engineering performance (Little, 2004; Al-Qadi, Elseifi & Carpenter, 2007; Copeland, 2011). Its low affinity for water, derived from the residual bitumen film, makes it comparatively insensitive to moisture a desirable attribute in regions with marked wet and dry seasons (Hossain, Masad & Pan, 2011). Reported performance is nonetheless influenced by binder ageing, gradation and the degree of compaction, and unbound RA can exhibit lower bearing capacity than well-graded natural aggregate unless blended or treated (Molenaar & van Niekerk, 2002; Zhang, Chen & Xu, 2015).

Although the behaviour of laterite in Nigerian road construction is well documented, comparatively little local data exist that directly compares laterite with RA under identical laboratory conditions and against the same national specification. This gap limits the confident, performance-based selection of reclaimed materials by engineers and policymakers. The present study addresses this gap through a controlled comparative evaluation of the index and strength properties of RA and laterite, supported by formal statistical testing.

II. LITERATURE REVIEW

2.1 Sub-base Materials in Road Construction

The sub-base distributes wheel loads to the subgrade, provides a working platform during construction, and contributes to drainage within the pavement structure (Arulrajah et al., 2012; Oloruntoba, 2020). Materials traditionally used include natural gravels, crushed stone, granular sub-base blends and stabilised soils, selected on the basis of strength, gradation, plasticity

and durability (Gidigas, 1976). Rising sustainability and cost concerns have driven interest in alternatives such as RA, recycled concrete aggregate and lateritic soils, particularly where good-quality natural aggregate is scarce or expensive (Olanipekun & Abegunde, 2015; Poon & Chan, 2006).

2.2 Laterite as a Sub-base Material

Laterite is a ferruginous residual soil rich in iron and aluminium oxides, formed by intense tropical weathering and widely distributed across Nigeria, Ghana, India and Brazil (Gidigas, 1976; O'Flaherty, 2002). Its suitability for sub-base use depends on gradation, plasticity, moisture content and bearing capacity, all of which vary with parent rock, depth and degree of weathering (Murthy, 2002). Well-drained, coarse-grained laterites exhibit higher bearing capacity and lower plasticity, whereas clay-rich variants lose strength when wet and may require stabilisation with cement or lime (Arulrajah et al., 2012; Osinubi & Nwaiwu, 2006). Typical engineering ranges reported in the literature are summarised in Table 1. Lateritic soils commonly achieve a soaked CBR of 30–50%, meeting the FMWH (1997) minimum of 30% for sub-base in flexible pavements.

Table 1: Typical geotechnical property ranges of lateritic soil (compiled from (Gidigas, 1976; FMWH, 1997; Ola, 1978))

Property	Typical Range	Significance for Sub-base
Particle-size distribution	10–70% gravel, 20–50% sand, 5–20% fines	Governs compaction and drainage
Plasticity index (PI)	10–25%	Low–moderate PI preferred for stability
Liquid limit (LL)	30–50%	Indicates workability
Soaked CBR	30–50%	Meets minimum sub-base requirement
Specific gravity	2.6–2.8	Influences density and compaction

2.3 Reclaimed Asphalt (RA) as a Sub-base Material

RA is produced by milling or removing aged asphalt pavement during rehabilitation. It typically comprises 90–95% aggregate and 5–10% aged binder by weight (Witczak & Tia, 2015), with the residual bitumen having oxidised and stiffened in service. After crushing and screening to a controlled gradation, RA exhibits moderate stiffness, good compactability and acceptable load-bearing capacity, especially when blended with natural aggregate or stabilised (Al-Qadi et al., 2007; Copeland, 2011). The bitumen film limits water absorption, conferring low moisture sensitivity, but can also reduce inter-particle friction, so that unbound RA often records lower CBR than dense natural aggregate (Molenaar & van Niekerk, 2002; Hossain et al., 2011). A representative composition is given in Table 2.

Table 2: Typical composition of reclaimed asphalt pavement (after FHWA, 2016)

Component	Percentage by Weight (%)
Coarse aggregate	45–60
Fine aggregate	30–45
Asphalt binder	3–7
Filler and fines	2–5

2.4 Previous Comparative Studies

Several investigations have benchmarked RA against natural materials. Hossain et al. (2011) reported unbound RA CBR values broadly in the 15–35% range, increasing markedly when RA was blended with virgin aggregate. Arulrajah et al. (2011, 2013) found that RA and RA-blend mixtures met base and sub-base requirements once compacted to specification, and that cement or cement-kiln-dust treatment substantially raised strength and stiffness. Olanipekun and Abegunde (2015) compared RA with natural aggregates for sub-base layers and concluded that RA is a competitive, lower-cost option for low-to medium-volume roads. For laterite, Osinubi and Nwaiwu (2006) demonstrated that cement and lime stabilisation significantly improves compaction and CBR characteristics, while Gidigas (1976) and O’Flaherty (2002) established the bearing-capacity and durability ranges now embedded in design practice. Collectively, these studies indicate that both materials can serve as sub-base when properly processed, but that direct, specification-referenced

comparisons under identical tropical conditions remain limited the gap this study addresses.

The reviewed literature establishes laterite as a reliable but moisture-sensitive natural material, and RA as a moisture-stable, sustainable reclaimed material whose unbound bearing capacity is sensitive to gradation and binder content. Few local studies compare the two head-to-head against the FMWH specification using a common test programme and statistical validation. This study provides that comparison.

III. MATERIALS AND METHODS

3.1 Research Design

An experimental, comparative design was adopted in which RA and laterite were subjected to an identical suite of geotechnical tests under controlled laboratory conditions. The results were analysed descriptively, compared directly, tested for statistical significance, and evaluated against the FMWH (1997) sub-base specification. The standards governing each test are listed in Table 3.

Table 3: Laboratory tests and governing standards

Test	Standard	Parameters Determined
Natural moisture content	BS 1377-2 (1990)	Moisture content (%)
Particle-size distribution	BS 1377-2 (1990); ASTM D422	% passing, Cu, Cc, classification
Atterberg limits	BS 1377-2 (1990); ASTM D4318	LL, PL, PI, SL
Compaction (modified Proctor)	BS 1377-4 (1990); ASTM D1557	MDD, OMC
California Bearing Ratio	BS 1377-4 (1990); ASTM D1883	Soaked and unsoaked CBR (%)

3.2 Materials

3.2.1 Reclaimed Asphalt (RA)

RA was collected from freshly milled stockpiles produced during the Federal Ministry of Works Keffi–Maraba Expressway expansion project. The material was dark grey to black, granular and coated

with residual bitumen, and was processed to a maximum particle size of 20 mm. Oversized particles, debris and contaminants were removed before testing.

3.2.2 Lateritic Soil

Laterite was excavated at a depth of approximately 1.0 m below the organic topsoil from a borrow pit in the North Bank area of Makurdi, Benue State. The soil was reddish-brown and coarse-textured with clayey fines, and was sealed in polyethylene bags to preserve its natural moisture during transport.

3.3 Methods

Representative samples were obtained from multiple points to ensure homogeneity. RA was air-dried, and large clumps were broken down with a rubber mallet. Laterite was air-dried to constant weight, freed of organic matter and coarse intrusions, pulverised and screened through a 20 mm sieve. Each material was thoroughly mixed before testing.

3.4 Laboratory Tests

Moisture content was determined on three replicate specimens per material by oven-drying at 105–110 °C to constant mass. Particle-size distribution was obtained by dry sieving oven-dried samples on BS sieves (10 mm to 0.075 mm) using a mechanical shaker; the percentage passing was plotted on a semi-logarithmic scale, and the gradation indices D_{10} , D_{30} and D_{60} , the coefficient of uniformity ($C_u = D_{60}/D_{10}$) and the coefficient of curvature ($C_c = D_{30}^2/(D_{10} \times D_{60})$) were computed. Atterberg limits were determined for laterite only — the liquid limit with the Casagrande apparatus and the plastic limit by thread-rolling (3 mm) — RA being non-plastic. Compaction was performed using the modified Proctor method (five layers, 25 blows with a 2.5 kg rammer) across a range of moisture contents to establish MDD and OMC. CBR specimens were compacted at OMC/MDD and penetrated at 1.25 mm/min; soaked specimens were submerged for 96 hours before testing.

3.5 Data Analysis

Results were summarised using descriptive statistics and compared graphically. One-way ANOVA assessed the significance of differences between materials, with Levene's test applied beforehand to confirm homogeneity of variance, and the effect size (ω^2) reported to indicate practical magnitude. Compliance was evaluated against FMWH (1997), AASHTO (2013) and BS 1377 (1990).

IV. RESULTS AND DISCUSSION

4.1 Natural Moisture Content

The average natural moisture content was 1.65% for RA and 56.38% for laterite (Table 4). The very low RA value reflects a hydrophobic residual bitumen coating its aggregates, limiting water absorption. The high as-sampled moisture of laterite is attributable to its clayey and silty fines, which retain water and make field compaction sensitive to moisture control (Bell, 1996; Nelson & Miller, 1992). One-way ANOVA confirmed a highly significant difference ($F = 11222$, $p < 0.001$, $\omega^2 = 0.999$; Levene's $F(1,4) = 2.749$, $p = 0.173$), as illustrated in Table 4.

Table 4: Average natural moisture content

Material	Average Natural Moisture Content (%)
RA	1.65
Laterite	56.38

4.2 Particle-Size Distribution and Soil Classification

Both materials were predominantly coarse-grained (Table 5, Fig. 2). RA had 73.18% passing the 10 mm sieve and only 2.82% passing 0.15 mm, while laterite was marginally coarser in the upper fractions (83.25% passing 10 mm) with a slightly higher proportion of intermediate fines. ANOVA on overall percentage passing showed no statistically significant difference ($F = 0.007$, $p = 0.932$), confirming that grading was broadly comparable.

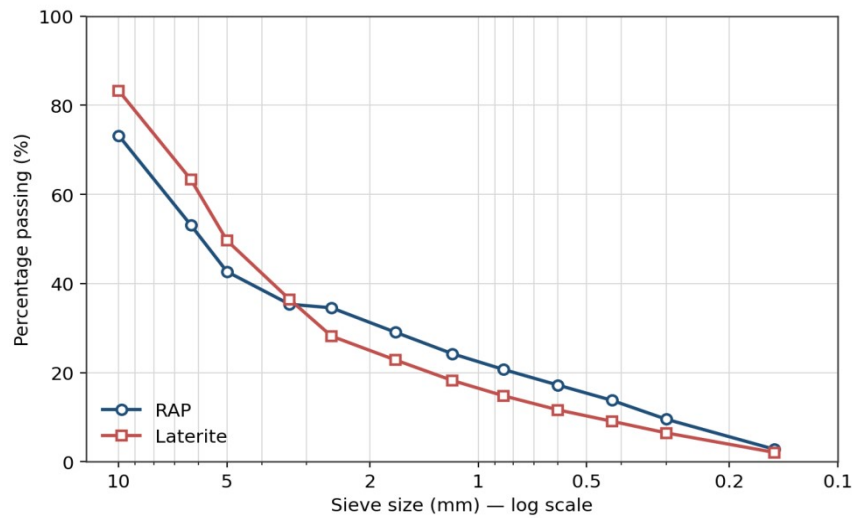


Fig. 1: Particle-size distribution curves

Source: Authors' laboratory results

The derived gradation indices are presented in Table 6. RA returned a coefficient of uniformity (C_u) of 23.7 and a coefficient of curvature (C_c) of 1.45, while laterite returned $C_u = 12.4$ and $C_c = 2.58$. Both satisfy the well-graded criteria for gravels ($C_u \geq 4$ and $1 \leq C_c \leq 3$) and contain less than 3% fines passing 0.075 mm. Accordingly, both classify as

well-graded gravels “GW” in the Unified Soil Classification System and A-1-a in the AASHTO system confirming their suitability as granular sub-base in terms of grading. The broad, continuous particle-size range explains the dense packing and stable compaction observed for both materials (Das, 2016; Holtz & Kovacs, 1981).

Table 5: Gradation indices and soil classification

Gradation Parameter	RA	Laterite
D_{10} (mm)	0.31	0.48
D_{30} (mm)	1.82	2.72
D_{60} (mm)	7.39	5.96
Coefficient of uniformity, C_u	23.7	12.4
Coefficient of curvature, C_c	1.45	2.58
Gravel > 4.75 mm (%)	58.3	52.0
Sand 0.075–4.75 mm (%)	38.9	45.8
Fines < 0.075 mm (%)	< 3	< 3
USCS classification	GW	GW
AASHTO classification	A-1-a	A-1-a

4.3 Atterberg Limits

The consistency limits of laterite (Table 6) gave a liquid limit of 37%, a plastic limit of 12.9% and a plasticity index of 24.1%, classifying it as a medium-plasticity material, with a low shrinkage limit of 3.6% indicating limited volume change on drying.

ANOVA confirmed a significant difference between the liquid and plastic limits ($F = 63.63$, $p = 0.001$, $\omega^2 = 0.913$). A medium plasticity index implies moderate susceptibility to deformation under moisture variation and reinforces the need for careful moisture control during compaction (Craig, 2004; Das, 2016). RA was non-plastic and not subjected to this test.

Table 6: Atterberg limits of laterite

Parameter	Value (%)	Remark
Liquid Limit (LL)	37.0	Typical for lateritic soil
Plastic Limit (PL)	12.9	Moderate plasticity
Plasticity Index (PI = LL – PL)	24.1	Medium-plasticity soil
Shrinkage Limit (SL)	3.6	Low volumetric shrinkage

4.4 Compaction Characteristics

RA attained a maximum dry density of approximately 1.70 g/cm^3 at an optimum moisture content of about 8%, and laterite a comparable 1.70 g/cm^3 at about 9% (Table 8, Fig. 3). The flatter response of RA around its peak confirms its

insensitivity to moisture, which simplifies field compaction; laterite, owing to its clay content, required slightly higher moisture. ANOVA found no significant difference in maximum dry density ($F = 0.034$, $p = 0.859$, $\omega^2 = 0.000$), indicating that both achieve similar densification under controlled effort.

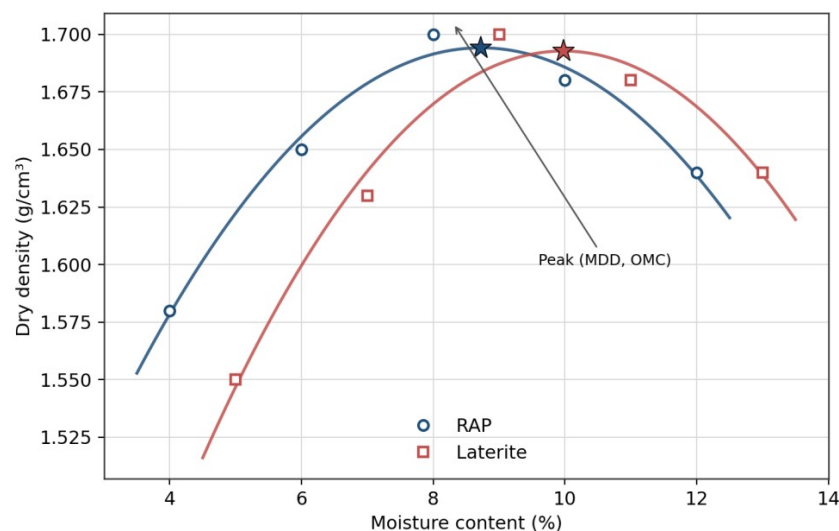


Fig. 2: Compaction curves (★ denotes MDD/OMC)

Source: Authors' laboratory results

4.5 California Bearing Ratio (CBR)

Laterite recorded higher bearing capacity than RA under both conditions (Tables 9 and 10, Fig. 4): unsoaked CBR of 38–40% (mean 39%) and soaked CBR of 32–34% (mean 33%), against RA's 25–27% (mean 26%) unsoaked and 20–22% (mean 21%) soaked. Both lost strength on soaking, but laterite remained at or above the 30% minimum for sub-base, whereas unbound RA fell below it in the soaked state.

This reflects the contrasting load-transfer mechanisms of the two materials. The bearing capacity of well-compacted laterite arises from frictional interlock and the partial cementation of its iron-oxide matrix, while the residual bitumen film on RA aggregates — though it confers moisture resistance — reduces inter-particle friction and lowers the unbound CBR (Molenaar & van Niekerk, 2002; Hossain et al., 2011). One-way ANOVA

confirmed a significant difference ($F = 27.17$, $p < 0.002$), with a large effect size ($\omega^2 = 0.766$). The

mean overall CBR was 36% for laterite and 23.5% for RA.

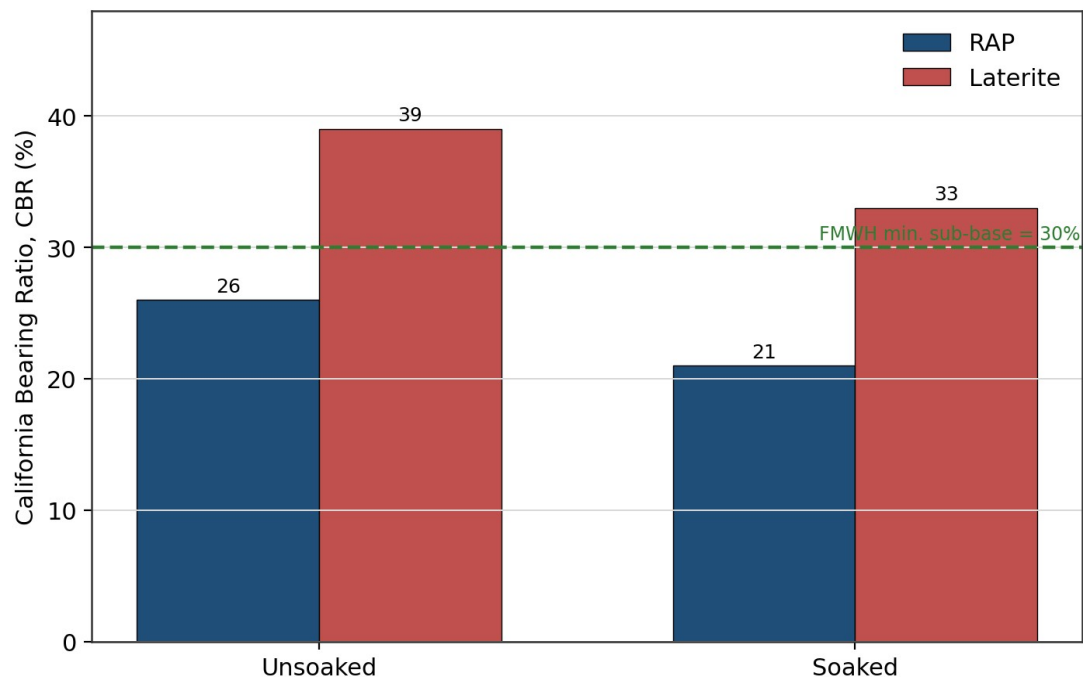


Fig. 3: Comparison of soaked and unsoaked CBR with the FMWH threshold

Source: Authors' laboratory results

4.6 Statistical Analysis

Table 7 consolidates the ANOVA outcomes. Moisture content, Atterberg limits and CBR differed significantly, whereas overall gradation and

maximum dry density did not. The pattern is internally consistent: the materials compact to similar densities and have comparable overall grading, but differ fundamentally in moisture sensitivity and bearing behaviour.

Table 7: Summary of one-way ANOVA results

Property	F	p-value	ω^2	Significance
Moisture content	11222	< 0.001	0.999	Significant
Particle size (% passing)	0.007	0.932	0.000	Not significant
Atterberg limits (LL vs PL)	63.63	0.001	0.913	Significant
Maximum dry density	0.034	0.859	0.000	Not significant
CBR	27.17	< 0.002	0.766	Significant

The results align well with published values, supporting their validity. The unbound RA CBR of 21–26% obtained here lies within the 15–35% range reported for unbound RA by Hossain et al. (2011) and Arulrajah et al. (2013), and is consistent with the observation that unbound RA frequently requires

blending or stabilisation to satisfy sub-base strength criteria (Molenaar & van Niekerk, 2002; Zhang et al., 2015). The laterite CBR of 33–39% falls within the 30–50% range established for tropical lateritic sub-base soils (Gidigas, 1976; FMWH, 1997). The medium plasticity ($PI = 24.1\%$) and the GW/A-1-a

classification are likewise typical of well-graded Nigerian laterites suitable for sub-base, as reported by Osinubi and Nwaiwu (2006) and Nwaiwu and Uzodinma (2020). The convergence of the present data with these independent studies lends confidence to the comparative conclusions.

From a purely structural standpoint, well-compacted laterite outperforms unbound RA in bearing capacity and more comfortably satisfies the FMWH sub-base requirement in the soaked state. However, this advantage is conditional on rigorous moisture control: laterite's high moisture retention and medium plasticity expose it to strength loss where drainage is poor or rainfall is seasonal, as is common across Benue, Makurdi and Nasarawa.

RA, by contrast, offers consistent, moisture-insensitive performance and clear environmental benefits, diverting milled waste from landfill, conserving virgin aggregate and lowering the carbon footprint of quarrying and haulage. Although its unbound soaked CBR fell short of 30% here, this is readily remedied: blending RA with natural aggregate or laterite, or stabilising it with cement or lime, is widely reported to raise CBR above specification while retaining RA's moisture resistance (Arulrajah et al., 2011; Zhang et al., 2015). A blended RA–laterite system is therefore particularly attractive, combining the bearing capacity of laterite with the moisture stability, sustainability, and durability of RA. The comparative trade-offs are summarised in Table 8.

Table 8: Summary of comparative advantages and limitations

Criterion	RA	Laterite
Moisture sensitivity	Very low — advantage	High — need control
Soaked CBR vs 30% min.	Below (unbound)	Meets requirement
Compaction / MDD	~1.70 g/cm ³ — comparable	~1.70 g/cm ³ — comparable
Plasticity	Non-plastic	Medium (PI 24.1%)
Environmental benefit	High (waste reuse)	Low (quarrying impact)
Cost/availability	Low where milling occurs	Low where locally won

Criterion	RA	Laterite
Recommended use	Blended or stabilised sub-base	Sub-base with drainage control

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study compared the geotechnical behaviour of RA and laterite as sub-base materials. The principal findings are:

- RA is non-plastic with very low moisture content (1.65%) and is largely insensitive to moisture, whereas laterite is of medium plasticity (PI = 24.1%) with high moisture retention (56.38%); the difference in moisture content is highly significant ($p < 0.001$).
- Both materials are well-graded gravels (USCS "GW"; AASHTO A-1-a) with fewer than 3% fines, are not significantly different in overall gradation ($p = 0.932$), and compact to a similar maximum dry density of about 1.70 g/cm³ ($p = 0.859$).
- Laterite recorded significantly higher CBR (mean 36%) than RA (mean 23.5%) ($F = 27.17$, $p < 0.002$, $\omega^2 = 0.766$); on soaked CBR, laterite met the 30% sub-base minimum while unbound RA did not.
- RA offers superior moisture stability and substantial environmental advantages through waste diversion and aggregate conservation, supporting circular-economy and sustainable-construction objectives.

Overall, laterite remains a strong sub-base material when locally available and moisture can be controlled, while RA is a technically viable and environmentally preferable alternative for low- to medium-traffic roads, provided it is processed, blended, or stabilised to meet the soaked-strength requirement.

5.2 Recommendations

- Unbound RA should be blended with natural aggregate or laterite, or stabilised with cement or lime, to raise its soaked CBR above the 30% sub-base minimum.
- Where laterite is used, adequate drainage and strict moisture-content control at compaction are essential to preserve its bearing capacity.
- Road agencies should encourage the adoption of RA and blended RA–laterite systems to reduce landfill waste and conserve natural aggregate.

- iv. Further research should include field trials, repeated-load and durability testing, and optimisation of RA–laterite blend proportions and stabiliser dosages, with larger sample sizes.

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Appendix

Raw CBR Data

AppendixA: CBR test results for RAP

Sample	Load @ 2.5 mm (kN)	Load @ 5.0 mm (kN)	CBR (%)	Condition
1	5.10	7.65	25	Unsoaked
2	5.35	8.05	27	Unsoaked
3	4.00	6.00	20	Soaked
4	4.25	6.35	22	Soaked

Appendix B: CBR test results for laterite

Sample	Load @ 2.5 mm (kN)	Load @ 5.0 mm (kN)	CBR (%)	Condition
1	6.50	9.80	38	Unsoaked
2	6.80	10.20	40	Unsoaked
3	5.50	8.00	32	Soaked
4	5.80	8.40	34	Soaked