

Strength and Durability Assessment of Calcium Carbide Residue Mix on Cement Stabilized Lateritic Soils for Flexible Pavement Applications

Bemene, Blessing¹, Oba Achemie Lewis^{2*}

Department of Civil Engineering, Rivers State University Nkpolu-Oroworukwo, Port Harcourt.

*Corresponding Author

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ABSTRACT

This study investigates the strength and durability performance of calcium carbide residue (CCR) blended with cement for stabilizing lateritic soils obtained from three locations—Alimini, Ogbogoro, and Ahoada—in Rivers State, Nigeria, for use in flexible pavement construction. Preliminary index tests classified the natural soils as A-2-4 to A-4 materials with specific gravities ranging from 2.67 to 2.71, while compaction tests conducted at varying cement contents (7–12%) revealed an optimum cement content of 9%, producing maximum dry densities of 1730–1735 kg/m³. Calcium carbide residue was subsequently incorporated at 0–30% into the cement-stabilized soils, and compaction, California Bearing Ratio (CBR) at curing periods of 7, 14, and 28 days and durability tests were performed. Results showed that maximum dry density decreased while optimum moisture content increased progressively with increasing CCR content, attributable to particle flocculation and the lower specific gravity of CCR relative to the soil particles. CBR and durability indices, however, exhibited a parabolic trend, peaking at 15% CCR for all three locations, with 28-day CBR values of 125%, 117.2%, and 116.5% recorded for Alimini, Ogbogoro, and Ahoada, respectively. The values recorded substantially exceed the minimum requirement for pavement base course materials. Durability indices similarly peaked at 93 – 98% at the same dosage. These findings establish 9% cement and 15% CCR as the optimum blend for stabilizing lateritic soils, offering a sustainable alternative to conventional stabilizers for flexible pavement construction in tropical regions.

Keywords: Calcium carbide residue; Cement stabilization; Lateritic soil; California Bearing Ratio; Durability; Flexible pavement

INTRODUCTION

Road infrastructure constitutes the backbone of economic development, particularly in developing countries such as Nigeria, where the majority of intra- and inter-city transportation depends on flexible pavements constructed on locally available subgrade materials. Lateritic soils, formed through the tropical weathering of parent rock and rich in sesquioxides of iron and aluminium, are the predominant subgrade and fill material across much of sub-Saharan Africa, including the Niger Delta region of Nigeria, owing to their widespread availability and relatively low cost of extraction. However, many naturally occurring lateritic soils exhibit variable and often marginal geotechnical properties—high plasticity, poor compaction characteristics, low bearing capacity, and susceptibility to moisture-induced strength loss—that render them unsuitable for direct use as pavement sub-base or base course materials without prior improvement [1; 2]. This deficiency is frequently cited as a contributory factor in the premature failure of flexible pavements across Nigeria, underscoring the continued need for cost-effective and reliable stabilization techniques suited to local materials.

Chemical stabilization using ordinary Portland cement remains the most widely adopted method of improving the strength, stiffness, and durability of weak subgrade and sub-base soils, owing to its well-

documented pozzolanic reaction with soil particles and its ability to significantly increase California Bearing Ratio (CBR) and unconfined compressive strength [2; 3]. Despite these performance benefits, cement production is a major contributor to global greenhouse gas emissions, accounting for approximately 5–8% of total anthropogenic carbon dioxide emissions worldwide, arising principally from limestone calcination and the energy-intensive clinker manufacturing process. With global cement demand projected to continue rising alongside urbanization and infrastructural expansion, the environmental and economic costs associated with cement-only stabilization have prompted growing research interest in supplementary or alternative binders capable of reducing cement consumption without compromising engineering performance.

Calcium carbide residue (CCR), a calcium hydroxide-rich by-product of acetylene gas production in the calcium carbide industry, has emerged as a promising, low-cost, and environmentally beneficial supplementary stabilizer. Owing to its high free-lime content, CCR reacts pozzolanically with the reactive silica and alumina present in fine-grained and lateritic soils in a manner analogous to hydrated lime, forming cementitious calcium-silicate-hydrate and calcium-aluminate-hydrate compounds that enhance soil strength while simultaneously diverting an industrial waste stream from landfill disposal [3; 4]. Numerous studies have demonstrated the effectiveness of CCR, used alone or in combination with other pozzolans such as fly ash, in improving the strength and durability of soft and expansive soils [5; 6; 7]. However, the performance of CCR as a partial or complementary stabilizer combined with cement in lateritic soils—particularly across multiple soil sources with differing index properties, as is typical of highway alignments traversing varied terrain—remains comparatively under-investigated, especially within the Nigerian geotechnical context.

Furthermore, while the beneficial pozzolanic contribution of CCR to strength development is increasingly well documented, its effect on the durability of stabilized lateritic soils under moisture-cycling conditions typical of tropical climates—where alternating wet and dry seasons subject pavement layers to repeated saturation and desiccation—has received comparatively limited attention in combined cement–CCR systems. Given that pavement failure in tropical regions is frequently linked to moisture-induced deterioration of subgrade and sub-base layers rather than static strength deficiency alone, a comprehensive evaluation encompassing compaction behaviour, bearing strength, and durability performance is necessary to establish CCR as a technically sound and practically viable partial cement replacement.

This study therefore investigates the strength and durability performance of calcium carbide residue blended with cement for stabilizing lateritic soils obtained from three distinct locations—Alimini, Ogbogoro, and Ahoada—in Rivers State, Nigeria. The specific objectives are to: (i) characterize the index and engineering properties of the natural lateritic soils and the stabilizing materials (cement and CCR); (ii) determine the optimum cement content based on compaction characteristics; (iii) evaluate the effect of incremental CCR addition on the compaction, CBR, and durability properties of the cement-stabilized soils at curing periods of 7, 14, and 28 days; and (iv) identify the optimum CCR content that simultaneously satisfies strength and durability requirements for flexible pavement base/sub-base application. The findings are expected to contribute to the development of a sustainable, locally sourced stabilization strategy that reduces dependence on cement while meeting the strength and durability requirements of relevant highway pavement specifications.

MATERIALS AND METHODS

Materials

The calcium carbide residue (CCR) was obtained from an auto mechanic workshop located in Woji town, Port Harcourt. The CCR collected, was oven dried for 24 hours, in order to eliminate possible moisture in the sample. The resulting CCR powder was passed through a 425- μ m sieve to remove large particles. The Dangote Portland cement was used in the study and obtained from a cement distribution outlet in Mile III building material market in Port Harcourt, Rivers State. The lateritic soil samples used, was collected were from Ahoada (latitude 5° 4' 61" N and longitude 6° 38' 0" E), Elele – Alimini (latitude 7° 37' 23.60" N and longitude 5° 55' 27.06" E) and Ogbogoro (latitude 4° 50' 47" N and longitude 6° 55' 51" E).

Methods

Classification and Characterization of Materials

The distribution of different grain sizes affects the engineering properties of soil. Sieve analysis provides the grain size distribution, and it is required in classifying the soil. Sieve analysis was carried out in accordance with [8] methods of testing soils for civil engineering purposes. The percent by weight of soil passing each opening was then plotted as a function of the grain diameter (corresponding to a sieve number) and the percentage passing sieve No. 200 was determined see Table 1. The liquid limit and plastic limit tests were conducted in accordance with [8] standard code of practice on the laterites. The results of the liquid limit, plastic limit and plasticity index (which was derived from the liquid limit and plastic limit) is shown in Table 1.

Specimen Preparation and Tests

The compaction characteristics of the laterites were determined using the standard proctor compaction test to determine the optimum moisture content at which the laterites reach maximum density (maximum dry density). The compaction test was carried out in according to [8]. Table 2 shows a summary of the maximum dry density and optimum moisture content of the various samples. The specific gravity of soil is an important parameter for calculation of the weight-volume relationship. Thus, the specific gravity of the lateritic soils, Portland cement and the Calcium Carbide residue were conducted in accordance with [9]. The specific gravity results are shown in Table 3.

Stabilization was carried out in two stages. In the first stage, each laterite was mixed with 7, 9 and 12% cement by dry weight of soil, and compaction tests were performed on each blend to identify the cement content giving the highest MDD; this was adopted as the optimum cement content for each location. In the second stage, the optimum cement–laterite mixture was partially replaced with CCR at 0, 5, 10, 15, 20, 25 and 30% by dry weight, and the compaction characteristics (OMC and MDD) of each CCR–cement–laterite blend were re-determined.

The California Bearing Ratio (CBR) test is a penetration test meant for the evaluation of subgrade strength of roads and pavements. In specimen preparation, the method adopted in preparing the test specimen was in accordance with the CBR test method as described in [8] and standardized under [10]. Compacted soil sample were prepared in the CBR standard mould and at the optimum moisture content, earlier determined from compaction test. The CBR was determined by conducting a load - penetration test on the 7, 14 and 28 days cured specimen for each of the percentage replacement of CCR. See Table 4 for the results

Durability is the ability of material (stabilized lateritic soil) to retain stability and integrity over years of exposure to the destructive forces of weathering. The durability of the specimen for each of the percentage replacement of CCR were determined by subjecting the briquettes samples to series of wet – dry test in accordance to [11] and the results shown in Table 5

RESULTS AND DISCUSSION

Preliminary Tests

The result of laboratory tests to determine the specific gravity and physical properties of laterites, cement and Calcium carbide residue (CCR) are presented in Table 1 and Table 2 respectively.

The particle-size analysis showed that the percentage passing the No. 200 sieve for the Alimini, Ogbogoro and Ahoada laterites (35.0%, 37.0% and 37.0%, respectively) lies at or slightly above the 35% threshold that separates granular (A-1/A-2) from silt–clay (A-4–A-7) soils in the AASHTO M145/ASTM D3282 classification system, placing the soils on the borderline of A-2-4 to A-4 groups, consistent with lateritic soils of similar genesis reported for southern Nigeria [12]. The corresponding Atterberg limits (LL = 22.7–35.6%; PI = 4.2–9.4%) satisfy the Federal Ministry of Works and Housing (FMWH, 2016) sub-base/base

requirement of $LL \leq 35\%$ and $PI \leq 12\%$, with Alimini approaching the LL ceiling. All three soils comfortably meet the more lenient subgrade requirement ($LL \leq 50\%$, $PI \leq 30\%$). The progressive reduction in PI from Alimini to Ahoada reflects a corresponding decrease in clay - mineral activity, a trend associated in the literature with higher sesquioxide content and more favourable response to pozzolanic stabilization [1; 13]. The bulk densities (1598–1641 kg/m³) and unit weights (15.67–16.10 kN/m³) of the natural laterites fall within the range typically reported for compacted Nigerian lateritic subgrade soils. The cement recorded a specific gravity of 3.15, matching the accepted value for ordinary Portland cement (3.10 – 3.16), while the CCR specific gravity (2.37) and lower bulk density (995 kg/m³) are consistent with values reported for calcium carbide residue, a lighter, more porous by-product dominated by Ca(OH)₂ [5; 14]. This density contrast implies that CCR will reduce the bulk density of blended stabilizer mixes relative to cement alone and may require a higher gravimetric dosage to achieve comparable binding efficiency, in line with established pozzolan-replacement principles. Compaction results showed maximum dry density increasing from 1550 kg/m³ (Alimini) to 1605 kg/m³ (Ahoada), with a corresponding rise in OMC (13.0 – 14.0%), an inverse MDD–OMC trend typical of lateritic soils and consistent with the decreasing plasticity across the three samples. These baseline values provide the reference against which the expected stabilization-induced reduction in MDD and increase in OMC commonly reported for cement- and CCR-stabilized lateritic soils [2; 6] can be evaluated in subsequent mix testing.

Table 1: Physical Properties of Laterites, Cement and Calcium carbide residue (CCR)

Test Parameters	Laterites from			Cement	calcium carbide residue (CCR)
	Alimini	Ogbogoro	Ahoada		
% passing sieve No 200	35.0	37.0	37.00	-	-
Liquid Limit (%)	35.60	22.70	23.10	-	-
Plastic Limit (%)	26.20	15.50	18.90	-	-
Plastic Index (%)	9.40	7.20	4.20	-	-
Bulk Density (kg/m ³)	1641.0	1598.0	1641.0	1500.0	995.0
Unit Weight (KN/m ³)	16.10	15.67	16/09	14.72	9.76
MDD (kg/m ³)	1550.0	1588.0	1605.0	-	-
OMC (%)	13.00	13.50	14.00	-	-
Specific Gravity	2.67	2.69	2.71	3.15	2.37

Overall, the natural laterites are classified as marginal-to-fair materials that satisfy subgrade specifications but require improvement to reliably meet sub-base/base standards, justifying the adopted cement CCR stabilization approach and aligning with prior studies demonstrating the effectiveness of CCR, alone or blended with cement, in upgrading marginal lateritic soils for pavement application [5; 7].

Table 2: Compaction test Result of Cement Stabilized Laterite

Percent. of cement	Locations					
	Alimini		Ogbogoro		Ahoada	
	MDD (kg/m ³)	OMC (%)	MDD (kg/m ³)	OMC (%)	MDD (kg/m ³)	OMC (%)

7	1680	15.5	1620	15.6	1600	16.1
9	1730	16.5	1730	16.5	1735	16.8
12	1660	15.8	1675	16.0	1665	16.3

Compaction results for the three laterite locations show a consistent trend across the 7–12% cement range: maximum dry density (MDD) rises from 7% to a peak at 9% cement, then declines at 12% cement, for all three sites — Alimini (1680 → 1730 → 1660 kg/m³), Ogbogoro (1620 → 1730 → 1675 kg/m³) and Ahoada (1700 → 1735 → 1665 kg/m³). Optimum moisture content (OMC) follows the same peak-and-decline pattern, rising from 7% to 9% cement before falling slightly at 12% in all three locations. Since MDD is maximized at 9% cement for all three locations (Alimini: 1730 kg/m³; Ogbogoro: 1730 kg/m³; Ahoada: 1735 kg/m³), with a measurable decline at 12%, 9% cement is identified as the optimum stabilizer content for all three laterite sources and was used in preparing the specimen.

Result of MDD and OMC of CCR stabilized Laterite

Table 3: Compaction Test Result of CCR and Cement Stabilized Laterite mix

CCR (%)	Locations					
	Alimini		Ogbogoro		Ahoada	
	OMC (%)	MDD (kg/m ³)	OMC (%)	MDD (kg/m ³)	OMC (%)	MDD (kg/m ³)
0	16.5	1730	16.5	1730	16.8	1735
5	17.0	1720	17.0	1725	17.0	1728
10	17.5	1710	17.6	1718	18.0	1721
15	18.2	1690	18.3	1710	18.5	1713
20	19.0	1670	19.2	1700	19.5	1703
25	20.0	1650	20.2	1690	20.5	1693
30	21.5	1620	21.5	1670	22.0	1673

The compaction test results in Table 3 show a consistent, decrease in MDD with increasing CCR content across all three locations — Alimini (1730 → 1620 kg/m³), Ogbogoro (1730 → 1670 kg/m³) and Ahoada (1735 → 1673 kg/m³) at 0 – 30% CCR. While OMC rises continuously over the same range, from 16.5 – 16.8% at 0% CCR to 21.5 – 22.0% at 30% CCR for all three soils.

This trend is characteristic of lime-type stabilizers. CCR is predominantly Ca(OH)₂, and its interaction with clay minerals proceeds mainly through cation exchange and flocculation/agglomeration of soil particles rather than the pore-filling and pozzolanic cementation typical of Portland cement [3; 4]. Flocculated soil particles form a more open, higher-void-ratio fabric that cannot be compacted to the same density as the original dispersed structure, producing a steady MDD reduction with rising additive content. The continuous OMC increase reflects the larger specific surface area created by flocculation and the additional water absorbed in the hydration/pozzolanic reaction, both of which raise the water demand of the mix as CCR content increases — a pattern reported consistently for CCR- and lime-stabilized fine-grained and lateritic soils [5; 14].

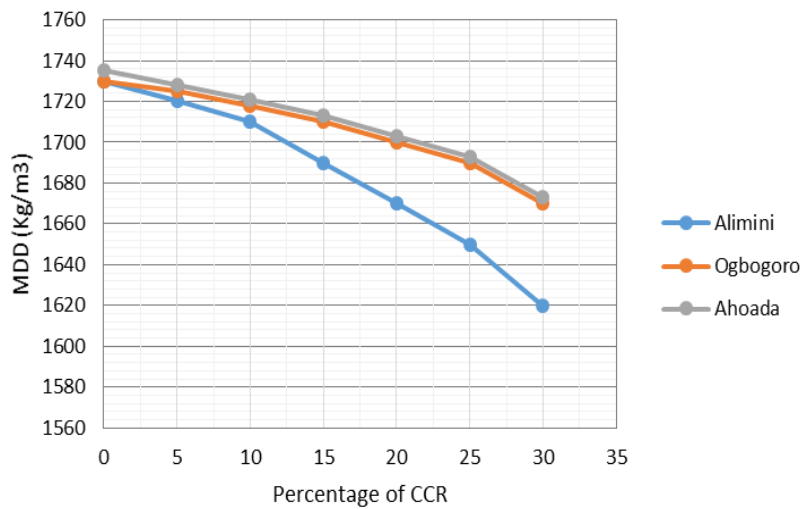


Figure 1: Graph of MDD against Percentage of CCR

The steady density loss is reinforced by the specific-gravity contrast between the materials: CCR ($G_s \approx 2.37$, from the earlier characterization results) is markedly lighter than the natural laterites ($G_s \approx 2.67 - 2.71$), so each increment of CCR progressively substitutes denser soil solids with a lower-density binder, compounding the flocculation-driven reduction in dry density [15]. This contrasts with the cement only trend observed previously for the same soils, where MDD initially rose to a peak near 9% before declining. A filler/cementation effect not mirrored here, confirming that CCR governs compaction behaviour through a fundamentally different mechanism.

Ahoada again records the highest MDD and OMC at every CCR dosage, followed by Ogbogoro then Alimini, consistent with the ranking observed in the cement dataset and attributable to Ahoada's lower natural plasticity index and correspondingly more efficient particle packing.

Because MDD decreases monotonically with no optimum peak within the tested range, density alone cannot define an "optimum" CCR content here, as it did for cement. In CCR/lime-type stabilization, the practical optimum dosage is normally established from strength and durability performance (UCS, CBR, wetting – drying resistance) rather than density, since a degree of density loss is often accompanied by strength gain once sufficient CCR is present to generate cementitious calcium-silicate/aluminate-hydrate products [6; 7]. It is recommended that CBR/UCS data be used to identify the practical optimum CCR content for this study — commonly reported in comparable investigations to fall in the 10–20% range — before progressing to durability testing and combined cement–CCR blends.

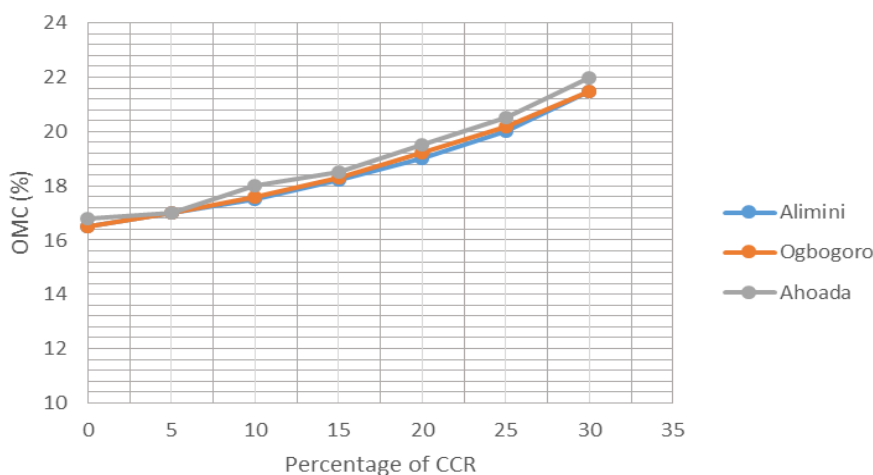


Figure 2: Graph of OMC against Percentage of CCR

Result of CBR of CCR stabilized Laterite

Table 4: California Bearing Ratio result for Different Percentage of CCR

CCR (%)	Location								
	Alimini			Ogbogoro			Ahoada		
	CBR			CBR			CBR		
	7 days	14 days	28 days	7 days	14 days	28 days	7 days	14 days	28 days
0	20.0	37.0	54.0	22.0	40.0	73.0	28.0	36.0	68.0
5	60.6	75.0	85.0	55.4	69.7	77.2	53.9	67.5	76.5
10	80.4	100.5	110.6	75.2	95.2	102.8	73.7	93.0	102.1
15	95.7	115.6	125.0	90.5	110.3	117.2	89.0	108.1	116.5
20	88.8	105.9	115.4	83.6	100.6	107.6	82.1	98.4	106.9
25	70.5	85.8	95.0	65.3	80.5	87.2	63.8	78.3	86.5
30	55.4	65.3	75.5	50.2	60.0	67.7	48.7	57.8	67.0

The CBR results in Table 4 show a clear parabolic (peak) trend for all three locations and all three curing periods: CBR rises sharply from 0% CCR, reaches a maximum at 15% CCR, and then declines progressively through 20%, 25% and 30% CCR. At the 15% peak, 28-day CBR values reach 125% (Alimini), 117.2% (Ogbogoro) and 116.5% (Ahoada) — substantial improvements over the untreated soils (54%, 73% and 68%, respectively). Strength also increases consistently with curing age at every CCR dosage (7 → 14 → 28 days), reflecting the progressive, time-dependent nature of pozzolanic strength gain.

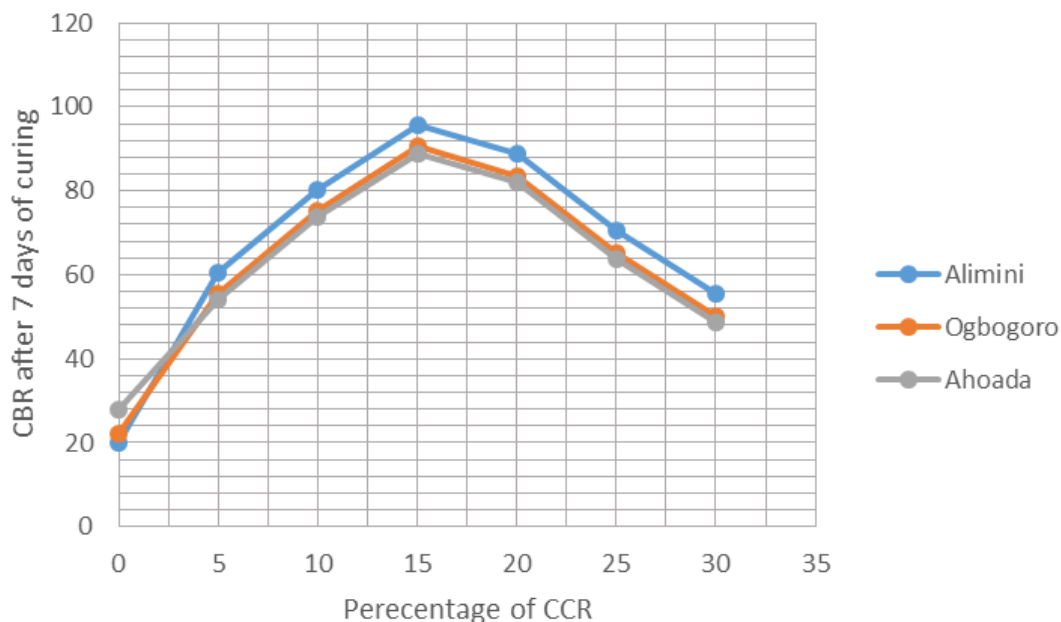


Figure 3: Graph of CBR after 7 Days of Curing against Percentage of CCR

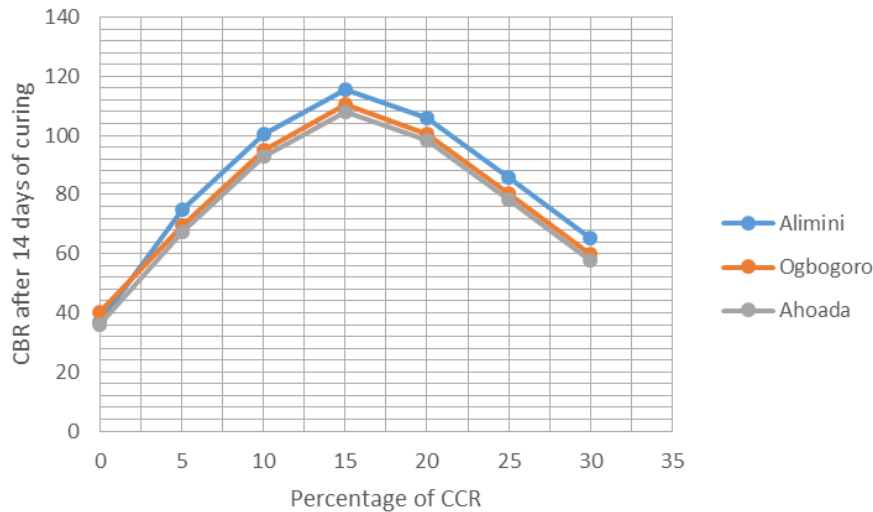


Figure 4: Graph of CBR after 14 Days of Curing against Percentage of CCR

This parabolic strength–dosage relationship is a well-established characteristic of calcium-carbide-residue and lime-type stabilization. Up to the optimum dosage, the $\text{Ca}(\text{OH})_2$ in CCR reacts with the reactive silica and alumina in the soil in a pozzolanic reaction, producing calcium-silicate-hydrate (C–S–H) and calcium-aluminate-hydrate (C–A–H) gels that bind soil particles and progressively fill pore spaces, increasing bearing capacity even as the compacted dry density falls (as shown in the earlier MDD/OMC results) [3; 4]. Beyond the optimum content, however, the excess $\text{Ca}(\text{OH})_2$ is no longer consumed by available reactive silica/alumina in the soil, and unreacted lime/CCR particles act as inert, weakly bonded fillers that increase porosity and reduce interparticle friction, causing the observed strength decline at 20–30% CCR — a pattern widely reported for CCR- and lime-stabilized lateritic and residual soils [7; 6; 5].

The consistent identification of 15% CCR as the strength-optimum dosage across all three locations and curing periods — despite the monotonic MDD decline observed at this same dosage — illustrates the well-documented divergence between density-based and strength-based optimization in chemically stabilized soils: the pozzolanic bonding contribution of CCR outweighs the loss in packing density up to the point where available reactive silica/alumina is exhausted [14]. The gain in CBR with curing time at every dosage further confirms that the strength mechanism is chemical (pozzolanic) rather than purely physical/mechanical, since physical densification effects alone would not continue to improve strength between 7 and 28 days.

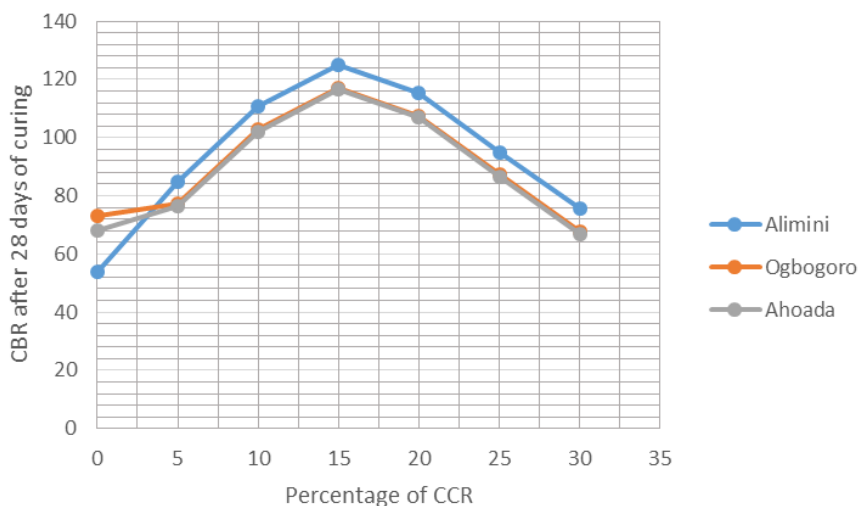


Figure 5: Graph of CBR after 28 Days of Curing against Percentage of CCR

Based on these results, 15% CCR is identified as the optimum stabilizer content for all three laterite sources, since it produces the maximum CBR at every curing age and satisfies the Federal Ministry of Works and Housing base-course requirement of minimum 80% CBR (unsoaked) by a wide margin — supporting its selection for further durability (wetting–drying/soaking) and combined cement–CCR blend investigations.

Result of Durability of CCR stabilized Laterite

The durability index rises with CCR content from 0% to a peak at 15% CCR for all three locations — Alimini (90% → 98%), Ogbogoro (86% → 95%) and Ahoada (82% → 93%) — then declines through 20%, 25% and 30% CCR, mirroring the same 15% optimum identified in the CBR strength data. Alimini consistently records the highest durability at every dosage, followed by Ogbogoro then Ahoada, matching the ranking already observed for MDD, OMC and CBR

Table 5: Durability Test Result for Different Percentage of CCR

CCR (%)	Location		
	Alimini	Ogbogoro	Ahoada
	Durability (%)	Durability (%)	Durability (%)
0	90	86	82
5	92	89	85
10	96	93	90
15	98	95	93
20	95	94	91
25	90	87	84
30	85	83	80

The upward trend (see figure 6) to 15% CCR reflects progressive pozzolanic reaction between the $\text{Ca}(\text{OH})_2$ in CCR and the reactive silica/alumina in the laterite, producing calcium-silicate-hydrate (C–S–H) and calcium-aluminate-hydrate (C–A–H) gels, along with natural carbonation of unreacted lime, both of which improve resistance to strength and mass loss under repeated moisture cycling [4; 16]. This mechanism is consistent with findings that CCR-stabilized soils gain measurable resistance to wetting–drying deterioration as curing and carbonation progress, with retained strength after wet – dry cycling shown to depend strongly on the proportion of CCR consumed in pozzolanic reaction versus left unreacted [16; 17]. Beyond the optimum content, the decline in durability at 20 – 30% CCR is attributable to the accumulation of unreacted, weakly bonded lime particles once available reactive silica/alumina in the soil is exhausted; these unbound fines create additional pore pathways for water ingress, increasing susceptibility to disintegration during wetting – drying cycles, a pattern directly documented for CCR-only stabilized clays, which have been reported to lose structural integrity after only a few wet–dry cycles when CCR dosage is not optimally matched to the soil's pozzolanic reactivity, in contrast to blended stabilizers that continue to gain or retain strength over many cycles [18; 19].

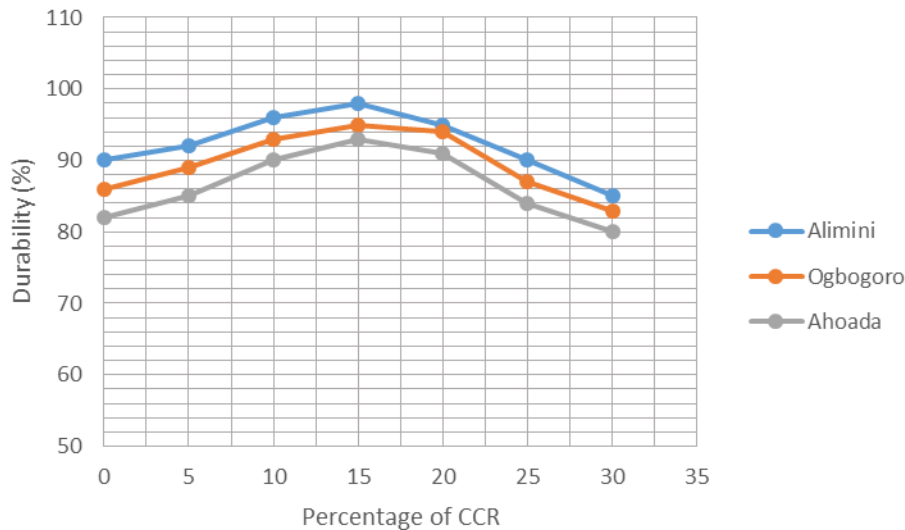


Figure 6: Graph of Durability against Percentage of CCR

The coincidence of the strength-optimum (15% CCR, from the CBR data) and durability-optimum at the same dosage across all three locations reinforces that this content represents the point of maximum effective pozzolanic consumption of the available CCR, consistent with the general lime/CCR stabilization principle that strength and durability gains track the degree of pozzolanic reaction rather than additive quantity alone [6; 7] beyond which additional stabilizer contributes to weight and cost without corresponding engineering benefit, and begins to compromise long-term field durability under the moisture cycling typical of tropical highway service conditions.

CONCLUSIONS

This study evaluated the strength and durability performance of calcium carbide residue (CCR) blended with cement-stabilized lateritic soils obtained from three locations—Alimini, Ogbogoro, and Ahoada—in Rivers State, Nigeria, for potential application in flexible pavement construction. Based on the laboratory investigations conducted, the following conclusions were drawn:

1. The natural lateritic soils from all three locations classified as A-2-4 to A-4 materials under the AASHTO system, with specific gravities ranging from 2.67 to 2.71, and satisfied subgrade specification requirements, though Ogbogoro and Ahoada marginally exceeded the recommended fines content for direct use as sub-base/base material, confirming the need for stabilization.
2. Compaction testing at varying cement contents (7 – 12%) revealed that maximum dry density increased to a peak at 9% cement for all three soils before declining at higher dosages, identifying 9% as the optimum cement content on the basis of densification behaviour.
3. Incorporation of CCR into the cement-stabilized soils produced a consistent, monotonic reduction in maximum dry density and a corresponding increase in optimum moisture content with increasing CCR content (0 – 30%), attributable to particle flocculation and the comparatively lower specific gravity of CCR relative to the soil solids.
4. In contrast to the density trend, CBR and durability results exhibited a parabolic response, both peaking at 15% CCR across all three locations. At this optimum dosage, 28-day CBR values of 125%, 117.2%, and 116.5% were obtained for Alimini, Ogbogoro, and Ahoada, respectively, while durability indices reached 93 – 98%, both substantially exceeding minimum specification thresholds for pavement base/sub-base materials.
5. The coincidence of the strength and durability optima at the same CCR dosage (15%) indicates that this content represents the point of maximum effective pozzolanic reaction between the available CCR and the reactive soil constituents, beyond which unreacted residue contributes to increased porosity and reduced performance.

On the basis of these findings, a combined stabilizer dosage of 9% cement and 15% CCR is recommended as the optimum blend for improving the strength and durability of lateritic soils from the three locations investigated, offering a technically sound and more sustainable alternative to full-cement stabilization for flexible pavement base and sub-base construction in tropical, laterite-dominated regions.

RECOMMENDATIONS

It is recommended that future work extend this investigation to include unconfined compressive strength and resilient modulus testing, extended wetting–drying and freeze–thaw durability cycling beyond a single durability index, microstructural analysis to confirm the pozzolanic reaction products responsible for the observed strength gains, and a comparative life-cycle cost and carbon-emission assessment of the cement–CCR blend relative to conventional full-cement stabilization, to further substantiate its viability for field-scale adoption.

Compliance with ethical standards

Ethical Approval

All experimental work was limited to laboratory testing of soil, cement, and calcium carbide residue samples in accordance with standard testing procedures

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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