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The use of soil-cement to improve the strength and stability of soil

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Abstract

This study examines the particle size distribution, workability, and compressive strength of concrete mixes containing laterite soil and fine aggregate. Compressive strength tests conducted at 7, 14, 21, and 28 days revealed that fine aggregate exhibited superior strength development compared to laterite soil. Concrete with fine aggregate achieved compressive strengths of 22.55 N/mm², 23.65 N/mm², 26.80 N/mm², and 30.00 N/mm² at 7, 14, 21, and 28 days respectively. In contrast, laterite soil mixes recorded 17.50 N/mm², 12.45 N/mm², 15.80 N/mm², and 17.65 N/mm² over the same periods, indicating slower and less consistent strength gain. Slump test results showed that fine aggregate mixes were more workable and cohesive than those made with laterite soil. Sieve analysis further revealed that fine aggregate had a well-graded particle size distribution, enhancing compactness and structural stability, whereas laterite soil was coarser and less uniform. Based on the results, fine aggregate is recommended for structural concrete applications requiring high early and long-term strength, while laterite soil is better suited for non-structural or low-load-bearing uses.

Key words: Soil-Cement; Laterite Soil; Soil Stabilization; Compressive Strength; Workability; Particle Size Distribution

1. Introduction

One of the key and most crucial materials for every construction project is soil. The soil's strength characteristics determine a structure's strength and longevity. Numerous research studies have revealed that the negative properties of organic soil result in extremely low shear strength and bearing capacity, along with high compressibility [1, 2].

Soil is a natural mixture of minerals, organic matter, gases, liquids, and countless living organisms, all of which are essential to sustaining life on Earth. However, when soil fails to meet the functional requirements needed for it to perform effectively as a geotechnical material, it is considered deficient [3, 4]. Such deficiencies can affect its suitability for use in various civil engineering applications, including backfills for retaining walls, clay liners for leachate containment, base courses for road construction, embankments for roads or dams, and subsoil bases for foundations.

These soils may include lateritic soils, black cotton soils, collapsible soils, or other types commonly found in tropical regions [5]. To enhance their engineering properties and make them suitable for construction purposes, a technique known as soil stabilization is applied. This process involves either the addition of stabilizing agents—such as cement, lime, or other chemical and non-chemical materials—or the application of specific treatment methods to improve one or more of the soil's physical or mechanical characteristics. Stabilization can be achieved either by physically mixing stabilizing agents with natural soil to form a homogeneous blend or by introducing the stabilizing material into undisturbed soil deposits, allowing it to permeate the soil pores and initiate interaction [6]. Among the various additives used, cement remains one of the most widely adopted materials for stabilizing expansive soils. Numerous studies have explored the effectiveness of cement stabilization in improving soil performance. However, under dynamic loading

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conditions—such as those experienced in pavement systems—cement-treated soils often exhibit excessive stiffness and brittleness, which can be undesirable. The structural performance of civil engineering infrastructure built on geomaterials (soil or rock) is significantly influenced by the mechanical behavior of these foundation materials [7, 8 & 9]

Soils provide foundational support for infrastructure such as roads, airports, and dams. While some natural soils are suitable for use in their native state, others require stabilization to improve their engineering properties and meet specific construction standards. In many developing regions, including Nigeria, the scarcity of conventional construction materials has prompted the adoption of locally available alternatives. Lateritic soils—rich in iron and aluminum—are surface deposits commonly found in tropical and subtropical regions, formed through the physical and chemical weathering of underlying rocks. In Nigeria, laterite is frequently used as a foundation material for civil engineering works, often without thorough consideration of its geotechnical behavior and long-term performance. This oversight has contributed to widespread structural failures in roadways, where subsurface engineering deficiencies are a major cause of instability [10].Regular soil testing is essential prior to highway design and construction due to the variability in the engineering properties of soils. The suitability of a soil for any engineering purpose is largely determined by factors affecting its performance and a thorough understanding of its geotechnical characteristics. Soil stabilization becomes necessary when natural soils, such as lateritic soils, exhibit poor quality or deteriorate before reaching their intended design life. Various stabilizing agents—such as cement kiln dust, rock flour, fly ash, lime, and others—are commonly incorporated to enhance soil properties. Clay soils, in particular, are problematic; they expand when wet, shrink when dry, and perform best in cold climates. According to the findings in [11], these behaviors make clay soils unstable and unreliable during service, especially in load-bearing applications. The properties of most lateritic soils require improvement due to their high clay content. To enhance the engineering performance and suitability of such soils for various construction purposes, different soil modification techniques are employed. Lime and cement are commonly used stabilizing agents for improving weak or soft soils, fine-grained and granular soils, as well as problematic soils with poor load-bearing capacity. Among these, cement is more widely used than lime due to its greater availability, cost-effectiveness, and higher strength performance. In fact, cement typically provides greater strength gains than an equivalent amount of lime [12, 13,].

In recent years, locally available waste materials have been increasingly utilized to reinforce weak soils as a cost-effective approach to modifying deficient soils. This form of soil stabilization emphasizes the efficient use of indigenous resources to reduce the overall cost of civil engineering projects and address associated environmental concerns [14, 15]. However, many of these locally sourced materials lack the necessary cementitious properties required to effectively bind soil particles and achieve the strength levels typically provided by cement in sustainable pavement applications. The hydration reaction associated with cement plays a critical role in enhancing soil properties, enabling improved strength, durability, and long-term performance [16, 17].

According to Ademila, rocks and soils fail when the applied load exceeds their bearing capacity [18]. The depletion of natural resources due to continuous exploration has driven the need to utilize readily available building materials for sustainable construction and resource conservation. However, the use of high-quality materials in road pavement construction often results in elevated costs [19]. This study aims to evaluate the improvement in the engineering properties of lateritic soil-cement mixtures to determine their suitability for cost-effective and durable road pavement applications.

2. Materials and methodology

2.1. Material Constituents

2.1.1. Cement

Dangote Cement, a reputable brand, was sourced from a supplier opposite Eco Bank, Uli, Anambra State. Approximately 50 kg was used for the tests.

2.1.2. Fine Aggregate

River sand was sourced from Onitsha, Anambra State. It was sieved to remove impurities and stored dry. About 50 kg was used.

2.1.3. Laterite soil

Laterite soil was sourced from Oba, a known location for quality lateritic material used in construction works.

2.1.4. Portable Water

Clean water suitable for mixing was sourced within the university [20]. About 20 litres were used.

2.2. Methodology

2.2.1. Sieve Analysis

Sieve analysis was performed on 1.5 kg of dried soil and sand using a standard sieve set and mechanical shaker to determine particle size distribution and assess materialsuitability for concrete mix design.

2.2.2. Moisture Content Test

Moisture content was determined by oven-drying soil and sand samples at 105°C for 24 hours. Samples were weighed before and after drying, and moisture content was calculated using:

Moisture content (%) = $[(W_2 - W_3) / (W_3 - W_1)] \times 100$,

where W_1 is the weight of the empty can, W2 is the weight of the wet sample with the can, and W3 is the weight after drying. This test was essential for correcting weight and volume calculations of materials.

2.2.3. Specific Gravity Test

The specific gravity of soil and sand samples was determined using a pycnometer. Weights were recorded for the empty pycnometer (W_1), with soil and water (W_2), and with water only (W_3). Specific gravity was calculated using the standard formula. This test helps in material identification and quality classification.

2.2.4. Atterberg Limits Test

The liquid limit, plastic limit, and plasticity index were determined to evaluate the soil's consistency under varying moisture conditions. The Casagrande apparatus was used for the liquid limit, while the plastic limit was determined by rolling soil threads until disintegration at 3 mm diameter. The plasticity index was calculated as PI = LL − PL.

2.2.5. Compaction Test

Compaction tests were performed to determine the maximum dry density and optimum moisture content. Soil samples at varying moisture contents were compacted in three layers in a Proctor mold, each layer receiving 25 blows. Dry densities were calculated and plotted to identify the peak values.

2.2.6. California Bearing Ratio (CBR) Test

The CBR test assessed the load-bearing capacity of the soil. Samples were compacted at optimum moisture content, soaked for 96 hours, and tested using a penetration plunger. Loads at various depths were recorded, and the CBR value was computed to evaluate sub-grade suitability.

2.2.7. Slump Test

The slump test was conducted to assess the workability of fresh concrete. A standard slump cone was filled with concrete in three layers, each tamped 25 times. The cone was then vertically lifted, and the slump value was measured as the vertical difference between the height of the cone and the displaced concrete. This test provided an indication of the mix's consistency and ease of placement.

2.2.8. Compressive Strength Test

The compressive strength test was performed to evaluate the concrete's capacity to resist axial loading. Concrete cubes (150 mm × 150 mm × 150 mm) were cast and cured in water for 7, 14, 21, and 28 days. After curing, each specimen was surface-dried and tested using a compressive testing machine. Load was applied until failure, and the maximum load was recorded to calculate the compressive strength.

3. Results and discussion

The samples were subjected to the following tests as outlined in the methodology.

3.1. Sieve Analysis

The particle size distribution of fine aggregate and laterite soil is presented in Table 1 and Table 2, with corresponding gradation curves in Figure 1 and Figure 2. Figure 3 shows a comparative analysis. Well-graded aggregates, as observed, improve the workability and strength of concrete.

Table 1 Sieve Analysis Test (fine aggregate)

Sieve No.	Weight of Sieved Sample (kg)	Weight of Sieve (kg)	Weight of Send (kg)	Percentage Retained (%)	Cumulative Percentage Retained(%)	Cumulative Percentage Passing(%)
S	0-35	0-30	0-05	3.33	3.33	96.67
10	0-35	0-30	0-05	3.33	6.66	93.34
12	0.40	0.30	0.10	6.67	13.33	86.67
20	0.60	0.30	0.30	20.00	33.33	66.67
30	0.60	0.30	0.30	20.00	53.33	46.67
40	0.65	0.30	0.35	23.33	76.66	23.34
80	0.65	0.30	0.35	23,33	99.99	0,01
Pan	0.30	0.30	0.00	0,00	100%	0,00%

Table 2 Sieve Analysis Test (laterite)

Sieve No,	Weight of Sieved Sample (kg)	Weigh t of Sieve (kg)	Weigh t of Latente (kg)	Percentage Retained (%)	Cumulative Percentage Retained(%)	Cumulative Percentage Passing (%)
3	0,50	0.30	0.20	13,33	13,33	86-67
10	0.35	0.30	0.05	3.33	16.66	83.34
12	0.35	0.30	0.05	3.33	19.99	80.01
20	0.55	0.30	0.25	16.67	36.66	63.34
30	0.60	0.30	0.30	20.00	56.66	43.34
40	0.60	0.30	0.30	20.00	76.66	23.34
30	0.60	0.30	0.30	20.00	96.66	3.34
Pan	0.05	0.30	0.05	3.34	100.00	0,00

3.2. Moisture content

Moisture content values for laterite and fine aggregate are presented in Table 3

Table 3 Moisture Content of Laterite and Fine Aggregate

Sample	Moisture Content (%)(Laterite)	Moisture Content (%) (FineAggregate)
Sample 1	5,00	4,92
Sample 2	5.08	5.00
Sample 3	5.18	5.09

3.3. Specific gravity

Specific gravity values for laterite and fine aggregate are presented in Table 4, aiding in material classification and mix proportioning.

Table 4 Specific Gravity of Laterite and Fine Aggregate Sample

Sample	Specific Gravity (Laterite)	Specific Gravity (Fine Aggregate)
Sample 1	2.55	2.60
Sample 2	2.60	2,62
Sample 3	2.65	264

3.4. Atterberg limit

The Atterberglimits, including liquid limit, plastic limit, and plasticity index for laterite and fine aggregate, are summarized in Table 5.

Table 5 Atterberg Limits of Laterite and Fine Aggregate

Sample	Liquid Limit (%) (Laterite)	Plastic Limit (%) (Laterite)	Plasticity Index (%) (Laterite)	Liquid Limit (%) (Fine Aggregate)	Plastic Limit (%) (Fine Aggregate)	Plasticity Index (%) (Fine Aggregate)
Sample 1	41	21	21	31	19	13
Sample 2	43	22	22	33	20	14
Sample 3	46	24	23	35	21	15

3.5. Compaction Test

Compaction characteristics, including Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), are essential for assessing the suitability of laterite and fine aggregate in soil-cement stabilization. These parameters identify the moisture level for effective compaction and the achievable maximum density. The results of the compaction tests are presented in Table 6.

Table 6 Compaction Test Results – OMC and MDD of Laterite and Fine Aggregate

Material	OMC (%)	MDD (g/cm3)
Fine Aggregate	11.5	2.10
Laterite Soil	13.2	1.85

3.6. California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) values for laterite and fine aggregate, indicating their load-bearing capacities, are presented in Table 5.

Table 7 CBR Values of Laterite and Fine Aggregate

Sample	CBR (%} (Laterite)	CBR (%) (Fine Aggregate)
Sample 1	20	13
Sample 2	22	15
Sample 3	24	17

3.7. Slump test

The slump values for fine aggregate and laterite soil, which reflect the workability of the fresh concrete mixes, are presented in Table 8.

Table 8 Slump Test Results

Material	Slump Value (mm)
Fine Aggregate	85
Laterite Soil	50

3.8. Compressive Strength Test

The average compressive strength of concrete samples made with fine aggregate and laterite soil at different curing ages is presented in Table 8.

Table 9 Average Compressive Strength of Fine Aggregate and Laterite Soil

Material	7 Days	14 Days	21 Days
Fine Aggregate	22.55	23.65	26.80
Laterite Soil	17.50	12.45	15.80

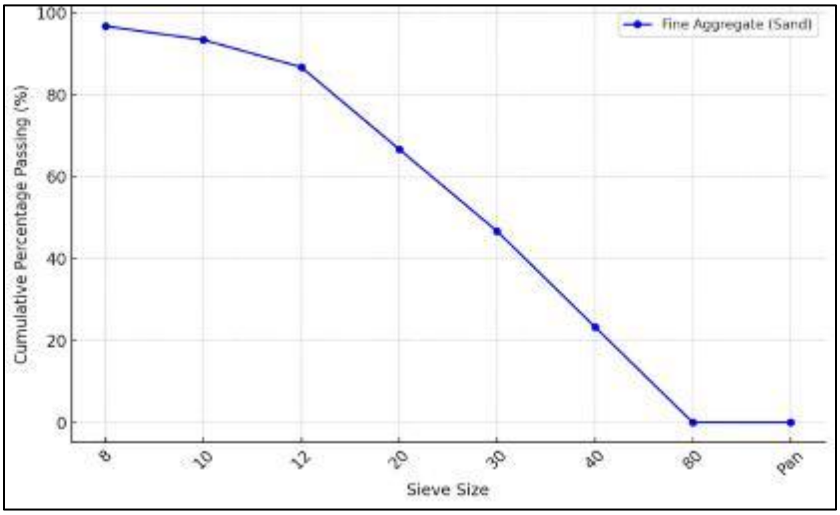

Figure 1 Grain Size Analysis of Fine Aggregate (Sand)

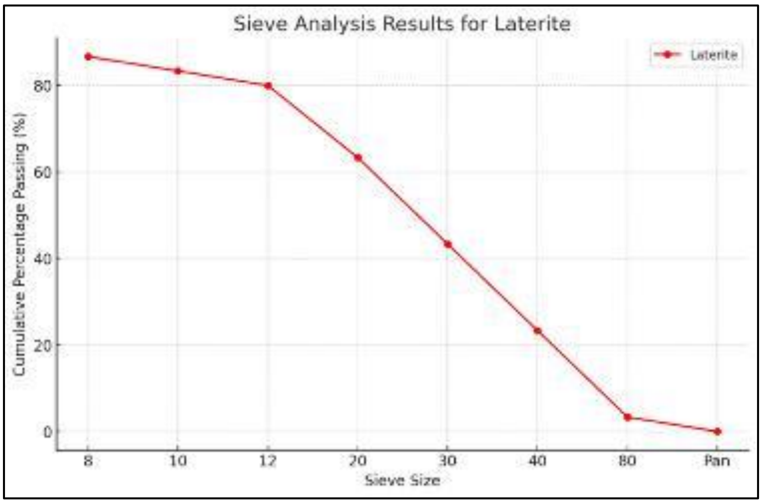

Figure 2 Grain Size Analysis of Laterite Soil

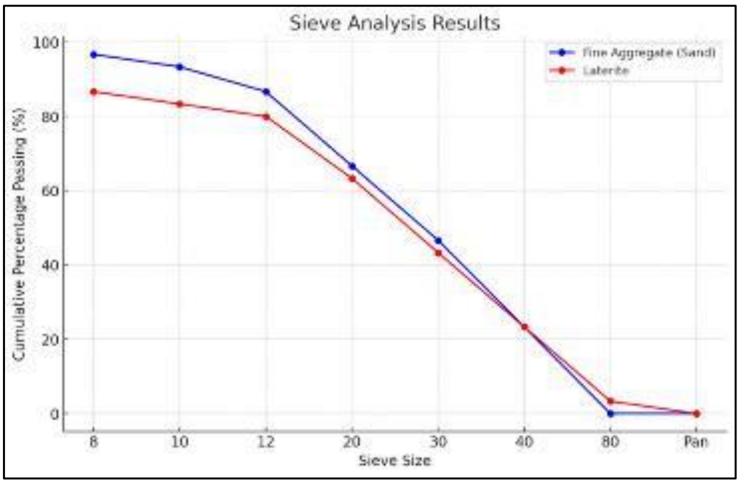

Figure 3 Grain Size Analysis of Fine Aggregate and Laterite Soil

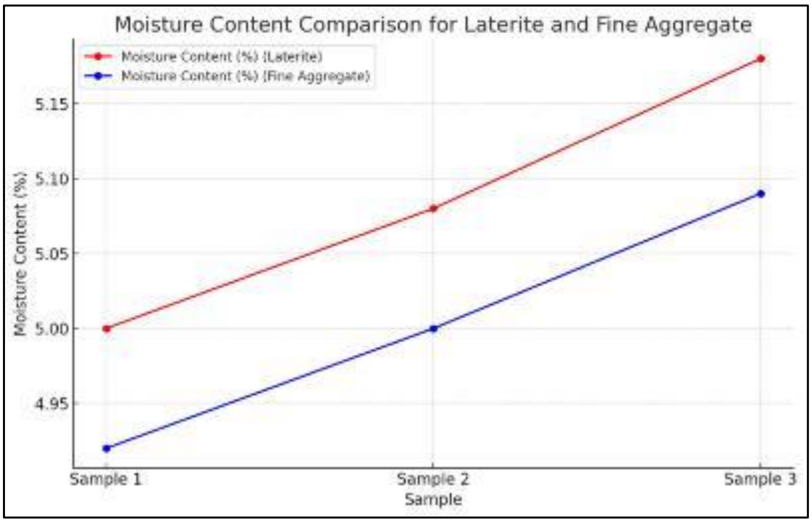

Figure 4 Moisture Content Comparison for Laterite and Fine Aggregate

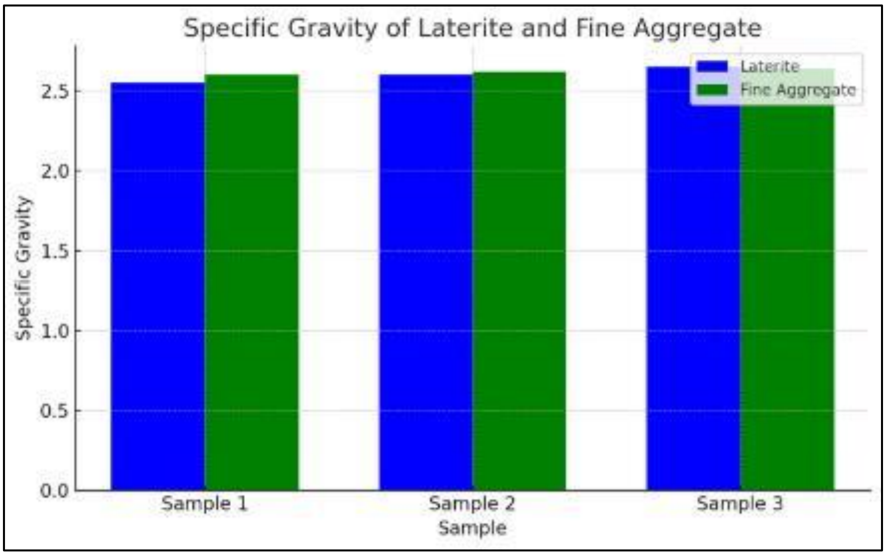

Figure 5 Specific Gravity Comparison for Laterite and Fine Aggregate

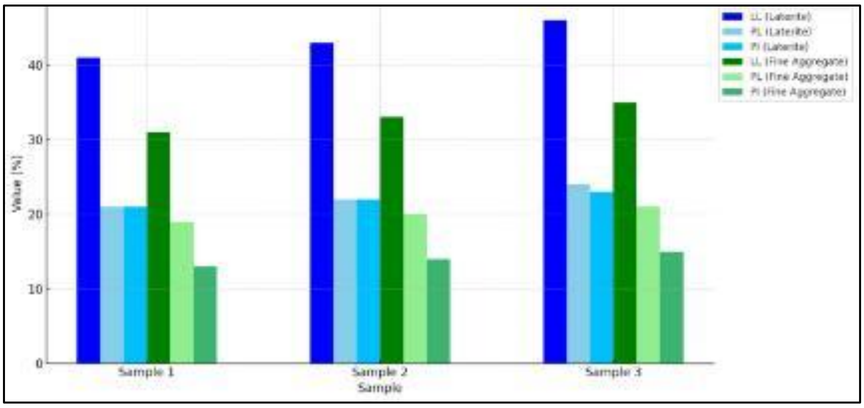

Figure 6 Atterberg Limits of Laterite and Fine Aggregate

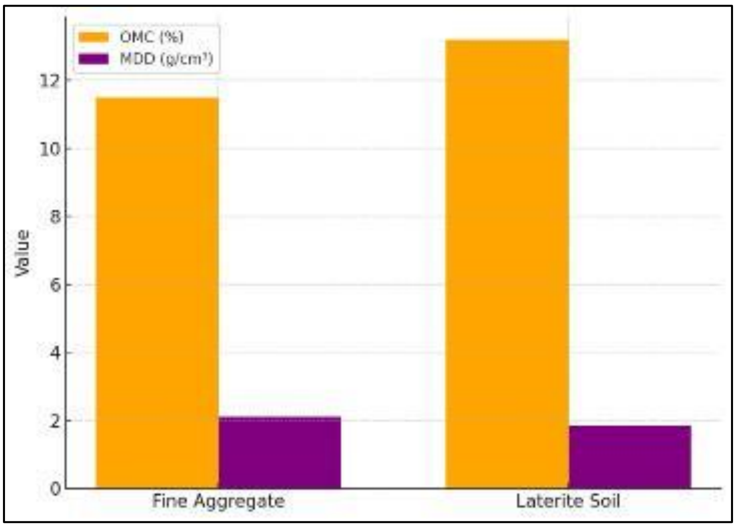

Figure 7 OMC and MDD of Fine Aggregate and Laterite Soil

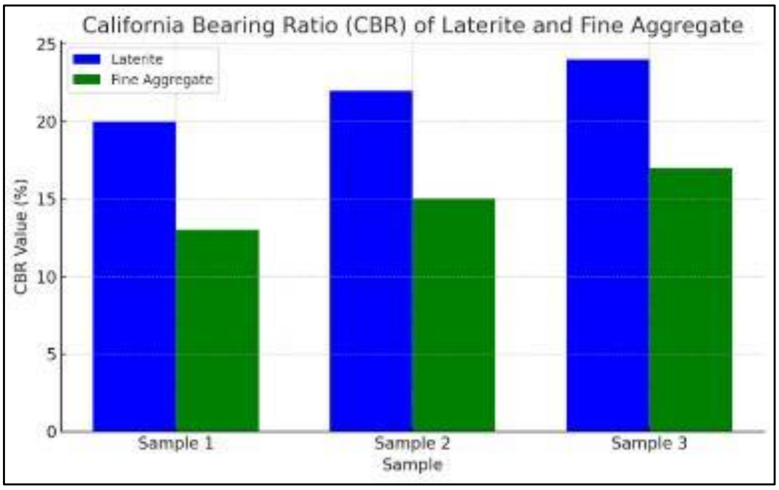

Figure 8 California Bearing Ratio (CBR) of Laterite and Fine Aggregate

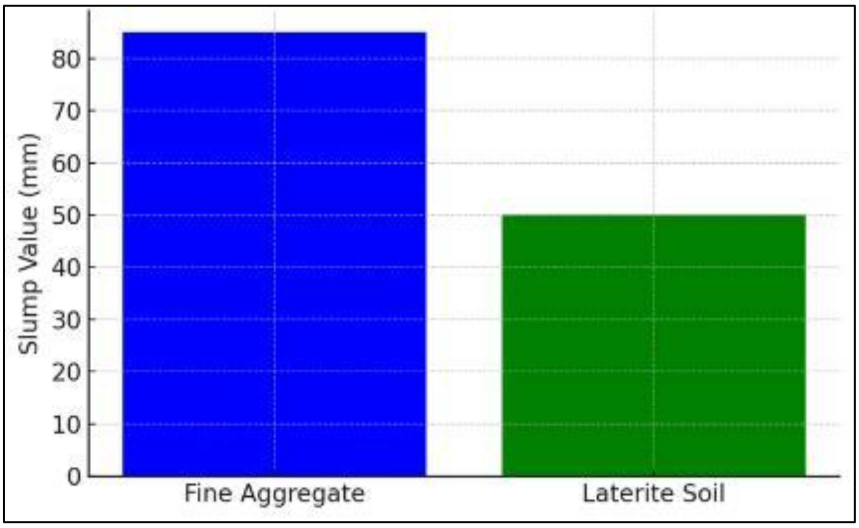

Figure 9 Slump Test Results for Fine Aggregate and Laterite Soil

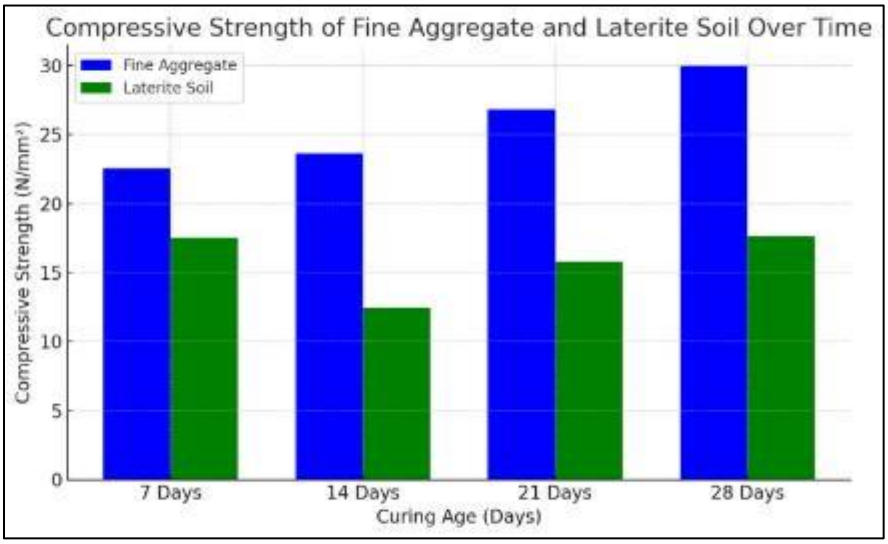

Figure 10 Compressive Strength of Fine Aggregate and Laterite Soil

4. Conclusion

This study assessed the compressive strength performance of concrete incorporating fine aggregate and laterite soil. The results revealed that fine aggregate consistently achieved higher compressive strength at all curing ages, reaching 30.00 N/mm^2 at 28 days. Its well-graded particle distribution also contributed to improved workability and compaction, making it highly suitable for structural concrete.

Laterite soil, in contrast, exhibited lower and less consistent strength, with a 28-day value of 17.65 N/mm^2. Although some strength gain was observed after 14 days, its performance suggests limited suitability for structural use. However, it may be appropriate for non-load-bearing applications or as a cost-effective partial replacement when blended with stronger aggregates.

4.1. Recommendations

- Fine aggregate is recommended for structural concrete requiring high compressive strength and durability.
- Laterite soil should be used in non-critical applications or blended with fine aggregate for cost savings where moderate strength is acceptable.
- Further research is encouraged to explore optimal mix ratios and the use of admixtures to improve laterite performance.
- Adequate curing and moisture control are essential, particularly for laterite mixes, to enhance strength development and prevent failure.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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