E-ISSN: 1116 - 2759 P-ISSN: 3027-0111
MPRI-EDIR | INTERNATIONAL JOURNAL OF EARTH DESIGN AND INNOVATION RESEARCH
VOL. 10 NO. 4 – OCTOBER, 2025

DURABILITY AND MECHANICAL PROPERTIES OF CONCRETE WITH GASHUA LATERITE AS PARTIAL FINE AGGREGATE REPLACEMENT UNDER SULPHATE EXPOSURE

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DOI: https://doi.org/10.70382/mejedir.v10i4.066

Abstract

The need for sustainable alternatives in the manufacturing of concrete has been fueled by the lack of natural river sand, its increasing cost, and the environmental damage caused by its uncontrolled extraction. Laterite soil, which is plentiful in tropical areas such as Nigeria, provides an affordable and environmentally beneficial alternative to river sand. This study examines the performance of laterized concrete produced with laterite soil from Gashua as partial replacement for fine aggregate at 0%, 10%, 20%, and 30% levels. Concrete samples were tested for workability, density, compressive strength, and resistance to magnesium sulphate ($MgSO_4$) attack after curing for 7, 14, and 28 days. The laterite soil was found to possess a specific gravity of 3.11 and a bulk density of 1791 kg/m³, indicating favorable load bearing capacity compared with conventional aggregates. Workability decreased consistently with higher laterite content. t 20% replacement, the mix recorded improved compressive strength and density, reaching 31.49 N/mm² and 2365 kg/m³, respectively compared to the control mix (30.01 N/mm², 2331 kg/m³). Laterized mixtures, especially at 20%, maintained greater strength (32.90 N/mm²) with $MgSO_4$ exposure than the control

Keywords: Laterized concrete, Compressive strength, Density, Magnesium sulfate ($MgSO_4$) resistance, Gashua laterite

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(23.37 N/mm²), indicating improved sulfate resistance. In conclusion, the results confirm that a reasonable amount of laterite (10–20%) improves sulfate durability and mechanical strength without sacrificing density, making laterite soil a practical, sustainable, and locally accessible substitute for river sand in the manufacturing of concrete.

Introduction

Concrete is one of the most widely used construction materials due to its durability, strength, and versatility. It is composed of several primary constituents, including cement, aggregates, water, and additives (Goel, Kalamdhad & Agrawal, 2018). The aggregates, which typically account for 60-80% of the concrete volume, play a crucial role in determining its mechanical properties. The two main types of aggregates used in concrete are coarse aggregates and fine aggregates. Coarse aggregates, such as crushed stone or gravel, provide bulk and stability to the concrete mixture, while fine aggregates, often in the form of sand, fill the gaps between the coarse particles, improving workability and contributing to the overall strength of the concrete (Rathore & Mondal, 2017).

Cement is defined as an adhesive substance that unites solid materials, acquiring temporary plasticity before hardening (Tkachenko, 2023). Water is required in the concrete mixture for the hydration process to occur. The water-to-cement ratio plays a crucial role in achieving the desired workability and strength. Excess water can weaken the concrete and lead to increased porosity, while insufficient water can hinder the hydration process and result in poor strength development (Fadele, 2018).

Sand has traditionally been used as fine aggregate in structural concrete. The commonest types of sand used in this regard in various parts of Nigeria are river sand, erosion sand, and dune sand (dug out sand). Unfortunately, these sand types are not readily available in many parts of the country, and could be rightly regarded as scarce material for concrete-making in those communities. Persons making concrete in such localities usually import sand from relatively distant places at high costs, and this increases the overall cost of making concrete and of providing housing for the people. Thus, there is an increasing need to source alternative locally available materials that could serve as suitable replacement to sand as fine aggregate in concrete. Laterite has the advantage of being readily available in most Nigerian communities. Besides being obtained intentionally in burrow pit excavations, it is also frequently obtained through various forms of excavations for substructure works, including excavations for foundations and septic tanks. However, unlike sand, laterite is a combination of different soil types, notably clay, sand, and silt. A good number of scholars have worked on laterite (Setiawan & Prawito,

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2022) established that, among other things, the presence of iron oxide accounts for its red colour. The presence of clay and silt particles in large quantities could make laterite fall short of the requirements of BS 882, (1992) for high quality concrete. Thus, the suitability or otherwise of using laterite as sole replacement for sand in concrete would depend greatly on the proportion of these fine particles in the laterite.

Previous studies on laterized concrete have mainly focused on its mechanical properties, including compressive, tensile, and flexural strengths under standard curing conditions. Isah et al. (2024) examined reinforced laterized concrete with laterite replacements of 0–40% and found that 10% replacement achieved the best performance, recording a compressive strength of 19.044 N/mm² after 28 days, indicating a suitable balance of strength and economy for structural use. Similarly, Garba et al. (2024), using a 1:2:4 mix ratio and 0.65 water–cement ratio, observed strength gains with curing age but reductions beyond 10% laterite content, concluding that higher replacements adversely affect both strength and durability. Ambrose et al. (2018) also reported that lateritic sand could replace river sand up to 50%, with strength comparable to conventional concrete, though workability decreased as laterite content increased.

While mechanical performance under normal conditions is fairly documented, the behavior of laterized concrete in aggressive environments is not well established. Exposure to magnesium sulfate ($MgSO_4$), a major source of sulfate attack, can lead to the formation of expansive compounds such as gypsum and brucite, causing cracking and strength loss. Assessing the resistance of laterized concrete to $MgSO_4$ exposure is therefore essential for structures in groundwater, marine, or industrial environments. Yet, no study has specifically investigated the performance of Gashua laterite based concrete under magnesium sulfate attack or established its optimal replacement level for such conditions. Therefore, evaluating the sulfate resistance of concrete incorporating alternative fine aggregates such as laterite is essential to ensuring long-term structural stability and service life under aggressive environmental condition.

Statement of the Problem

Natural river sand is the main fine aggregate used in the making of concrete in Nigeria's building sector. However, the demand for river sand has sharply increased due to fast urbanization and infrastructure construction, resulting in shortages and rising pricing in a number of places. Ogunbode, Ajibade, and Yusuf (2021) found that the depletion of accessible deposits was a major factor in the over 60% increase in river sand costs between 2015 and 2020. Up to 25% of riverbank vegetation has been lost, and streams have become significantly silted, as a result of excessive dredging to suit development needs (Akinwumi, Olatunbosun, & Ayodele, 2020). Due to the lack of natural sand in landlocked

areas of northern Nigeria, such Yobe and Borno States, transportation expenses now make up between 30 and 40 percent of the overall cost of materials, rendering the manufacturing of conventional concrete unsustainable from an economic standpoint (Ezeokonkwo & Okonkwo, 2022).

One major obstacle to the production of concrete in Gashua, northeastern Nigeria, is the lack of locally accessible river sand. Geological restrictions and the absence of adjacent river systems restrict availability to natural sand, requiring reliance on costly imported resources. This difficulty emphasizes the necessity of finding workable, locally sourced alternatives. The region's plentiful lateritic soil, which is high in iron and aluminum oxides, has the potential to partially replace river sand. Thus, the purpose of this study is to determine whether Gashua laterite soil may be used as a sustainable and economical partial substitute for fine aggregate in the manufacturing of concrete.

Aim and Objectives of the Study

The aim this study is to assess the durability and suitability of concrete containing laterite soil from Gashua as a partial replacement for fine aggregate. The specific objectives include:

i. To characterize the source laterite by evaluating its properties.
ii. To determine the optimal replacement level that balances strength, workability, and durability
iii. To determine the effect of effect of $MgSO_4$ exposure on compressive strength and density of laterized concrete.

Significance of the Study

The nation's growing construction industry is currently depleting most of the minerals used to make concrete, particularly fine aggregate. Therefore, the findings of this study will be useful to different stakeholders as a source of knowledge about the usage of laterite soil as a substitute material for building construction projects in order to lessen the depletion of natural sand for the manufacturing of concrete. The study's results will also serve as a guide for future investigations on environmentally suitable substitutes for concrete materials in building.

Scope of the Study

The study will focus on Gashua, Bade Local Government Area, Yobe State, as the primary study area. This study was conducted to find out the suitability of laterite soil from Gashua as fine aggregate replacement in concrete production.

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This study was conducted to explore the characteristics of laterite soil and its impact on concrete performance. It examines the key soil properties such as specific gravity, water absorption, particle size distribution through sieve analysis, and bulk density to assess its suitability for construction. Additionally, to ensure long term performance, the durability aspects of concrete was investigated, focusing on the resistance to magnesium sulphate ($MgSO_4$) exposure.

Water

Water is essential for the chemical reaction between cement and other components, allowing the concrete to set and gain strength. Domestic Potable tap water inside the building departmental lab was used throughout the laboratory aspect of this research work and in accordance with BS EN1008-2 (2002) water specification for concrete works.

Cement

The binding substance that keeps the concrete mixture cohesive is cement. The strength, durability, and setting time of laterite concrete are influenced by the kind and amount of cement employed. Ashaka cement, which has a grade of 42.5 and complies with BS EN 196-6:2018 requirements, is used in this experimental investigation. It met the requirements specified in the Nigerian Industrial Standard (NIS) 444-1 (Standard Organization of Nigeria 2003) and was purchased in Bauchi metropolis of Bauchi state.

Fine aggregate (River sand)

The river sand was graded by 4.75mm BS sieve. The sand was in conformity with BS EN 12620-2013 which states that material should be clean free from impurities such as silts, clay and vegetables. Particle size distribution and moisture content were tested to determine the properties of the fine aggregate.

Coarse Aggregate

Coarse aggregate consists of larger particles such as gravel or crushed stone. It adds strength and stability to the concrete mix, enhancing its mechanical properties. The selection of appropriate sizes and types of coarse aggregate influences the structural characteristics of laterite concrete and conformed to BS EN 12620:2013. The coarse aggregates were sourced in Bauchi with a grain size ranging from 14 to 20 mm.

Laterite Soil

Laterite soil, a naturally occurring material, is a crucial component in laterite concrete. The soil is rich in aged clay and ranges in color from yellow to reddish-brown. The laterite used

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in this study was taken from a borrow pit at Federal University Gashua, which was one meter deep. The soil was sampled and classified according to BS 1377-2:1990 at a depth of 1 meter at Gashua, Bade Local Government Area of Yobe State (latitude: 12.8751, longitude: 11.0102).

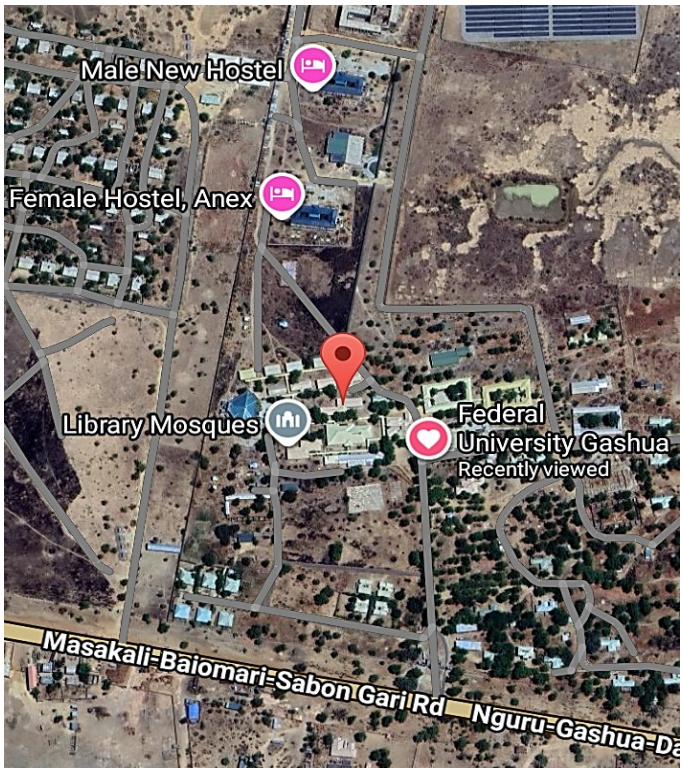

Plate 1: Map showing point of excavation of laterite soil sample

Physical Properties Tests on Fine and Coarse Aggregates

The specific gravity test followed BS 812:2 (1975). Particle size distribution of fine and coarse aggregates followed BS 812-103.1 (1985). Bulk density test on coarse aggregate followed BS EN 1097-6:2013.

Concrete Mix Design

For this investigation, 30 N/mm^2 was the mix design concrete grade. With a focus on durability rather than only strength, the mix design process is based on the protocol followed in accordance with BS EN 206:2013 + A2:2021. The physical characteristics of the coarse aggregates or aggregate types to be used are the primary factor in the design for strength because the hardened concrete mixture's strength cannot be appreciably greater than that of the coarse aggregates used. Table 1 shows the proportion of ingredients.

Table 1: Mix Proportion of Laterite Concrete

Parameters	0%LS	10%LS	20% LS	30% LS
Water content (kg/m^3	190	190	190	190
Cement content (kg/m^3)	380	380	380	380
Laterite soil (kg/m^3)	0	60	120	180
Sand content (kg/m^3)	600	540	480	420
Coarse agg. 20mm (kg/m^3)	1175	1175	1175	1175

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Mixing Procedure and Sample Preparation

In compliance with BS 1881-125:2013, the concrete mixing procedure was done by hand, guaranteeing consistent and even material blending. To guarantee even mixing, cement and laterite soil were first dry-mixed for around three minutes. After adding the river sand, the mixture was mixed for three more minutes. Once the dry mix was homogeneous, water was added gradually and stirred for three more minutes. Then, coarse aggregate was added and well mixed for three more minutes to create a uniform wet mix. After that, three layers of the freshly laterized concrete were poured into 100 × 100 × 100 mm cube molds, and each layer was compacted using 25 tamping strokes to release trapped air and guarantee uniform density. 180 cube specimens in all as shown in Table 2, including the control mix (0%), were created, representing laterite replacement levels of 0%, 10%, 20%, and 30% by weight of fine aggregate. To prevent moisture loss, the specimens were wrapped in plastic sheets after casting and allowed to set at room temperature for a full day.



(a) (b) (c)

Plate 2: Mixing Procedure and Sample Preparation of Laterite Concrete (a) weighing of material (b) mixing of concrete (c) casting of concrete samples

Table 2: Concrete Samples for Different Laterite Soil (LS) Content

Microbial Solution Replacement (% by weight of water)	Control	0% LS	10% LS	20% LS	30% LS	Total
Compressive strength at 7, 14, and 28 days (100×100×100 mm)	9	9	9	9	9	45
Density at 7, 14, and 28 days (100×100×100 mm)	9	9	9	9	9	45
Compressive strength at 7, 14, and 28 days ($MgSO_4$ exposure test)	9	9	9	9	9	45
Density at 7, 14, and 28 days ($MgSO_4$ exposure test)	9	9	9	9	9	45
Total number of specimens = 180						

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Curing Method

After casting, the concrete specimens were covered with plastic sheets and left to set in the laboratory for 24 hours before being demold. The demoulded cubes were cured in accordance with BS EN 12390-2:2019 at a temperature of 27 ± 5 °C. The specimens were cured in potable water for 7, 14, and 28 days before being tested for compressive strength and density. To conduct the magnesium sulphate ($MgSO_4$) exposure test, the cubes were first cured in water for 28 days, then immersed in a 1.5% $MgSO_4$ solution for 7, 14, and 28 days before testing.



Plate 3: Curing of laterite concrete samples

Workability of Fresh Laterite Concrete

The workability of the fresh laterite concrete was measured using slump test in accordance with BS EN 12350- 2:2019. The test was carried out using metal cone, the cone was filled up with concrete in three different stages with each stage tamped with metal rod 25 times. The cone was then lifted, and the slump measured as the distance from the top of the slump concrete to the top of the inverted cone. It is measured in (mm).



Plate 3: Slump test on fresh laterized concrete mix

Density of Laterite Concrete

The concrete density measurement was carried out at 7, 14 and 28 days. The densities of the concretes were expected to reduce over time because the specimens were subjected to air drying at room temperature after demolding until days of testing. The density measurement was conducted according to BS EN 12390-7:2019. The density of each specimen was calculated using Equation (1).

$$D = \frac{M}{V} \quad \text{----------} \quad (1)$$

Where D is the density of the concrete specimen in kg/m³, M is the mass of the specimen and V its volume.

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Plate 4: Determination of dry density of concrete samples

Compressive strength of Laterite Concrete

The compressive strength test was carried out using the universal crushing machine conform to BS EN 12390-3 (2009). The compressive strength test was carried out at 7, 14 and 28 days respectively. The average of three samples were presented as the compressive strength result. The final value was obtained by averaging the results of three identical specimens, as shown in Equation (2).

$$Compressive\ strength\ (N/mm^2) = \frac{\text{load(N)}}{\text{surface area}\ (mm^2)} \quad \text{----------} (2)$$



Plate 5: Compressive strength test on hardened laterized concrete

Magnesium Sulphate Resistance of Laterite Concrete

The durability of concrete during its service life is reported to be affected by ingress of sulphate ions. In this study, the impact of sulphate attack on the density and compressive strength of concrete containing laterite soil as a partial replacement of conventional fine aggregate according to BS EN 196-5:2005. 100 x 100 x 100mm concrete cubes was produced and cured at ambient temperature for 28 days before being subjected to a 1.5% concentration magnesium sulphate ($MgSO_4$) solution for 7, 14 and 28 days respectively. The solution was prepared by diluting 500g of $MgSO_4$ in 30 liters of water separately to obtain the desired concentration. The concrete durability was investigated through mass change determination and residual compressive strength at 7, 14, and 28 days of immersion for the solutions. Compressive strength of the immersed specimens was compared with that of the control specimens left to cured at room temperature for same curing period. The reduction in strength was calculated using the approach followed by Mehta *et al.* (2016).

$$Reduction\ \text{in}\ strength\ (\%) = \frac{X-Y}{X}\ X\ 100\% \quad \text{----------}(3)$$

Where; X = Average strength of concrete cured with 0% concentration

Y = average strength of samples subjected to magnesium sulphate ($MgSo_4$).

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Physical Properties of Aggregates

The physical properties of fine and coarse aggregates are presented in Table 3. All measured values fall within the acceptable limits specified by the relevant standard codes, indicating that the aggregates are of good quality and suitable for concrete production.

Table 3: Properties of the Aggregates

Property	Fine Aggregate (River Sand)	Fine Aggregate (Laterite soil)	Coarse Aggregate (Crushed Granite)
Specific Gravity	2.58	3.11	2.72
Bulk Density (kg/m³)	1525	1791	1727

Sieve Analysis of Fine and Coarse Aggregate

The particle size distributions of the fine aggregate, coarse aggregate, and lateritic soil are presented in Figure 1 and 2. The fine aggregate conforms to the grading limits specified by BS 882:1992, with a fineness modulus of 2.68, indicating a well-graded material suitable for concrete production. The coarse aggregate exhibits a grading pattern consistent with the nominal 20 mm specification (Grading G) outlined in BS EN 12620:2013+A1:2008, confirming its compliance with standard requirements. The sieve analysis of the lateritic soil, conducted in accordance with BS 1377-2:1990, shows a predominance of sand sized particles with lesser proportions of silt and clay. The high fines content is reflected by 93.98% passing the 75 µm sieve, while the fineness modulus of 2.81 places the laterite within the acceptable range of BS 882:1992, signifying its potential suitability as a partial replacement for fine aggregate in concrete.

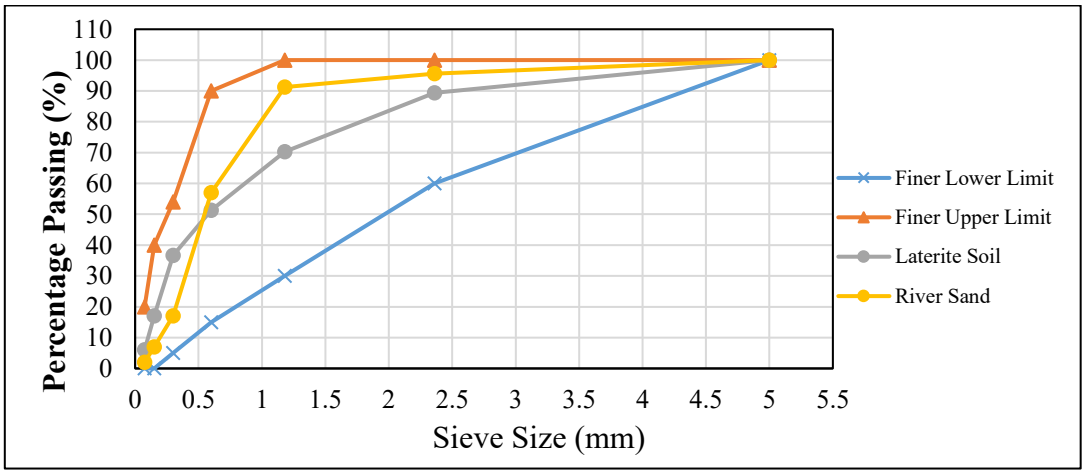

Figure1: Sieve analysis graph showing well graded fine aggregates (laterite soil and river sand) used in the research.

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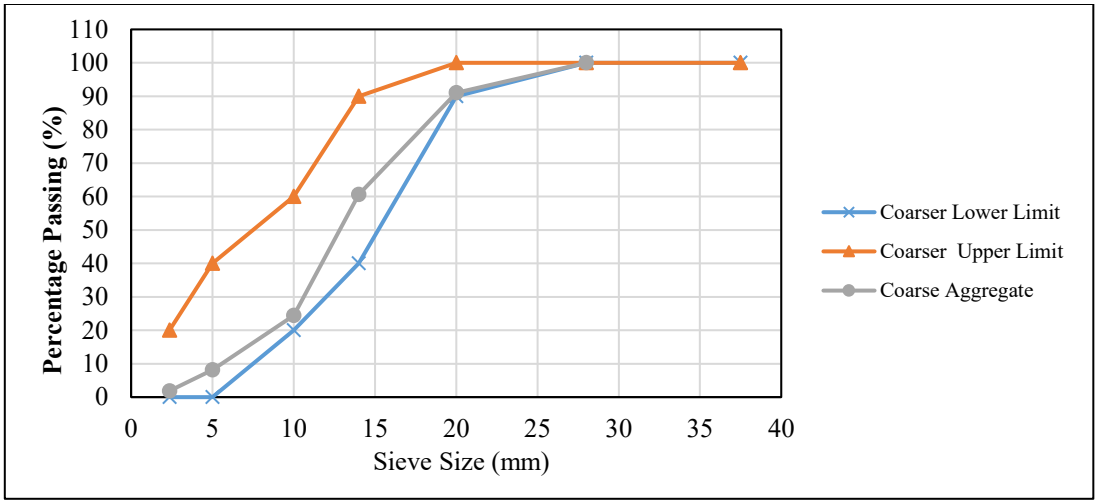

Figure 2: Sieve analysis graph showing well graded coarse aggregate used in the research.

Workability of Laterized Concrete

Figure 3 presents the slump results of concrete mixes containing laterite as a partial replacement for fine aggregate. All mixes showed actual slump and were categorized as low workability. Slump values consistently decreased from 25 mm in the control mix (0% laterite) to 8 mm at 30% replacement. Due to laterite's clayey texture and high water absorption capacity, which lower the amount of free water available for lubrication and produce a stiffer mix, workability is reduced. Similar patterns have been documented by Adamolekun et al. (2024) and Arum et al. (2022), who pointed out that too much laterite reduces workability because of its fine fraction and absorptive qualities.

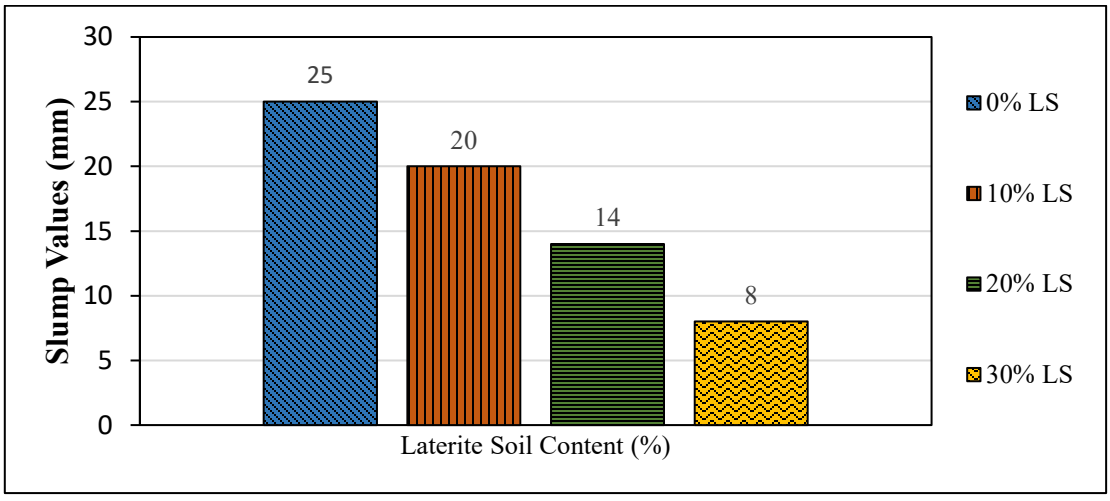

Figure 3: Slump result of concrete samples

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Density of Laterized Concrete Cured in Water

The density of the hardened concrete specimens, determined in accordance with BS EN 12390-7:2019, exhibited a slight increase with curing age across all mixes. Figure 4 illustrates the density development of laterized concrete cubes cured in water for 7, 14, and 28 days. At 28 days, the control mix recorded an average density of 2331 kg/m³, while mixes containing 10%, 20%, and 30% laterite achieved densities of 2357 kg/m³, 2365 kg/m³, and 2353 kg/m³, representing increases of 1.11%, 1.46%, and 0.94%, respectively, relative to the control. The observed rise in density up to 20% replacement indicates enhanced particle packing and reduced void content, whereas the slight decline at 30% replacement suggests the limiting effect of excessive laterite content on compactness.

Whereas all mixes showed a collectively decrease in density after lengthy curing and sulphate exposure, the 10-20% replacement levels displayed greater stability and durability.

This tendency is consistent with the specific gravity data, implying that laterite helps to produce relatively lightweight yet structurally reliable concrete. Although lower, the lateritic mix produced acceptable compaction, which is consistent with recent findings (Nurudeen & Musa, 2024; Garba, Mohammed, & Sani, 2024). Both the control and lateritic mixes in this investigation meet the structural concrete criteria, as defined by BS EN 12390-7:2019, which classifies concrete above 2000 kg/m³ as normal weight.

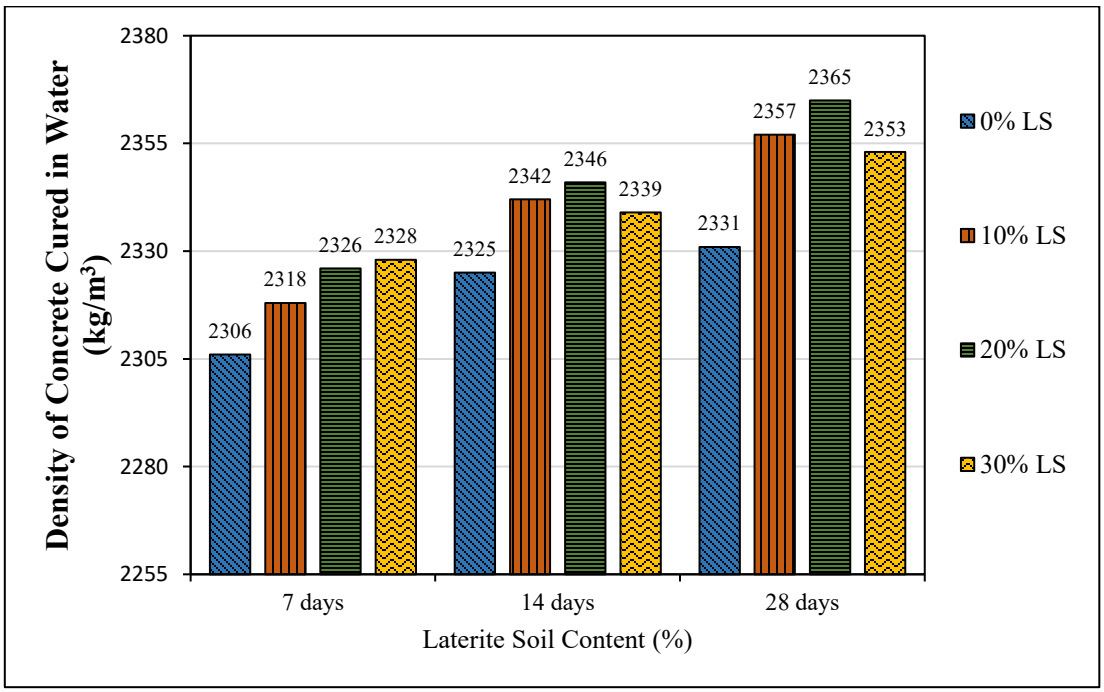

Figure 4: Densities of laterized concrete cured in water

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Compressive Strength of Laterized Concrete Cured in Water

The compressive strength of laterite concrete cubes that were cured in water for 7, 14, and 28 days is shown in Figure 5, along with the percentage variations from the control mix. Significant strength gains were observed at 7 days following laterite substitution, the 10% and 20% mixes exhibited increases of 8.0% and 8.8%, respectively, while the 30% mix produced the largest early age gain of 20.8% in comparison to the control. The control recorded 25.90 N/mm² at 14 days, whereas the 10% and 20% replacements increased by 2.8% and 5.3%, respectively, while the 30% mix only exhibited a slight 1.0% rise. At 28 days, 20% replacement produced the best strength, increasing it by 4.9% above the control, whereas 10% replacement produced a slight 1.1% improvement.

However, the 30% replacement mix showed a minor 2.2% decrease in compressive strength, demonstrating the negative impact of high laterite concentration on the development of long term strength. These results show that up to 20% laterite incorporation improves strength performance, which is consistent with earlier research that found that moderate replacement levels resulted in better mechanical properties, whereas excessive substitution reduces strength (Garba et al., 2024; Agboola et al., 2024).

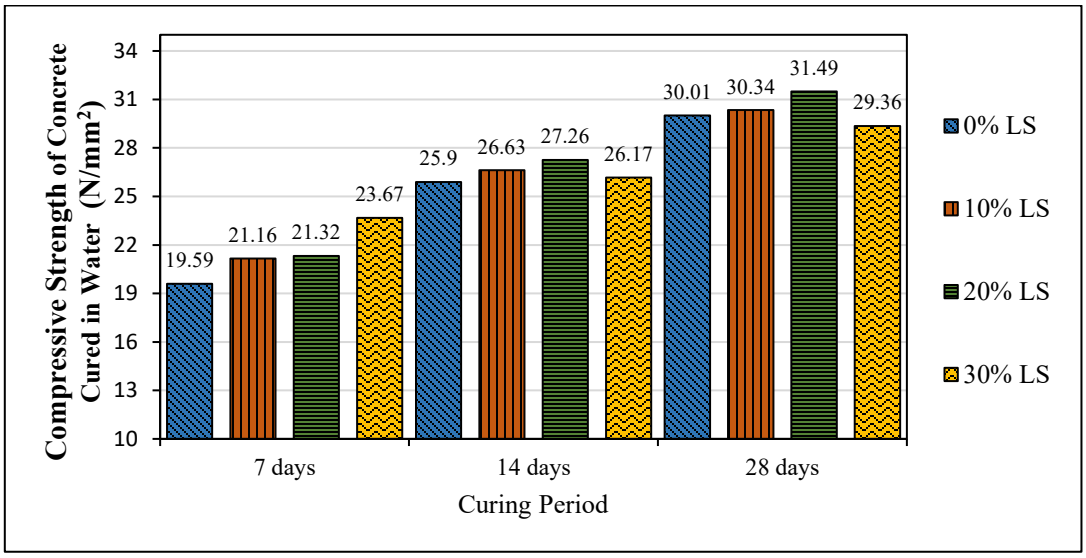

Figure 5: Average comprehensive strength of laterized concrete samples cured in water

Density of Laterized Concrete under Magnesium Sulphate Exposure

The density variation of laterite concrete cubes cured in $MgSO_4$ solution for 7, 14, and 28 days is Shown in Figure 6, which shows the incremental mass variations brought on by sulphate attack. With average percentage variances of 0.10%, 0.05%, 0.04%, and 0.13% for the control, 10%, 20%, and 30% laterite replacements, respectively, at 7 days, mass

fluctuations were minor, suggesting minimal degradation at an early stage. The average mass losses after 14 days increased marginally to 0.13%, 0.07%, 0.07%, and 0.06%, indicating that the 10–20% laterite mixes were equally effective in preventing sulphate ingress as the control.

More noticeable alterations were seen after 28 days the control mix lost the most mass (4.06%), whereas the 10%, 20%, and 30% laterite mixes lost less 1.13%, 1.64%, and 3.04%, respectively. At 10%, 20%, and 30% replacement levels, these findings indicate improvements in sulphate resistance of 72.2%, 59.6%, and 25.1% above the control.

This pattern illustrates that while excessive replacement reduces performance, moderate replacement (10–20%) improves durability under sulphate exposure, most likely as a result of better pore structure and decreased permeability. According to Garba et al. (2024) and Agboola et al. (2024), moderate laterite insertion enhances the chemical durability of concrete in harsh settings. These findings are in line with their findings. Additionally, all mixes maintained densities within the normal weight concrete range, confirming their structural viability in accordance with BS EN 12390-7:2019.

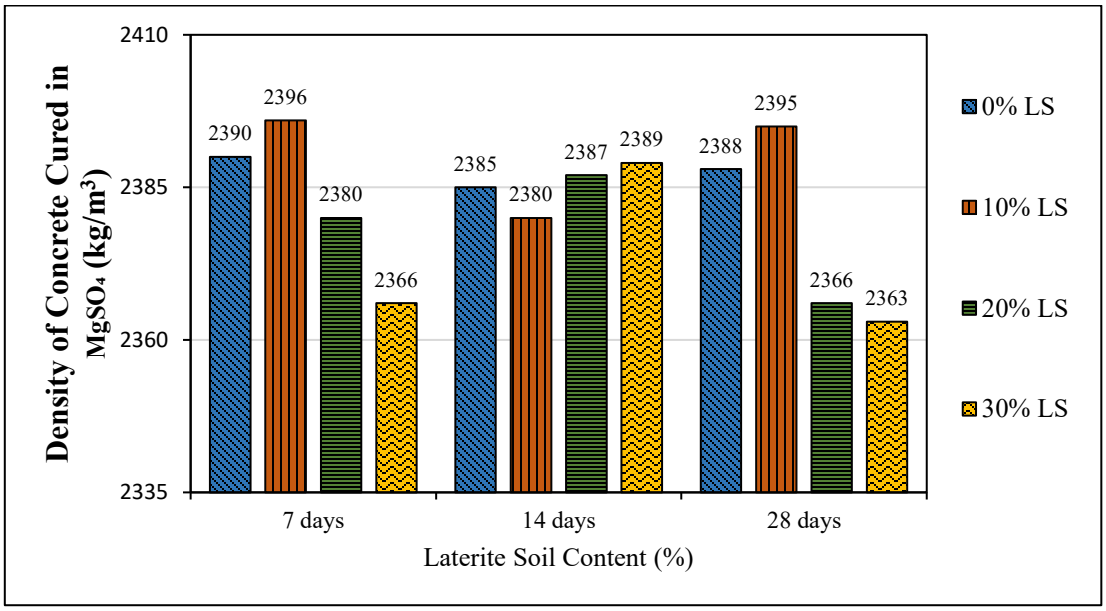

Figure 6: Average 28days density of laterite concrete cured in $MgSo_4$ solution

Compressive Strength of Laterite Concrete under Magnesium Sulphate Exposure

At 28 days, there were noticeable differences in the compressive strength of laterite concrete cubes cured in water and $MgSO_4$ solution as shown in Figure 7. Under water curing, the control mix reached 30.01 N/mm²; however, in $MgSO_4$, it fell to 23.37 N/mm², indicating a 22.1% strength reduction brought on by sulfate attack. The strength dropped

by 2.8%, from 30.34 N/mm² (water curing) to 29.48 N/mm² ($MgSO_4$), at 10% laterite replacement. On the other hand, mixes with 20% and 30% laterite performed better in the aggressive medium, achieving 32.90 N/mm² and 32.70 N/mm², respectively, as opposed to 31.49 N/mm² and 29.36 N/mm² in water curing, which represents strength improvements of 4.5% and 11.4%, respectively.

This trend suggests that resistance to sulphate attack is improved by moderate to high laterite incorporation (20–30%), perhaps as a result of the creation of a denser matrix that restricts ion penetration. On the other hand, under conventional curing, the control and 10% replacement mixes fared better, indicating their vulnerability to chemical deterioration. These results are consistent with those of Agboola et al. (2024), who found that adding additional ingredients to concrete increases its chemical stability and durability in harsh settings.

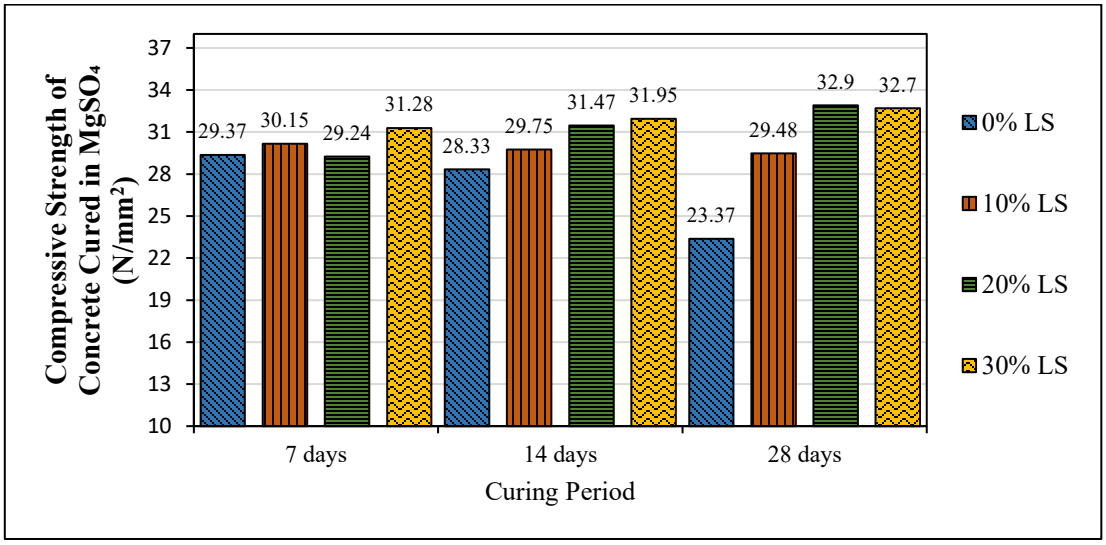

Figure 7: Average compressive strength of laterite concrete cured in $MgSo_4$ solution

Conclusion

i. At 20% laterite replacement, the concrete's compressive strength reached its maximum at 28 days, measuring 31.49 N/mm², which was 4.9% higher than the control mix. Strength decreased after this point because there were more vacancies and less particle bonding.

ii. The density of the hardened concrete decreased slightly with increasing laterite content but remained within the normal weight classification specified by BS EN 12390-7:2019, confirming its suitability for structural applications.

iii. All mixtures experienced an overall decrease in compressive strength upon exposure to $MgSO_4$ solution. However, concretes with 10–20% laterite replacement demonstrated higher sulfate resistance than the control, indicating improved durability in aggressive environments.

iv. Hence, the findings of this research confirm the potential of laterite as a sustainable partial replacement for fine aggregate in concrete is reinforced by the finding that moderate substitution (10–20%) enhances both compressive strength and sulfate resistance ($MgSO_4$), without compromising density requirements.

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