



REVIEW ARTICLE

A CRITICAL REVIEW OF LATERITIC CONCRETE: INFLUENCE ON STRENGTH, DURABILITY, AND SUSTAINABILITY IN CONSTRUCTION

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ABSTRACT

This paper presents a critical review of lateritic concrete as a sustainable alternative to conventional concrete, with emphasis on its material characteristics, mechanical performance, durability behaviour, and environmental implications. The review synthesizes findings from published studies on laterite-based concrete, including research on partial aggregate replacement, supplementary cementitious materials, fibre reinforcement, and alternative binders. The literature indicates that, under specific mix proportions and curing conditions, partial replacement of conventional aggregates with laterite—commonly within the range of 20–50%—can produce concrete with strength properties comparable to those required for certain structural and non-structural applications. However, performance is strongly influenced by laterite mineralogy, grading, moisture sensitivity, and pore structure. Several studies further reported that the incorporation of materials such as fly ash, palm oil fuel ash (POFA), fibres, and geopolymer binders can improve selected durability and strength characteristics. From an environmental perspective, the reviewed studies suggest reported reductions in embodied carbon and lifecycle impacts, although the magnitude of such benefits varied widely depending on mix design, transport distance, and binder composition. The review also identified key limitations, including regional variability of laterite deposits, inconsistent testing and characterization methods, limited long-term durability data, and challenges related to standardization and large-scale implementation. Future research should prioritize harmonized evaluation protocols, region-specific mix optimization, and field-based performance validation to support the broader application of lateritic concrete in sustainable construction.

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1.0 Introduction

1.1 Global Sustainability Challenge in Concrete

Concrete remains the most widely used construction material globally, with annual production estimated at about 33 billion tonnes, making it the second most consumed substance after water (Ikponmwosa et al., 2017). However, the environmental burden associated with conventional concrete production is substantial. Cement manufacture alone contributes approximately 5–8% of global CO₂ emissions (Khaiyum et al., 2023). More recent estimates further indicate that the cement industry emitted about 2.3 GtCO₂ in 2022, increasing to roughly 2.4 GtCO₂ in 2023 (Andrew et al., 2024). In addition to cement-related emissions, the extraction of natural aggregates such as sand presents major ecological concerns. According to UNEP (2023), about six billion tonnes of sand and other sediments are dredged annually from marine and coastal environments, placing extraction rates close to natural replenishment limits. This unsustainable exploitation contributes to riverbank erosion, biodiversity loss, and hydrological disruption, thereby reinforcing the need for more sustainable concrete materials.

1.2 Lateritic Concrete as a Regional Solution

In response to these environmental and resource pressures, lateritic concrete has emerged as a promising alternative, particularly in tropical regions where laterite is abundant and conventional fine aggregates may be limited. Laterite has been investigated as a partial replacement for river sand in concrete, with several studies reporting satisfactory mechanical performance alongside reduced dependence on environmentally sensitive aggregate sources (Akeke *et al.*, 2012; Bari *et al.*, 2014). Additional improvements have been achieved through the incorporation of supplementary materials such as palm oil fuel ash (POFA) and fly ash, which can enhance selected engineering properties while lowering the environmental footprint of cementitious systems (Adnan *et al.*, 2017; Alabi *et al.*, 2024). In this context, lateritic concrete offers not only a sustainability pathway but also a regionally appropriate material option for local infrastructure development (Asiedu, 2017).

1.3 Limitations of Existing Studies and Reviews

Despite its promise, the widespread application of lateritic concrete remains constrained by a number of technical and practical challenges. These include regional variability in laterite composition, high water absorption, porosity, and inconsistent fresh and hardened performance (Alawode, 2011; Ige, 2013). Furthermore, although many studies have examined individual aspects of lateritic concrete—such as strength properties, durability behaviour, or material modification—existing literature is often fragmented. Current reviews tend to focus on isolated performance indicators and do not sufficiently integrate durability, environmental sustainability, and emerging technologies such as geopolymer binders, fibre reinforcement, AI-based mix optimization, embedded sensing, and digital fabrication approaches. As a result, there remains a need for a more comprehensive and critical synthesis that connects these dimensions and clarifies the current state of knowledge.

1.4 Objectives and Contribution of this Review

This review addresses that gap by providing a critical synthesis of the literature on lateritic concrete with emphasis on strength, durability, and sustainability implications. In addition to examining conventional mix behaviour, the review evaluates recent advances involving supplementary cementitious materials, alternative binders, fibre reinforcement, and data-driven mix design approaches. The paper therefore contributes by: (i) integrating mechanical, durability, and environmental findings within a single review framework; (ii) highlighting emerging technologies that may improve the performance and monitoring of lateritic concrete; and (iii) identifying key research gaps related to standardization, regional material variability, and large-scale implementation. By doing so, the review provides a more up-to-date basis for assessing the suitability of lateritic concrete for resilient and low-carbon construction.

2. Properties and Composition of Lateritic Concrete

2.1 Chemical Properties of Laterite

The chemical and mineralogical composition of lateritic soils are the properties that determine their suitability for concrete production, influencing factors such as reactivity, durability, and compatibility with binders.

According to Aziz *et al.* (2023), Laterite soils Chemical composition are silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3), with minor constituents like titanium dioxide (TiO_2) and manganese oxide (MnO).

Table I: Laterite oxides composition. (Aziz *et al.* 2023)

Oxide	Range (%)
SiO_2	30 – 55
Al_2O_3	10 – 35
Fe_2O_3	20 – 45
TiO_2	0.5 – 2
MnO	0.1 – 1

Mineralogically, lateritic soils are dominated by kaolinite, goethite, and hematite, with occasional traces of montmorillonite. Kaolinite, a 1:1 phyllosilicate, increases plasticity but also raises water demand due to its high

surface area (Cardona Pérez *et al.*, 2021). Borbi *et al.* (2024) observed that untreated clay minerals may cause shrinkage cracks, necessitate calcination or blending with non-clay aggregates. Iron oxides such as hematite and goethite contribute to structural strength—hematite’s crystalline structure enhances hardness, while goethite’s needle-like morphology improves interparticle bonding (Khalid *et al.*, 2024). Raja and Vijayan (2021), using XRD and SEM techniques, found that an optimal Fe₂O₃ content of 15–25% balances strength and workability by minimizing pore connectivity.

Table 2: Laterite Minerals Composition (Cardona Pérez *et al.*, 2021, Khalid *et al.*, 2024)

Mineral	Typical Proportion (%)
Kaolinite	~ 40
Goethite	~ 35
Hematite	~ 20
Montmorillonite	~ 5

2.2 Physical Properties of Laterite

Lateritic soils, formed through intense tropical weathering, exhibit a wide particle size distribution (PSD) ranging from ultra-fine clay (<0.002 mm) to coarse sand (≈4.75 mm), with fines content (<0.075 mm) significantly higher than conventional river sands (Akeke *et al.*, 2012; Ephraim *et al.*, 2012). This high fine content increases water demand and reduces packing efficiency in concrete mixes. Studies show that washing lateritic sand to remove clay-sized particles improves flow and compressive strength to levels comparable with natural sand (Bari *et al.*, 2014), while untreated laterite requires up to 15% more water due to the surface area of clay minerals (Adnan & Halim, 2017). Blending with quarry dust or crushed glass enhances gradation, increases the uniformity coefficient (Cu), and improves mechanical performance (Dongapure & Mangalgi, 2014; Akanbi *et al.*, 2021).

Regional variability in parent rock further influences PSD: basalt-derived laterites tend to be coarser and iron-rich, while granitic sources yield finer, clay-rich soils (Queiroz de Carvalho, 1984). In southwestern Nigeria, lateritic deposits with up to 25% clay-sized particles necessitate localized sieve analysis and corrective measures to meet grading requirements (Osunade, 2002). To ensure optimal performance, each batch of laterite should undergo full sieve analysis (4.75 mm to 75 µm) to determine Cu and Cc. When PSD falls outside the desired envelope, adjustments such as mechanical washing, blending, or the use of superplasticizers must be applied proportionally (Arum & Oni, 2023). With rigorous local characterization and targeted mix design, lateritic soils can be transformed into well-graded aggregates that offer ecological and economic benefits without compromising concrete quality.

Table 3: Particle size distribution of laterite, laterite blended with 30% quarry dust, and river sand (Compiled from Published Studies)

Sieve Size (mm)	Laterite (%)	Laterite + 30% Quarry Dust (%)	River Sand (%)
4.75	100	100	100
2.36	90	95	98
1.18	75	85	90
0.60	60	75	80
0.30	40	60	65
0.15	25	45	50
0.075	15	30	30

Literature-derived particle size distribution of laterite, laterite blended with 30% quarry dust, and river sand compiled from published studies. The compiled data indicates that blending laterite with quarry dust improves the fines distribution and shifts the grading closer to that of river sand.

Laterite typically exhibits a specific gravity in the range of 2.2–2.8, which is generally lower than that of river sand and granite because of its comparatively porous and iron-rich composition (Asiedu, 2017; Atoyebi *et al.*, 2018). This trend suggests that concrete incorporating laterite may have a lower density than conventional concrete made with natural sand or granite aggregates. The relatively lower specific gravity also indicates a higher likelihood of increased water demand and moisture sensitivity, which may influence workability and, in

some cases, the hardened properties of the concrete. In addition, the wide range reported for laterite reflects regional and mineralogical variability, highlighting the need for source-specific characterization when comparing material performance.

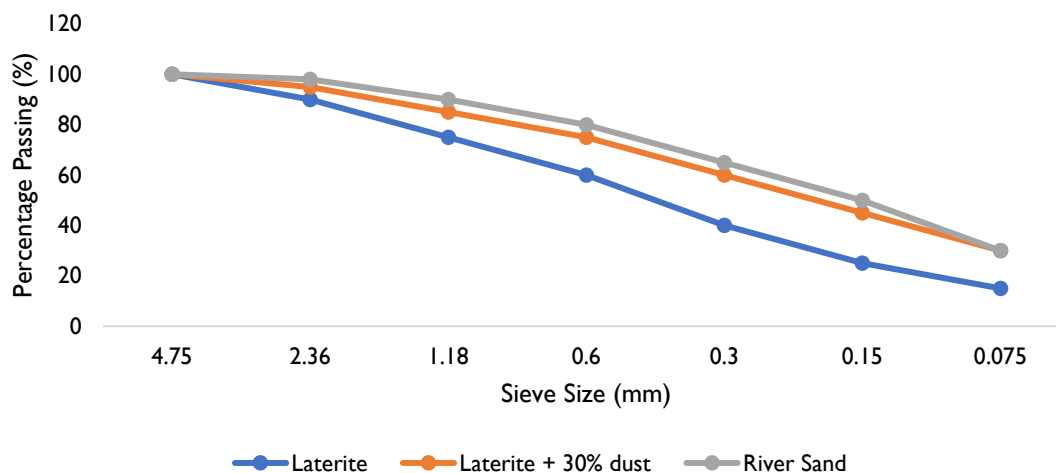


Figure 1: Particle size distribution of laterite, laterite with 30% quarry dust, and river sand (plotted from Compiled Published Studies)

This lightweight nature offers benefits like thermal insulation and reduced structural load (Ukpata *et al.*, 2012), but also increases water absorption, which can weaken concrete. Standards such as ASTM C127/C128 and BS 812: Part 2 help ensure its suitability, while blending with denser aggregates or using sealants can mitigate absorption issues. Bulk density of laterite falls between 1,400–1,800 kg/m³, lighter than conventional aggregates (Bari *et al.*, 2014; Afolayan *et al.*, 2019). Its porous nature is associated with higher water absorption, commonly reported in the range of 5–12%, which can increase paste demand and affect mix consistency (Atoyebi *et al.*, 2018). Where particle-size distribution is discussed, sieve analysis should be referenced to an established standard such as ASTM C136/C136M for fine and coarse aggregates; for material finer than the 75 μm (No. 200) sieve, ASTM C117 is used in conjunction with sieve analysis. ASTM C136/C136M specifically covers the determination of aggregate particle-size distribution by sieving and notes that accurate quantification of material finer than 75 μm cannot be achieved by sieve analysis alone. In EN-based practice, BS EN 933-1 may be cited as the reference method for determining aggregate particle-size distribution by washing and dry sieving. These grading data are important because a finer and more continuous distribution can improve packing efficiency, whereas poorly graded lateritic materials may increase void content, water demand, and variability in fresh and hardened concrete performance. Additives such as superplasticizers, fly ash, and geopolymers have therefore been reported to improve workability and select durability properties, although their effectiveness remains dependent on material source and mix design (Fei & Chen, 2021).

Table 4 laterite & River Sand Physical Properties (Compiled from Published Studies)

Material	Specific Gravity	Bulk Density (kg/m ³)	Source
Laterite	2.2 – 2.8	1,400 – 1,800	Asiedu (2017); Atoyebi <i>et al.</i> (2018); Bari <i>et al.</i> (2014)
River Sand	2.6 – 3.0	1,600 – 1,800	Afolayan <i>et al.</i> (2019)

3. Mechanical Performance of Lateritic Concrete

3.1 Compressive Strength

Compressive strength in lateritic concrete is influenced by aggregate replacement ratio, curing regime, and the physical characteristics of the laterite itself. Evidence from laboratory-based studies suggests that partial replacement of fine or coarse aggregates with laterite, often within the range of 30–50%, can produce compressive strength values broadly comparable to those of conventional concrete under optimized mix design and curing conditions, with reported values commonly falling within the range of 20–30 MPa (Akeke *et al.*, 2012; Bari *et al.*, 2014; Afolayan *et al.*, 2019). By contrast, higher replacement levels, particularly in the range of 70–100%, are more frequently associated with strength reductions, which have been linked to increased porosity, higher water demand, and less efficient particle packing (Adnan & Halim, 2017). The incorporation of supplementary materials such as palm oil fuel ash (POFA) and fly ash has been reported to improve strength in some lateritic mixtures by refining pore structure and enhancing matrix densification (Alabi *et al.*, 2024).

Age-related strength development in lateritic concrete may also be slower than in conventional mixes, particularly where the laterite exhibits high water absorption. However, extended curing periods and the use of modified binder systems, including calcined laterite and geopolymer binders, have shown potential to improve later-age strength in controlled studies (Elinwa, 2022; Fei & Chen, 2021). It should be noted, however, that many of these reported outcomes are derived from laboratory-optimized conditions, where material selection, curing control, and mix proportioning are carefully managed. In field applications, performance may be more variable due to differences in material source, moisture condition, workmanship, and curing quality, indicating that laboratory results should not be generalized without context-specific validation.

Table 5: Lateritic Concrete Compressive Strength (Compiled from Published Studies)

Property	Replacement Ratio / Condition	Strength Range	Remarks / Source
Compressive Strength	30–50% laterite (fine aggregate)	20–30 MPa	Comparable to standard concrete (Akeke <i>et al.</i> , 2012; Bari <i>et al.</i> , 2014)
Compressive Strength	30% lateritic stone (coarse aggregate)	~25–30 MPa	Maintains workability and strength (Afolayan <i>et al.</i> , 2019)
Compressive Strength	70–100% laterite	10–25% strength	Due to porosity and fines; mitigated by POFA/fly ash (Adnan & Halim, 2017; Alabi <i>et al.</i> , 2024)
Compressive Strength	Steam curing	30% early strength	Accelerates hydration (Elinwa, 2022)
Compressive Strength	Seawater curing + fly ash	35–40 MPa at 90 days	Enhances long-term durability (Alabi <i>et al.</i> , 2024)

3.2 Tensile and Flexural Strength

The tensile and flexural performance of lateritic concrete is influenced by aggregate morphology, mix proportion, curing regime, and the use of reinforcement or supplementary materials. Laboratory studies on cast specimens under standard curing conditions suggest that partial replacement of conventional fine aggregate with lateritic sand, typically up to about 50%, can produce split tensile strengths in the range of 2.5–3.0 MPa, which are broadly comparable to those reported for conventional concrete in similar test conditions (Ukpata *et al.*, 2012). At higher replacement levels, however, reductions in tensile strength are more commonly observed, often due to weaker cement–aggregate bonding and the higher porosity associated with lateritic materials (Atoyebi *et al.*, 2018).

Similarly, laboratory-based investigations indicate that fibre reinforcement using materials such as bamboo, steel, coconut husk, or sisal can enhance tensile and flexural behaviour by improving crack resistance and post-cracking toughness (Patil & Saravanan, 2023; Borbi *et al.*, 2024). Under controlled mix design and curing conditions, lateritic concrete modified with fly ash and well-graded aggregates has been reported to achieve flexural strengths of approximately 4.5–5.5 MPa (Raja & Vijayan, 2021). These findings are promising, but they largely reflect laboratory-optimized conditions; actual performance in field applications may vary depending on specimen dimensions, curing quality, material consistency, and site workmanship.

Table 6: Lateritic Concrete Split tensile Strength (Compiled from Published Studies)

Property	Replacement Ratio / Condition	Strength Range	Remarks / Source
Split Tensile Strength	50% lateritic sand	2.5–3.0 MPa	Comparable to conventional concrete (Ukpata <i>et al.</i> , 2012)
Split Tensile Strength	70% lateritic sand	15–20% strength	Due to poor bonding and porosity (Atoyebi <i>et al.</i> , 2018)
Split Tensile Strength	Bamboo fiber reinforcement	25% strength	Improves crack resistance (Atoyebi <i>et al.</i> , 2018)
Split Tensile Strength	Steel fiber reinforcement	tensile resilience	Delays failure (Patil & Saravanan, 2023)
Flexural Strength (MOR)	Optimized lateritic mix + fly ash	4.5–5.5 MPa	Comparable to conventional concrete (Raja & Vijayan, 2021)

3.3 Comparison with Conventional Concrete

Lateritic concrete provides notable cost advantages over conventional mixes, reducing material costs by 20–30% due to the local availability of laterite and reduced reliance on river sand and crushed stone (Asiedu, 2017; Afolayan *et al.*, 2019). For example, lateritic gravel as an all-in aggregate lowered production costs by

25% in West African road projects (Asiedu, 2017). However, high replacement levels ($\geq 70\%$) often reduce compressive and tensile strength by 10–25% because of increased porosity and fines (Adnan & Halim, 2017; Atoyebi *et al.*, 2018). In non-structural applications, this trade-off is acceptable, while structural uses benefit from partial replacements (30–50%) Lateritic concrete blended with POFA or fly ash has shown promising results in controlled studies. Alabi *et al.* (2024) reported 35–40 MPa at 90 days for seawater-cured lateritic concrete with fly ash; however, the associated 15% cost reduction is context-dependent and may vary with local availability, transport, processing, and quality-control conditions. Accordingly, the potential benefits of such mixes should be considered alongside limitations such as material variability and limited field validation.

Optimization strategies further enhance performance. Superplasticizers improve workability and reduce water demand, with polycarboxylate-based admixtures increasing slump retention by 20% (Arum & Oni, 2023). Pozzolans such as fly ash, POFA, and calcined laterite reduce porosity and boost durability, while geopolymer binders enhance chloride resistance for marine environments (Ghani *et al.*, 2022). Fiber reinforcement addresses tensile limitations: sisal fibers increased flexural toughness by 40% (Patil *et al.*, 2024), steel fibers improved split tensile strength by 25% (Patil & Saravanan, 2023), and coconut husk fibers optimized crack resistance without sacrificing workability (Borbi *et al.*, 2024). These interventions position lateritic concrete as a cost-effective, sustainable alternative for diverse construction applications.

4. Durability Characteristics of Lateritic Concrete

The durability of lateritic concrete in aggressive environments has been assessed mainly through laboratory exposure tests, and the reported performance depends strongly on mix composition, pore structure, curing conditions, and the use of supplementary materials. In accelerated laboratory studies, sulfate resistance has been linked to the relatively high iron oxide content of some lateritic materials, which may reduce susceptibility to expansive reactions, while pozzolanic additives such as fly ash and geopolymer binders have been reported to lower permeability and improve chemical stability under controlled test conditions (Queiroz de Carvalho, 1984; Alabi *et al.*, 2024; Fei & Chen, 2021). Chloride ingress, however, remains a major concern because the relatively high porosity and water absorption of lateritic concrete can increase the risk of reinforcement corrosion, particularly in marine exposure conditions. Laboratory-based studies further suggest that mixes containing fly ash, palm oil fuel ash (POFA), or calcined laterite-based geopolymer binders may reduce chloride penetration relative to unmodified lateritic concrete, although the extent of improvement varies with mix design and test method (Adnan & Halim, 2017; Ghani *et al.*, 2022).

Similarly, evidence on carbonation and freeze–thaw performance is derived predominantly from laboratory investigations rather than long-term field observations. Reported carbonation depths and freeze–thaw responses therefore reflect controlled or accelerated testing environments and should not be interpreted as direct predictors of in-service performance. Some studies indicate that supplementary cementitious materials such as fly ash and POFA can reduce carbonation progression and help maintain alkalinity under laboratory conditions, while optimized aggregate grading and fibre reinforcement may improve resistance to freeze–thaw damage in cast specimens (Atoyebi *et al.*, 2018; Raja & Vijayan, 2021; Arnold *et al.*, 2023). However, field-based evidence on the long-term durability of lateritic concrete under sustained environmental exposure remains limited. As a result, current findings should be interpreted as indicative of potential durability trends rather than conclusive proof of long-term performance in practice.

Water absorption, porosity, and permeability are critical durability drivers, influencing chloride ingress, sulfate attack, and freeze–thaw damage. Lateritic aggregates absorb 5–12% water, creating capillary voids that accelerate deterioration. Mitigation strategies include pozzolanic additives, fiber reinforcement, and surface sealants, which densify the matrix and block fluid pathways. Field studies confirm that fly ash-modified lateritic concrete achieves low permeability and enhanced chloride resistance in marine and urban structures (Alabi *et al.*, 2024). Despite these advances, regional variability and long-term exposure data (>10 years) remain research priorities to standardize lateritic concrete for sustainable infrastructure.

5. Microstructural and Bonding Characteristics of Lateritic Concrete

Microstructural evidence suggests that lateritic concrete generally has higher porosity and a weaker interfacial transition zone (ITZ) than conventional concrete, mainly because of the high water absorption of lateritic materials and the presence of clay-related microcracks (Atoyebi *et al.*, 2018; Raja & Vijayan, 2021). SEM observations reported in the literature indicate that untreated lateritic mixes may contain interconnected capillary pores, typically within the range of 5–50 μm , and these pore networks can increase permeability and reduce durability. In contrast, the incorporation of pozzolanic additives such as fly ash and palm oil fuel ash

(POFA) has been reported in some laboratory studies to refine the pore structure and reduce ITZ porosity. This improvement is commonly associated with the formation of secondary C–S–H gels, which enhance particle bonding and may improve resistance to sulfate attack (Alabi et al., 2024; Adnan & Halim, 2017). Geopolymer binders have also shown potential to produce denser matrices with fewer visible ITZ defects under controlled conditions, thereby improving resistance to chloride ingress relative to untreated lateritic mixes (Fei & Chen, 2021). Similarly, fibre reinforcements such as sisal and bamboo have been reported to improve crack bridging and flexural toughness, although the extent of improvement depends on fibre dispersion, matrix compatibility, and specimen preparation (Patil et al., 2024). Overall, these microstructural characteristics are important in practice because features such as pore connectivity, ITZ quality, and microcrack development directly influence water absorption, permeability, strength retention, and resistance to aggressive agents such as chlorides and sulfates. Therefore, improving the microstructure of lateritic concrete is essential for achieving mixes that are not only mechanically adequate but also more durable and reliable in field applications.

Table 7: Indicative durability trends for lateritic concrete under different exposure conditions, extrapolated from available laboratory and limited field studies

Exposure Condition	Indicative Strength Retention Trend	Critical Degradation	Proposed Mitigation Strategy
Marine	75–85% over extended exposure periods	Chloride-induced corrosion	Fly ash-geopolymer hybrid binders
Urban	80–90% over extended exposure periods	Carbonation	20–30% fly ash + surface sealants
Tropical	85–95% over extended exposure periods	Biological growth	POFA + bio-resistant admixtures
Arid	70–80% over extended exposure periods	Salt crystallization	Sisal fibers + quarry dust blending

Porosity and pore-size distribution significantly influence durability. Lateritic concrete contains more mesopores (2–50 µm) than conventional mixes, accelerating chloride ingress and freeze–thaw damage (Ghani et al., 2022). Mitigation strategies include fly ash, which reduces mesopores by 30%, and calcined laterite in geopolymer systems, which converts macropores to micropores, improving cohesion (Alabi et al., 2024; Ghani et al., 2022). Aggregate blending with quarry dust and fiber reinforcement also curbs macropores and crack propagation (Dongapure & Mangalgi, 2014; Patil et al., 2024). These modifications enhance durability and structural performance, making lateritic concrete suitable for marine and aggressive environments.

Bonding mechanisms combine mechanical interlock from laterite’s angular morphology with chemical reactions between lateritic silica/alumina and cement hydration products. Hematite (Fe₂O₃) accelerates C-S-H formation but requires dosage control to avoid delayed setting (Queiroz de Carvalho, 1984; Arnold et al., 2023). Pre-wetting aggregates, silica fume, and superplasticizers stabilize water-cement ratios, while moist curing maximizes hydration (Atoyebi et al., 2018; Arum & Oni, 2023). Practical applications confirm these strategies: fly ash-modified lateritic concrete maintained ITZ porosity below 12% after five years in marine exposure, and hybrid lateritic-granitic composites achieved frost-resistant void contents (Alabi et al., 2024; Arnold et al., 2023). These insights underscore the need for tailored mix designs to optimize laterite’s sustainability and structural performance.

6. Sustainability and Economic Feasibility of Lateritic Concrete

Lateritic concrete offers significant environmental benefits by reducing reliance on non-renewable aggregates and lowering carbon emissions. Substituting river sand and quarried stone with laterite curbs ecological degradation and decreases transportation-related emissions. Studies show that incorporating lateritic gravel can reduce river sand consumption by up to 80% (Asiedu, 2017). Additionally, using industrial by-products like fly ash and POFA enhances durability while promoting waste valorization. These pozzolanic materials improve matrix density and strength, aligning lateritic concrete with circular economy principles.

Carbon footprint and embodied energy are markedly lower in lateritic concrete compared to conventional mixes. Partial cement replacement with fly ash reduces CO₂ emissions by 25–30%, while geopolymer systems using calcined laterite achieve up to 60% emission reductions (Alabi et al., 2024; Ghani et al., 2022). Embodied energy drops by 20–40% due to localized sourcing and reduced quarrying. Cost analysis reveals 20–30% savings in material procurement for non-structural applications, though structural uses may incur 5–10% higher initial

costs due to stabilization additives. These costs are offset by lifecycle savings, with maintenance reductions of up to 50% over 50 years, making lateritic concrete economically competitive for long-term projects.

Regional availability and compositional variability influence feasibility. Laterite covers 70–80% of tropical soils, reducing extraction and transport costs, but clay-rich deposits require stabilization through pozzolans or compaction. Quality control measures—such as gradation analysis, chloride permeability tests, and computational mix optimization—ensure durability and performance. Implementation challenges differ by region: developing areas benefit from laterite's abundance but face standardization gaps, while developed regions struggle with regulatory inertia and infrastructure adaptation. Addressing these disparities through tailored quality protocols and regulatory modernization can position lateritic concrete as a globally scalable, sustainable alternative.

7. Challenges and Research Gaps in Lateritic Concrete

1. Standardization

One of the most immediate challenges in lateritic concrete research is the lack of standardized material characterization and mix design procedures. Laterite varies significantly in mineral composition, particularly in terms of iron oxide, clay fraction, and particle grading, and this variability directly affects strength development, shrinkage behaviour, water demand, and durability (Adnan & Halim, 2017; Alabi et al., 2024). At present, many reported mix designs remain empirical and are often tailored to specific local materials, making comparison across studies difficult. The integration of supplementary cementitious materials (SCMs), such as fly ash and palm oil fuel ash (POFA), adds further complexity because the optimum dosage depends not only on binder chemistry but also on laterite composition and curing regime (Ghani et al., 2022).

Without standardized characterization and proportioning methods, results from one region cannot be reliably transferred to another. This limits reproducibility, delays code development, and makes it difficult for practitioners to adopt lateritic concrete with confidence.

2. Long-term durability

Existing studies on lateritic concrete are dominated by laboratory-based and accelerated exposure tests, while long-term field data remain scarce. This is especially problematic because lateritic materials exhibit characteristics such as higher water absorption, variable clay content, and mineralogical heterogeneity, which may influence deterioration mechanisms differently from conventional aggregates (Atoyebi et al., 2018; Elinwa, 2022). In addition, conventional durability assessment methods do not always capture laterite-specific issues, including clay-induced instability and possible interactions involving iron-rich constituents (Arnold et al., 2023).

Durability performance governs service life, maintenance needs, and lifecycle cost. Without reliable long-term evidence, it is difficult to justify lateritic concrete for infrastructure exposed to marine, urban, tropical, or arid conditions, and lifecycle assessment remains uncertain.

3. Structural code integration

The application of lateritic concrete in structural members remains constrained by the absence of adequate design guidance in existing structural codes. Many current standards are based on assumptions that do not reflect lateritic material behaviour, particularly with respect to water absorption, density, shrinkage, and bond performance. For example, conventional aggregate criteria often assume water absorption values below 3%, whereas lateritic materials may exhibit values in the range of 5–12%, which can influence both fresh and hardened concrete properties (Raja & Vijayan, 2021). In reinforced applications, the limited available data suggest that bond strength and reinforcement compatibility may vary considerably depending on mix composition and laterite characteristics (Ukpatha & Ephraim, 2012; Patil & Saravanan, 2023).

Without integration into structural design codes, lateritic concrete will remain largely confined to experimental studies or non-structural uses. Code recognition is essential for safe design, regulatory acceptance, and wider uptake in real projects.

4. Digital optimization and scale-up

Emerging digital and computational tools offer promising opportunities to address some of the current limitations in lateritic concrete research. Machine learning, response surface methodology, and other optimization techniques have been proposed to improve mix design efficiency by predicting the effects of water–cement ratio, laterite content, and SCM dosage, thereby reducing the number of trial batches required (Khalid et al., 2024; Patil et al., 2024). Other emerging directions include 3D printing for low-cost housing applications, embedded sensing for real-time monitoring, and advanced modified binders such as nano-silica-enhanced geopolymer systems. However, most of these developments remain at laboratory scale, and their practical scalability is still uncertain.

Digital optimization can accelerate material development and reduce experimental cost, but its value depends on robust datasets and field validation. Without successful translation from laboratory models to site conditions, these tools will remain exploratory rather than transformative.

8. Conclusion

This review indicates that lateritic concrete has significant potential as a more sustainable alternative to conventional concrete, particularly in regions where laterite is readily available and can be integrated with supplementary materials such as fly ash, palm oil fuel ash, fibres, or alternative binders. However, its suitability is not universal. The performance of lateritic concrete reflects an important trade-off: while it can reduce dependence on conventional aggregates and support lower-impact construction, these advantages are often accompanied by challenges related to higher water absorption, porosity, material variability, and greater sensitivity to mix proportioning and curing conditions.

The viability of lateritic concrete therefore depends on several key conditions. These include reliable local material characterization, appropriate mix design adjustment, adequate curing control, and the use of suitable performance-enhancing modifications where necessary. In this sense, lateritic concrete is best understood not as a direct one-to-one substitute for conventional concrete in all contexts, but as a material whose effectiveness depends on matching local laterite characteristics with appropriate engineering treatment and intended application.

The review also shows that the future development of lateritic concrete will depend less on demonstrating isolated laboratory successes and more on addressing the practical barriers to wider adoption. Priority research should focus on developing laterite-specific testing and mix design frameworks, generating long-term field-based durability evidence, improving integration into structural design codes, and validating emerging digital optimization tools under real construction conditions. Greater alignment between materials research, standardization, and field implementation will be essential if lateritic concrete is to move from a promising regional material to a dependable option for resilient and low-carbon infrastructure.

References

- Adnan, SH., and Ab Halim, AH. 2017. Effect of replacing fine aggregate and cement with lateritic soil and palm oil fuel ash (POFA) on the compressive and split tensile strength of concrete. In: Concrete Materials, pp. 8-15, Penerbit UTHM, UTHM. ISBN 978-967-0764-84-9.
- Afolayan, JO., Oriola, FOP., and Sani, JE. 2019. Effects of partial replacement of normal aggregates with lateritic stone in concrete. *Journal of Applied Sciences and Environmental Management*, 23(5): 905-910.
- Akanbi, D., Sule, E., Achema, F., and Bakam, V. 2021. Performance evaluation of crushed glass in stabilizing lateritic soil for road pavement layers. *Journal of Engineering and Technology*, 4: 1-10.
- Akeke, GA., Ephraim, M.E., Akobo, I., and Ukpata, JO. 2012. Structural properties of concrete containing lateritic sand and quarry dust as fine aggregates.
- Alabi, S., Arum, C., Akande, AR., Mahachi, J., and Afolayan, JO. 2024. Effects of blended Portland-fly ash cement on compressive strength of seawater mixed and cured lateritic concrete. *Journal of Civil Engineering and Urbanism*, 9: 1-10.

Alawode, O., and Idowu, OI. 2011. Effects of water-cement ratios on the compressive strength and workability of concrete and lateritic concrete mixes. *Pacific Journal of Science and Technology*, 12(2): 99-105.

Andrew, RM., Peters, GP. and Canadell, JG. 2024. Global CO₂ emissions from cement production: 1928–2023. *Earth System Science Data*, 16, 1–18.

Arnold, AA., Ng'ambi, S., and Arnold, AA. 2023. Ex-situ and in-situ manufacturing procedures for optimizing the characteristics of a soil concrete based on lateritic gravels and granitic aggregates: application in road construction. *International Journal of Pavement Research and Technology*, 16(5): 1117-1128.

Arum, C., and Oni, O. 2023. Workability and compressive strength of concrete containing binary cement, mixed fines, and superplasticizer. *Facta Universitatis, Series: Architecture and Civil Engineering*, 21(3): 305-320.

Asiedu, RO. 2017. Using lateritic gravel as all-in aggregate for concrete production. *Journal of Engineering, Design and Technology*, 15(1): 114-126.

Atoyebi, OD., Modupe, AE., Aladegboye, OJ., and Odeyemi, SV. 2018a. Dataset of the density, water absorption and compressive strength of lateritic earth moist concrete. *Data in Brief*, 20: 1728-1733.

Atoyebi, OD., Odeyemi, SO., and Orama, JA. 2018b. Experimental data on the splitting tensile strength of bamboo reinforced lateritic concrete using different culm sizes. *Data in Brief*, 21: 1888-1893.

Aziz, A., Felaous, K., Alomayri, T. and Jindal, BB. 2023. A state-of-the-art review of the structure and properties of laterite-based sustainable geopolymer cement. *Environmental Science and Pollution Research*, 30(19), 54333–54350.

Bari, A., Hassan, AZA., UI Haq, SA., and Halhalli, V. 2014. Compressive and tensile strength of concrete using lateritic sand and river sand as fine aggregate. *International Journal of Engineering Research and Technology*, 1: 1-6.

Borbi, E., Danso, H., and Appiah-Kubi, E. 2024. Effect of lateritic stone aggregate and coconut husk fiber on the properties of concrete. *Open Journal of Civil Engineering*, 14(2): 151-162.

Cardona Pérez, A., Wanderley Neto, RV., Llanque Ayala, RJ., and Camapum de Carvalho, J. 2021. Effect of osmotic suction on the stability of microaggregations and aggregations in a lateritic soil. *MATEC Web of Conferences*, 337: 01012.

Queiroz de Carvalho, JBO. 1984. Lateritic aggregate used to fabricate concrete. *Bulletin of the International Association of Engineering Geology*, 29(1): 79-81.

Dongapure, AR., and Mangalgi, SS. 2014. Study on strength of concrete using lateritic sand and quarry dust as fine aggregates. *International Journal of Engineering Research and Technology*, 3(1): 1-5.

Elinwa, AU. 2022. Comparative analysis of curing methods: natural and activated lateritic concrete. *Journal of Building Material Science*, 4(1): 1-8.

Ephraim, ME., Akobo, I., Ukpata, JO., and Akeke, GA. 2012. Structural properties of concrete containing lateritic sand and quarry dust as fine aggregates. In: *Advances in Civil Engineering and Building Materials*, pp. 68-73, Trans Tech Publications Ltd.

Fei, S., and Chen, K. 2021. High-temperature resistance of lateritic soil-based geopolymer concrete in comparison with Portland cement. In: *2021 7th International Conference on Hydraulic and Civil Engineering and Smart Water Conservancy and Intelligent Disaster Reduction Forum (ICHCE and SWIDR)*, pp. 238-242, IEEE.

Ghani, U., Hussain, S., Amin, NU., Imtiaz, M., Khan, SA., and Naeem, M. 2022. Chloride and sulfate resistance of calcined lateritic clay-based geopolymer. *Journal of the Chemical Society of Pakistan*, 44(2): 343-350.

Ige, AO. 2013. Performance of lateritic concrete under environmental harsh condition. *International Journal of Research in Engineering and Technology*, 2(8): 252-256.

Ikponmwoosa, EE., Ehikhuenmen, SO. and Salau, MA. 2017. Comparative analysis of the compressive strength of concrete with waste glass as partial replacement for sand. *Nigerian Journal of Technology (NIJOTECH)*, 36(4), 1052–1058.

Iron, UH., Ufan, CO., and Effiong, AU. 2024. Comparative study of cube and cylinder crushing strengths of laterized concrete. *International Journal of Multidisciplinary Research and Analysis*, 7(2): 131-137.

Khaiyum, M., Rahman, ME. and Karim, MR. 2023. Environmental impacts of cement production and mitigation strategies toward sustainable concrete. *Journal of Cleaner Production*, 385, 135641.

Khalid, AA., Gora, AM., Rafindadi, AD., Haruna, SI., and Ibrahim, YE. 2024. Response surface methodology approach for the prediction and optimization of the mechanical properties of sustainable laterized concrete incorporating eco-friendly calcium carbide waste. *Infrastructures*, 9(11): 206.

Osunade, JA. 2002. Effect of replacement of lateritic soils with granite fines on the compressive and tensile strengths of laterized concrete. *Building and Environment*, 37(4): 423-427.

Patil, S., and Saravanan, A. 2023. Effect of lateritic aggregate and steel fiber on fresh and mechanical properties of concrete. *International Journal of Civil Engineering*, 10(1): 1-8.

Patil, S., Bhaskar, R., and Xavier, J. 2024a. Optimization of rheological and mechanical properties of sustainable lateritic self-compacting concrete containing sisal fiber using response surface methodology. *Journal of Building Engineering*, 83: 108574.

Patil, S., Xavier, J., and Raja, R. 2024b. Experimental evaluation and statistical modeling of sustainable sisal fiber-reinforced fly ash-based lateritic concrete using response surface methodology. *Journal of Building Engineering*, 83: 108498.

Raja, R., and Vijayan, P. 2021. Investigations on mechanical characteristics and microstructural behavior of laterized high strength concrete mix. *Arabian Journal for Science and Engineering*, 46(12): 12165-12177.

Ukpata, JO., Ephraim, ME. and Akeke, GA. (2012). Compressive strength of concrete using lateritic sand and quarry dust as fine aggregate. *ARPJ Journal of Engineering and Applied Sciences*, 7(1), 81–92.

United Nations Environment Programme (UNEP). (2023). Sand and sustainability: 10 strategic recommendations to avert a crisis. Nairobi, Kenya: UNEP.