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Optimizing And Predicting the Performance of Lateritic Concrete Enhanced with PCE-Superplasticizers Using Response Surface Methodology

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Abstract- ***This research employed response surface methodology (RSM) to optimise lateritic concrete with the inclusion of HYDROPLAST 240GP, a PCE superplasticizer, to improve workability and compressive strength while reducing the deleterious impacts of the clay content in laterite. Experimental mixtures with different laterite replacement levels (7.5–30%) of sand fine aggregates and superplasticizer dosages (0.8–1.5%) were assessed were used. compressive strength tests at 7 and 28 days, and microstructural analyses employing SEM, EDX, and XRD techniques were done. The combination of 7.5% laterite replacement and 1.15% HYDROPLAST 240GP resulted in the highest 28-day compressive strength of 22.6 N/mm², in contrast to 22.09 N/mm² observed in the control sample. SEM, EDX, and XRD analyses showed denser microstructure characterised by reduced porosity, increased calcium silicate hydrate formation, improved hydration products, and a uniform distribution of elements in the optimised mix. The RSM model showed that enhancing laterite replacement at 13–15% with a superplasticizer dosage of approximately 1.15% improved strength and gave good workability. The findings indicate that HYDROPLAST 240GP and RSM effectively optimised lateritic concrete mix designs, providing a cost-efficient and sustainable alternative appropriate for laterite-rich areas.***

Keywords; Lateritic concrete, Response Surface Methodology, HYDROPLAST 240GP, Compressive strength

I. INTRODUCTION

Concrete is the second most widely used material worldwide, following water, and is fundamental to Despite its widespread use, structural failures particularly in developing countries like Nigeria are often linked to poor-quality materials and substandard aggregates (Amadi & Eberemu, 2012). This is especially prevalent in traditional earth construction, where unstabilized lateritic materials have shown susceptibility to failure during seasonal flooding, leading to significant economic and human costs (Ndububa & Mukaddas, 2016). This has prompted a growing interest in alternative materials that are both locally available and environmentally sustainable.

Lateritic soil, abundant in tropical regions, has emerged as a promising substitute for conventional fine aggregates in concrete production (Olawuyi & Olusola, 2010). Lateritic concrete, or laterized concrete, offers economic and ecological advantages by reducing reliance on natural sand and lowering production costs (Adewuyi & Adegoke, 2008). However, the lateritic soils in regions like Abuja are often poorly graded with a predominance of sand and a lower-than-optimal clay content, which poses significant challenges to workability and strength while also reducing their inherent binding capacity (Ndububa, Nnebe, & Onche, 2025; Ndububa & Mukaddas, 2016).

To address these limitations, researchers have explored the use of chemical admixtures particularly superplasticizers to enhance the performance of lateritic concrete. Polycarboxylate ether (PCE)-based superplasticizers, such as HYDROPLAST 240GP, have shown potential in improving fluidity without increasing water demand, thereby preserving or enhancing compressive strength (Soutsos, Khayat, & Sivalingam, 2011). Nonetheless, the interaction between lateritic soils and superplasticizers remains complex due to the heterogeneity of laterite in terms of mineral composition and particle size distribution (Rao & Reddy, 2002).

Moreover, the long-term durability of lateritic concrete modified with superplasticizers under tropical environmental conditions is under-researched, and the cost implications of using such admixtures in low-income settings raise further questions about feasibility (Poon & Lam, 2009).

These gaps underscore the need for a systematic approach to mix optimization that balances performance, cost, and sustainability. This study aims to optimize lateritic concrete using HYDROPLAST 240GP through Response Surface Methodology (RSM), focusing on improving workability and compressive strength while addressing the challenges posed by laterite's clay content. By integrating experimental testing with predictive modelling and microstructural analysis, the research seeks to provide a robust framework for sustainable concrete design in laterite-rich regions.

II. MATERIALS AND METHODS

A. *Materials*

Ordinary Portland Cement (OPC), branded as Dangote Cement, was sourced from a local distributor in Abuja and stored in a cool, dry environment prior to use. The cement met ASTM C150 specifications for compatibility with superplasticizers and served as the primary binder (Saichand, 2019).

The river sand fine aggregate was collected from Jere river in Abuja, sieved through a 4.75 mm mesh, and air-dried to a saturated surface-dry condition. The sand was partially replaced with laterite at specified percentages.

Coarse Aggregate (Granite) (4.75–20 mm) was obtained from a quarry in Kubwa, Abuja, and met ASTM C33/C33M grading requirements.

Potable water from the Civil Engineering Laboratory, University of Abuja, was used, meeting ASTM C1602 quality standards.

Laterite was sourced from a borrow pit located in the Citec area of Abuja municipality. Geotechnical profiling confirms that lateritic soils in the Abuja area are typically classified as poorly graded 'Clayey Sand' (SC) under the Unified Soil Classification System (USCS), which aligns with the properties of the material used in this study (Ndububa et al., 2025), the laterite was obtained from a depth of 300 mm. Samples were air-dried for two weeks, and used to replace sand at 0%, 7.5%, 15%, 22.5%, and 30% by weight.

Superplasticizer HYDROPLAST 240GP, a polycarboxylate ether (PCE)-based admixture, was dosed at 0.8%, 1.15%, and 1.5% by cement weight, in line with manufacturer recommendations and ASTM C494-19 (ASTM International, 2019) and main constituents are seen in Table 1.

Table 1: Main constituents of HYDROPLAST 240GP and their functions.

Constituent	Function	Relevance to Lateritic Concrete
PCE Copolymer	Electrostatic repulsion & steric hindrance	Disperses cement/laterite particles, reduces water demand
Set Control Modifiers	Regulate early hydration	Maintain slump in high-fines mixes
Defoamer	Suppress foam	Control air entrainment
Water Carrier	Disperse active components	Ensure uniform admixture distribution

B. *Mix Design, Casting and Curing*

The concrete mix was designed in accordance with BS EN 206- (British Standards Institution, 2013) to achieve a target characteristic compressive strength of 25 N/mm² at 28 days and a workable slump between 10–30 mm. An initial water-cement (w/c) ratio of 0.50 was selected for the control mix based on established principles for the target strength (Neville, 1995).

A control mix, containing 0% laterite and 0% superplasticizer, was first established to serve as a control. The experimental variable involved the partial replacement of fine aggregate (sand) by laterite at incremental percentages of 0%, 7.5%, 15%, 22.5%, and 30% by mass. For the mixes containing laterite, a superplasticizer was introduced at dosages of 0.8%, 1.15%, and 1.5% by weight of cement. The w/c ratio was adjusted from the initial value of 0.50 on a trial basis as necessary to achieve the target slump range; all adjustments were meticulously recorded. Workability was quantified immediately after mixing via the slump test, conducted in full compliance with ASTM C143/C143M (ASTM International, 2015). For each unique mix proportion, three 150 mm cubes were cast. The fresh concrete was compacted to remove entrapped air and demoulded after 24 hours. In accordance with standard curing procedures, the specimens were subsequently cured by immersion in a water tank maintained at a constant temperature of 27 ± 2 °C BS EN 12390 (British Standards Institution, 2019) until testing at prescribed ages of 7 and 28 days.

C. Methodology

2.1 Particle Size Distribution (Sieve Analysis)

The particle size distribution of the fine aggregate was determined in accordance with the standard procedure outlined in ASTM C136/C136M (ASTM International, 2019). Approximately 500 g of air-dried sand was weighed and washed through a 75 µm sieve to remove dust and fines. The washed sample was then oven-dried at 105 ± 5°C to a constant mass before mechanical sieving for 15 minutes. This washing step ensures the distribution reflects only the granular skeleton of the aggregate, which is critical as its grading significantly influences the workability and mechanical properties of concrete (Das, 2010; Neville, 2011).

For the lateritic soil, a modified approach was necessary to align with the research objective. This study investigates laterite as a potential partial replacement for fine aggregate in its natural, as-excavated state, which includes its inherent silt and clay content. These fines are integral to laterite's structure and binding properties (Amadi et al., 2017). Furthermore, characterizing the material in its 'as-excavated' state is critical, as the performance of lateritic concrete is influenced by the natural gradation and clay/silt content, which varies by location (Ndububa et al., 2025; Ndububa & Mukaddas, 2016). Washing the laterite, as done with the sand, would have artificially removed these key components, thereby altering the fundamental material property under investigation. Consequently, the lateritic soil was simply oven-dried at 105 ± 5°C to a constant mass to eliminate moisture and then sieved identically to the sand without the initial washing step. This approach provided the particle size distribution of the material's dry aggregate fraction, simulating how it would be batched into a concrete mix in a practical application. This ensured the particle size distribution reflected the material's natural grading (Amadi et al., 2017).

The mass retained on each sieve was measured, and the percentage retained, cumulative percentage retained, and percentage finer were calculated. The coefficients of uniformity (C_u) and curvature (Cc) were derived from the distribution:

$$\text{Percentage retained (\%)} = \frac{\text{mass of soil retained on the sieve(g)}}{\text{total mass of soil sample}} \times 100 \quad (1)$$

$$\text{Cumulative percentage retained} = \sum \text{Percentage retained (\%)} \quad (2)$$

$$\text{Cumulative Percentage Finer (\%)} = 100 - \text{Cumulative percentage retained} \quad (3)$$

$$\text{Coefficient of Curvature} = \frac{D60}{D10} \quad (4)$$

$$\text{Coefficient of Uniformity} = \frac{(D30)^2}{D10 \times D60} \quad (5)$$

D_{10}, D_{30}, D_{60} = Particle diameters at which 10%, 30%, and 60% of the soil is finer, respectively.

2.2 Specific Gravity and Water Absorption

The specific gravity and water absorption of the fine aggregate (sand) and lateritic soil were determined using a pycnometer method in accordance with ASTM C128 (ASTM International, 2015). The specific gravity of the coarse aggregate (granite) was determined following ASTM C127 (ASTM International, 2015). The results are essential for concrete mix design and volume-based calculations. The specific gravity (Gs) is then calculated using the formula:

$$Gs = \frac{W_s}{W_s + W_w + W_c} \quad (6)$$

where W_s is the weight of soil solids, W_w is the weight of water, W_c and is the weight of the soil sample in water.

2.3 Concrete Mix Design, Casting, and Curing

A control mix with a proportion of 1:2:4 (cement:sand:granite) by weight and a water-cement (w/c) ratio of 0.5 was used as the baseline (Neville, 1995). Laterite was introduced as a partial replacement for fine aggregate at levels defined by the experimental design. The HYDROPLAST 240GP superplasticizer was added at varying dosages (0.8–1.5% by weight of cement) as per the manufacturer's recommendations and ASTM C494/C494M (ASTM International, 2019). The constituent materials were mixed thoroughly in a laboratory drum mixer. The fresh concrete was used for workability tests immediately after mixing. For compressive strength tests, 150 mm cubes were cast, compacted on a vibrating table, and finished smooth. The specimens were demoulded after 24 hours and submerged in a water-curing tank maintained at 27 ± 2°C until the time of testing ASTM C192/C192M (ASTM International, 2019).

2.4 Workability (Slump) Test

The workability of the fresh concrete mixes was assessed using the slump test in accordance with ASTM C143/C143M (ASTM International, 2015). The concrete was placed in a standard slump cone in three layers, each rodded 25 times. The cone was lifted vertically, and the slump value was measured as the difference in height between the mold and the displaced original center of the slumped concrete. The target slump range for this study was 75–100 mm, ensuring adequate consistency for handling and placement without segregation (Khayat, 1999).

2.5 Compressive Strength Test

The compressive strength of the hardened concrete was determined in accordance with ASTM C39/C39M (ASTM International, 2021). Tests were conducted on cube specimens at 7, 14, and 28 days of curing. The tests were performed using a compression testing machine with a constant loading rate of 140 kg/cm²/min. The compressive strength was calculated using equation:

$$\text{Compressive Strength (N/mm2)} = \frac{\text{Applied load (N)}}{\text{Area of Cube (mm×mm)}} \quad (7)$$

Where applied load (N) = Force

2.6 Oxide Composition Analysis

The chemical composition of the lateritic soil was determined using X-ray Fluorescence (XRF) spectroscopy following ASTM C114 (ASTM International, 2018; ISO 12677). Samples were dried, pulverized to a fine powder to ensure homogeneity, and analyzed using an XRF spectrometer calibrated with certified reference materials. This analysis quantified the percentages of major oxides (e.g., SiO_2, Al_2O_3, Fe_2O_3), which is crucial for understanding the material's chemical reactivity and potential pozzolanic activity in a cementitious matrix (Mehta & Monteiro, 2006; Rao & Reddy, 2002).

2.7 Experimental Design and Optimization using RSM

Response Surface Methodology (RSM) was employed to optimize the concrete mix using a Central Composite Design (CCD) in Minitab software. This statistical technique is effective for modeling and optimizing processes with multiple variables (Box & Wilson, 1951; Ogundiran & Akinmoladun, 2013). The independent variables were:

A: Superplasticizer Dosage (% by weight of cement)
B: Water-Cement Ratio
C: Laterite Content (% replacement of sand)

The responses measured were slump (workability) and compressive strength at 7 and 28 days. The CCD generated a set of experimental runs, and second-order polynomial models were fitted to the data. The adequacy of the models was checked using analysis of variance (ANOVA). The models were then used to generate response surface plots and identify the optimal combination of factors that simultaneously maximized the desired responses.

2.8 Microstructural Analysis

Select samples from optimal mixes and the control were subjected to microstructural analysis using Scanning Electron Microscopy (SEM) to examine the morphology of the hydration products and the interfacial transition zone (ITZ) between the cement paste and the lateritic aggregate. This analysis provided insights into the microstructural modifications, such as pore refinement and improved particle bonding, induced by the superplasticizer (Mehta & Monteiro, 2006; Siddique, 2011).

III. RESULTS AND DISCUSSIONS

3.1 Material Properties

The fundamental properties of the constituent materials (fine aggregate, laterite, and granite) were characterized to understand their influence on the concrete mix. The particle size distribution, presented in Figure 1 and Figure 2, was analyzed to determine the uniformity coefficient (Cu) and coefficient of curvature (Cc), key indicators of grading quality (ASTM International, 2017). The specific gravity (G) of each material was also determined, as it significantly impacts the density and yield of the concrete.

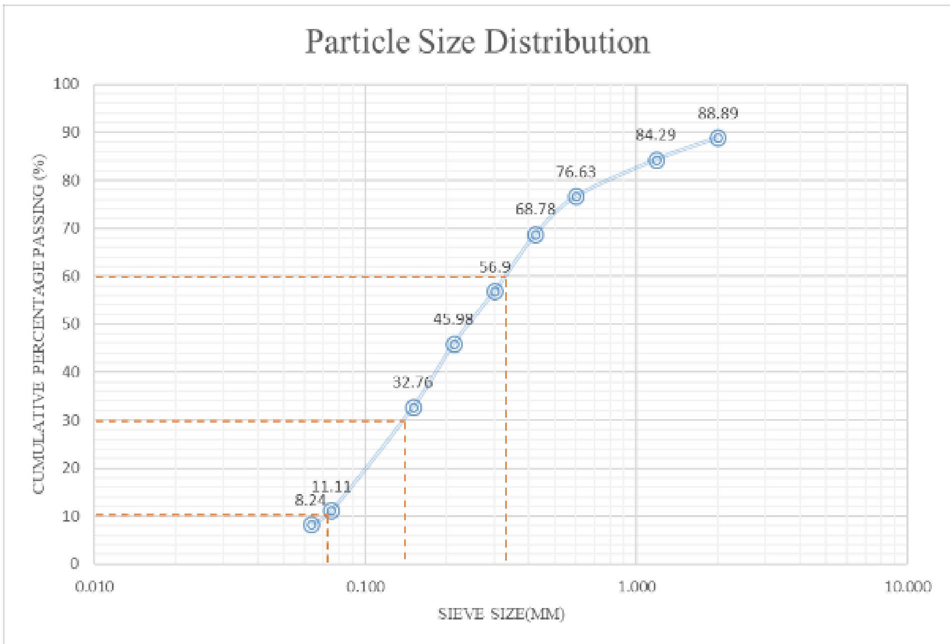

Figure 1: Particle size distribution analysis of fine aggregate

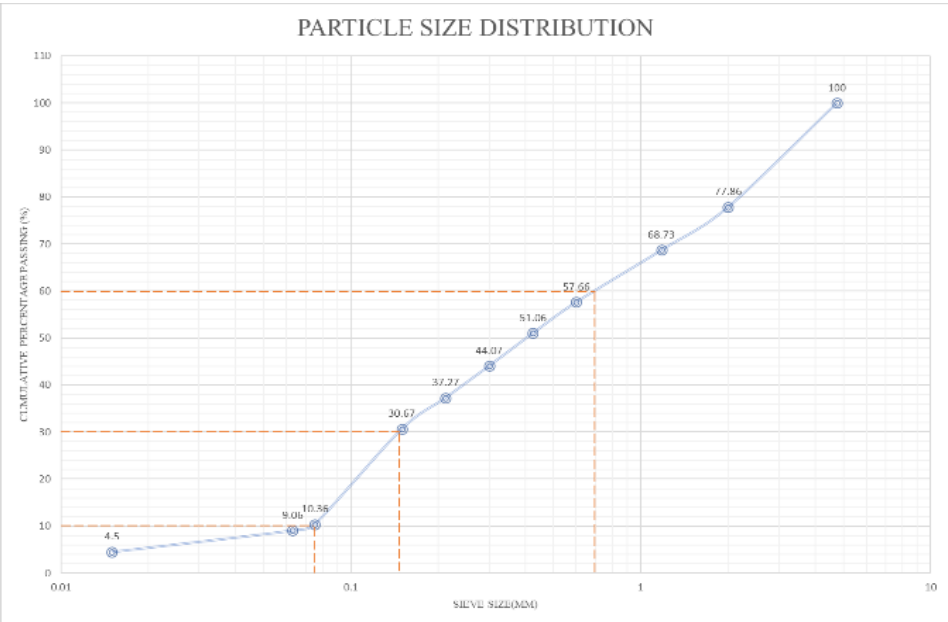

Figure 2: Particle size distribution analysis of Laterite

Table 2: Gradation and Specific Gravity Properties of Materials

Property	Fine Aggregate	Laterite	Coarse Aggregate (Granite)
D_{10} (mm)	0.07	-	-
D_{30} (mm)	0.140	-	-
D_{60} (mm)	0.333	-	-
Coefficient of Uniformity, Cu	4.76	-	-
Coefficient of Curvature, Cc	0.84	-	-
Fineness Modulus	-	-	1.53
Specific Gravity	1.708	1.655	2.149

The fine aggregate was classified as poorly graded (Cc = 0.84 < 1) and moderately uniform (Cu = 4.76 < 5), suggesting a potential for lower packing density which could increase water demand (Das, 2010). The laterite contained a significant fraction of fines (14.36% passing 0.075 mm), indicating a high-water demand potential. The crushed granite had a fineness modulus of 1.53, confirming a coarse and well-graded aggregate suitable for structural concrete. The specific gravity values were 1.708 for fine aggregate, 1.655 for laterite, and 2.149 for granite. The lower specific gravity of the laterite, compared to the conventional fine aggregate, confirms its lighter weight, which will influence the density of the resulting concrete.

3.2 Workability

The workability of the fresh concrete mixes, measured by slump test, is crucial for placement and compaction. The results, detailed in Table 3 and visualized in Figure 3, demonstrate a clear trend. The slump test results indicate a decrease in workability with increasing laterite replacement levels. At 0.8% superplasticizer dosage, slump values reduced from 3.0 mm at 0% laterite to 1.1 mm at 30% laterite. Similar trends were observed for 1.15% and 1.5% dosages, with values dropping to 1.0 mm and 0.8 mm, respectively, at 30% laterite. These results suggest that laterite increases the cohesiveness of the mix, reducing fluidity. However, increasing superplasticizer dosage helped maintain workability, highlighting the admixture's effectiveness in improving flowability.

Table 3: Slump Test Results

Combination	Laterite Content (%)	Superplasticizer Dosage (%)	Slump (mm)
Control	0	0	9.5
1	0	0.8	3.0
2	7.5	0.8	1.9
3	15	0.8	1.8
4	22.5	0.8	1.4
5	30	0.8	1.1
6	0	1.15	3.0
7	7.5	1.15	1.4
8	15	1.15	1.2
9	22.5	1.15	1.2
10	30	1.15	1.0
11	0	1.5	3.0
12	7.5	1.5	1.3
13	15	1.5	1.0
14	22.5	1.5	0.8
15	30	1.5	0.8

A pronounced inverse relationship exists between laterite content and workability. The slump value decreased from 9.5 mm for the control mix (0% laterite, 0% superplasticizer) to as low as 0.8 mm for mixes with 30% laterite content. This is directly attributable to the high fines content and angularity of the laterite particles, which increase the surface area and internal friction of the mix, thereby reducing fluidity (Amadi et al., 2017). The incorporation of the Polycarboxylate Ether (PCE)-based superplasticizer (HYDROPLAST 240GP) helped mitigate this reduction. For a constant laterite content, a higher superplasticizer dosage generally resulted in a slightly higher slump, highlighting its role in dispersing particles and reducing water demand. However, its effectiveness was subdued at high laterite replacement levels (>22.5%), where the water demand of the fines dominated.

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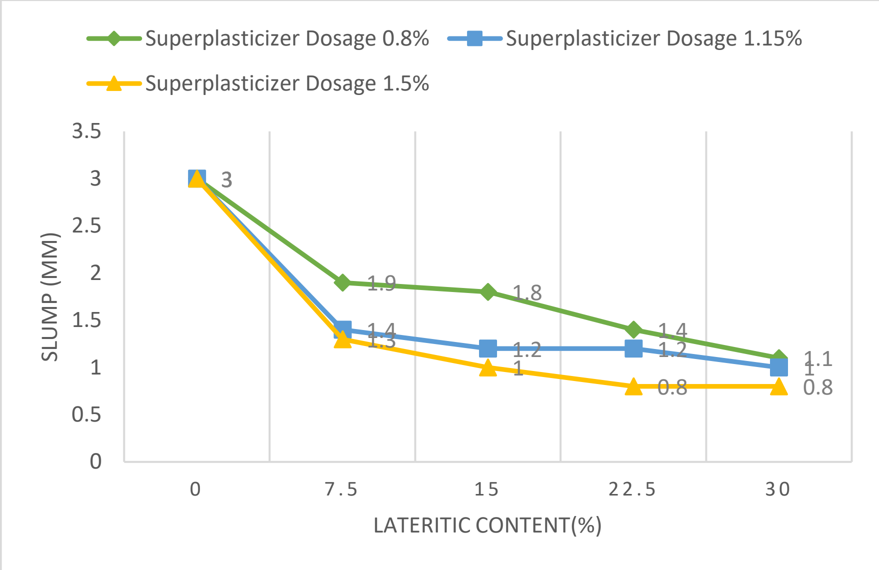

Figure 3: Slump for Different Laterite and Superplasticizer Dosages

3.3 Compressive Test Results

The compressive strength development at 7 and 28 days for all 15 mix combinations is the core of this investigation. The results, summarized in Table 4 and Figure 4, reveal significant effects of both laterite content and superplasticizer dosage.

At 7 days (Table 4 and Figure 4), compressive strength consistently decreased with increasing laterite content for a given superplasticizer dosage. For instance, at 0.8% dosage, strength dropped from 16.83 N/mm² (0% laterite) to 2.13 N/mm² (30% laterite). This is due to the dilution of cementitious material and the lower binding capacity of laterite compared to sand. Interestingly, the optimal superplasticizer dosage for early strength appeared to be 0.8-1.15%, as the 1.5% dosage sometimes led to reduced early strength (e.g., 7.9 N/mm² for 0% laterite at 1.5% dosage vs. 16.83 N/mm² at 0.8%), potentially due to over-dispersion and initial air entrainment.

Table 4: Compressive Strength Results at 7 and 28 Days

Laterite Content (%)	Superplasticizer Dosage (%)	7-Days Mean Compressive Strength (N/mm²)	28-Days Mean Compressive Strength (N/mm²)
0	0	16.40	22.09
0	0.8	16.83	14.67
7.5	0.8	11.53	6.80
15	0.8	6.70	7.23
22.5	0.8	4.90	14.13
30	0.8	2.13	8.76
0	1.15	14.00	11.56
7.5	1.15	15.00	22.60
15	1.15	9.13	22.40
22.5	1.15	4.17	14.93
30	1.15	2.63	19.23
0	1.5	7.90	17.53
7.5	1.5	9.90	18.93
15	1.5	8.73	14.63
22.5	1.5	8.90	11.87
30	1.5	6.17	14.03

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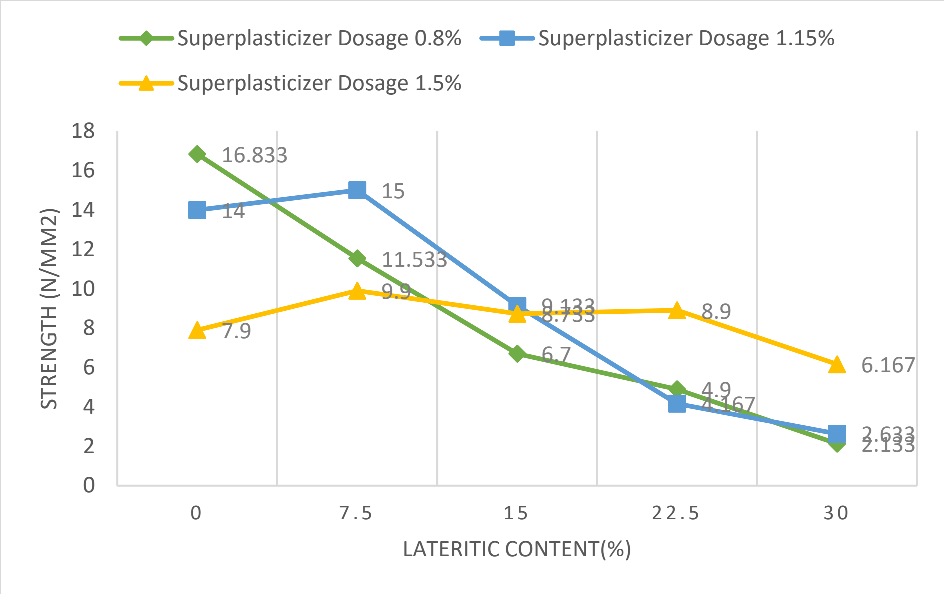

Figure 4: Average Concrete Strength for Different Laterite and Superplasticizer Dosage Content at 7 Days

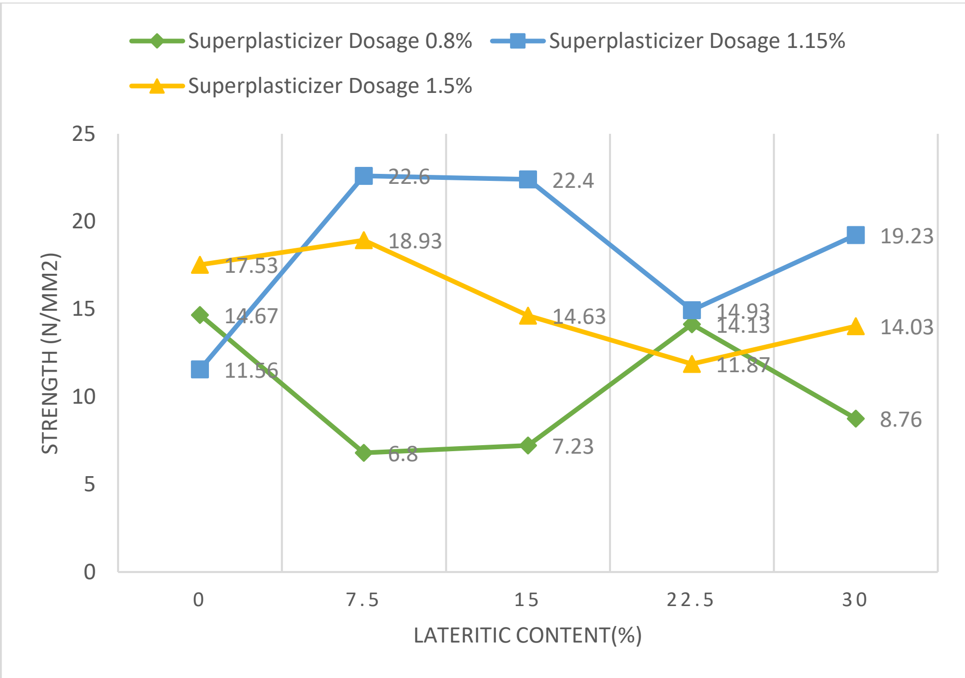

Figure 5: Average Concrete Strength for Different Laterite and Superplasticizer Dosage Content at 28 Days

The 28-day results (Figure 5) revealed a more complex interaction. While high laterite content (30%) still resulted in low strength (~8-19 N/mm²), a crucial finding emerged: a moderate replacement of 7.5% laterite with 1.15% superplasticizer yielded the highest 28-day strength of 22.60 N/mm², exceeding the control mix (22.09 N/mm²). This suggests that with optimal chemical admixture dosage, laterite can participate effectively in the hydration process, potentially through filler and pozzolanic effects, leading to enhanced long-term strength. Beyond this optimum, strength declined, confirming that excessive laterite replacement compromises the structural integrity of the concrete matrix.

3.4 Optimization and Prediction of Lateritic Concrete using Response Surface Methodology (RSM) with Minitab

Response Surface Methodology (RSM) was employed to optimize the mix design, establishing a mathematical relationship between the input variables (laterite content and superplasticizer dosage) and the key responses (slump, 7-day and 28-day compressive strength).

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The analysis of variance (ANOVA) for the developed models showed high significance. The model for slump was particularly robust, with an R^2 value of 91.31%, indicating that the model explains over 91% of the variability in the slump data. The Pareto chart confirmed that laterite content was the most dominant factor negatively affecting workability, while superplasticizer dosage had a smaller positive effect. For strength, the 28-day model was used for optimization as it represents the concrete's design strength. The interaction between the variables was found to be complex but significant.

Table 6: Results of the Response Optimization

Optimization Goal	Laterite Content (%)	Superplasticizer Dosage (%)	Predicted Slump (mm)	Predicted 28-Day Strength (N/mm²)	Composite Desirability
Max Strength & Workability	0	1.13	2.83	18.38	0.815
Max Strength with Laterite	13.33	1.24	1.24	18.84	0.676

The numerical optimization, aimed at maximizing strength while maintaining workability, yielded two primary solutions (Table 6). The most relevant solution for this study, which utilizes laterite, identified an optimal mix of 13.33% laterite content and 1.24% superplasticizer dosage, predicting a 28-day compressive strength of 18.84 N/mm². This was validated by experimental results; a mix with 15% laterite and 1.15% superplasticizer achieved an even higher experimental strength of 22.40 N/mm².

The relationship between the variables and the 28-day strength was captured by the following regression model in uncoded units:

$$\text{28-Day Strength} = -50.0 + 0.240A + 109.2B - 0.0026A^2 - 43.2B^2 - 0.182AB$$

(Where A = Laterite Content (%), B = Superplasticizer Dosage (%)

This model was used to predict performance across the design space. For example, the model predicted a strength of 18.53 N/mm² for a mix with 13% laterite and 1.15% superplasticizer, with a 95% confidence interval of (13.17, 23.88) N/mm² as seen in Table 7.

Table 7: Tabulated Prediction for Concrete Strength at 28 Days

Prediction	Laterite Content (%)	Superplasticizer Dosage (%)	28-Day Concrete Strength (N/mm²)	95% Confidence Interval (CI)	95% Prediction Interval (PI)
1	13	1.15	18.526	(13.17, 23.88)	(7.25, 29.80)
2	13.5	1.5	15.857	(10.47, 21.24)	(4.57, 27.15)
3	15	1.15	18.440	(13.05, 23.83)	(7.15, 29.73)
4	15	1.5	15.692	(10.30, 21.09)	(4.40, 26.99)
5	17	1.15	18.333	(12.98, 23.68)	(7.06, 29.61)

The contour plot (Figure 7) visually summarizes the optimization, showing the region of maximum strength (darker green). The plot confirms that the highest strengths are achieved with moderate laterite content (approximately 10-15%) and a superplasticizer dosage between 1.1% and 1.3%. This optimized mix design demonstrates that lateritic concrete can be engineered to meet structural strength requirements efficiently.

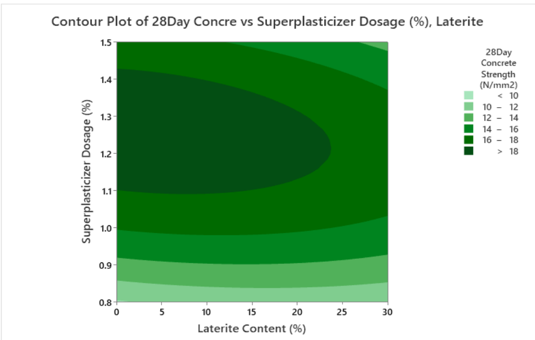

Figure 7: Contour Graph showing relationship between Superplasticizer Dosage, Laterite Content and Concrete Strength

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3.5 Microstructural Analysis

Microstructural analysis was conducted on samples to elucidate the reasons behind the observed macroscopic strength performance, with a focus on the optimal mix (7.5% laterite, 1.15% superplasticizer). Scanning Electron Microscopy (SEM) revealed a direct correlation between the mix design and the concrete's internal structure. The optimized sample (Figure 8) exhibited a dense and compact microstructure with significantly reduced porosity and well-defined interfacial transition zones (ITZ) between the aggregate and the cement paste. This enhanced cohesion and reduced void space are direct contributors to high compressive strength and are attributed to the effective particle dispersion enabled by the PCE superplasticizer. In contrast, mixes with high laterite content showed increased microcracking and a more porous structure, explaining their inferior strength. Energy-Dispersive X-ray Spectroscopy (EDX) was used to determine the elemental composition. The analysis (Figure 9) confirmed the presence of key elements essential for hydration: Calcium (Ca) and Silicon (Si) from cementitious reactions, and Iron (Fe) and Aluminum (Al) originating from the laterite. The optimized sample showed a favourable distribution of these elements. A critical finding was a higher Calcium-to-Silicon (Ca/Si) ratio in the optimized mix, suggesting enhanced formation of calcium silicate hydrate (C-S-H) gel, the primary strength-giving phase in concrete.

X-ray Diffraction (XRD) analysis provided definitive evidence of the crystalline phases present. The diffractogram (Figure 10) for the optimized sample showed prominent peaks for Portlandite ($Ca(OH)_2$) and, most importantly, well-defined peaks for calcium silicate hydrate (C-S-H). The strong presence of these hydration products confirms a high degree of cement hydration, directly correlating with the high compressive strength achieved. Peaks for Quartz (SiO_2) from the aggregates and Maghemite/Magnetite (Fe_2O_3/Fe_3O_4) from the laterite were also identified

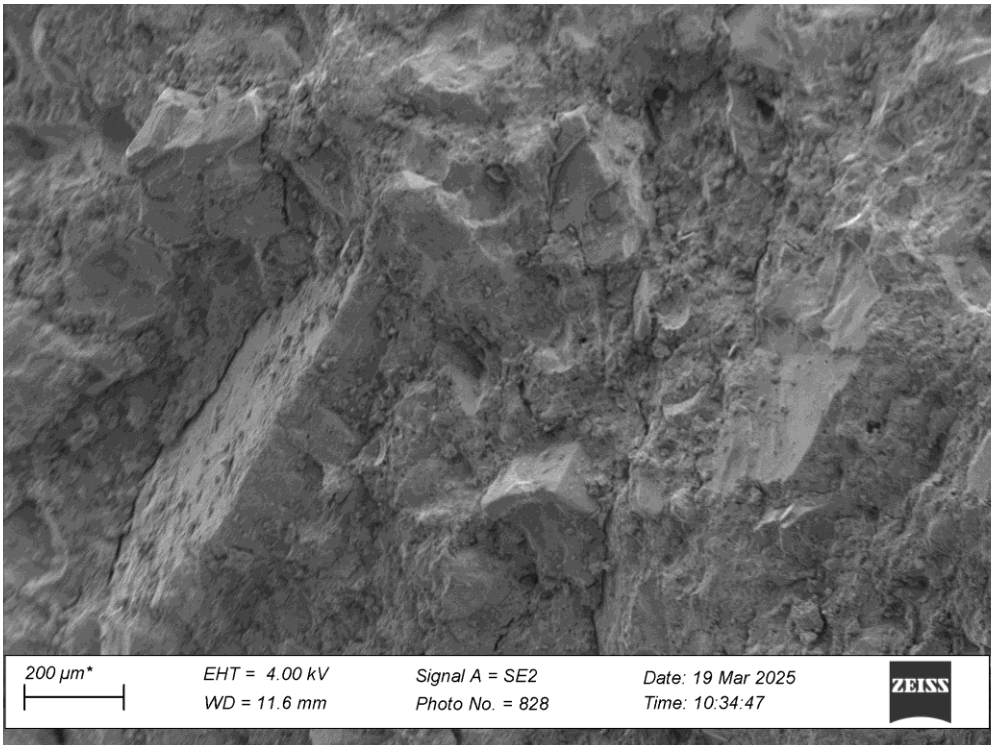

Figure 8: Microstructure of the lateritic concrete sample at a moderate magnification

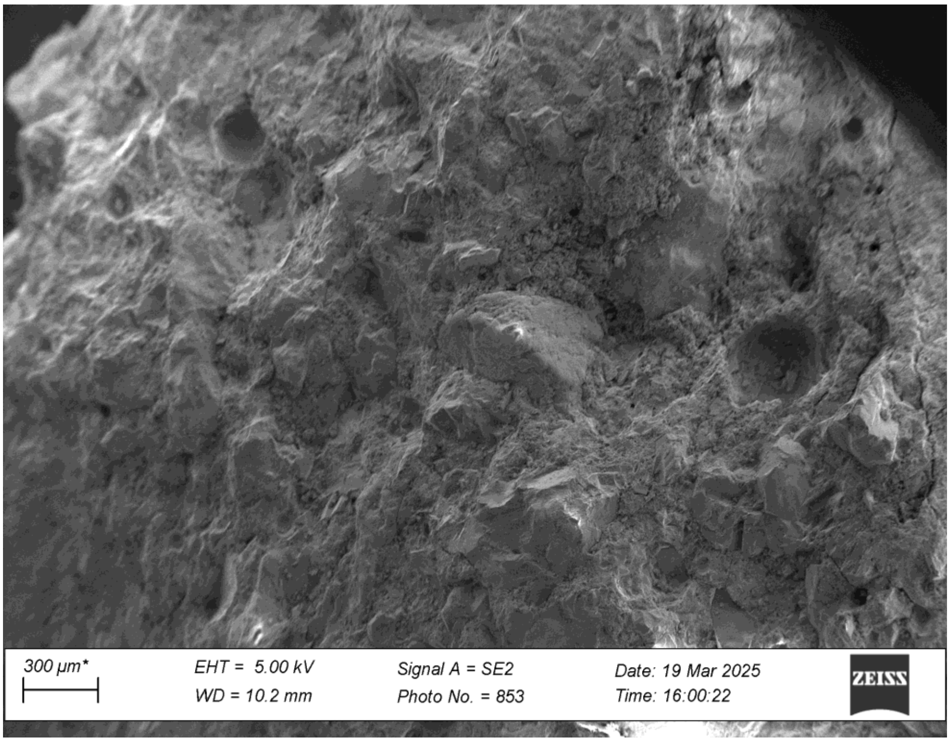

Figure 9: EDX Spectrum of the lateritic concrete

EDXRF spectra (Figures 11 and 12) confirm Abuja Laterite's elemental profile under Cu (40 kV) and Pd (20 kV) filters. Dominant silicon peaks (1.7–2.0 keV) validate its high silica content (48.1 % SiO_2), explaining strength potential and high-water demand. Iron and manganese peaks (6.4–6.6 keV), especially intense under Pd, reflect 8.9 % Fe_2O_3, contributing to cohesion and strength when properly dispersed. Lower-energy peaks (3.3–4.5 keV) for K, Ca, and Ti indicate clay mineral presence; low CaO confirms poor natural cementing, supporting PCE admixture use. Trace Zn and Br suggest minor durability-impacting impurities.

Overall, spectra affirm the siliceous, iron-rich, clayey nature of Abuja Laterite, aligning with previous research and justifying the RSM-guided superplasticizer strategy for enhanced workability and strength. In conclusion, the microstructural evidence from SEM, EDX, and XRD analyses provides a definitive explanation for the macroscopic strength results. The optimal combination of 7.5% laterite and 1.15% superplasticizer promotes a dense microstructure, facilitates efficient hydration, and enhances the formation of strength-giving C-S-H gel, thereby maximizing the compressive strength of the lateritic concrete. In conclusion, the microstructural evidence from SEM, EDX, and XRD analyses provides a definitive explanation for the macroscopic strength results. The optimal combination of 7.5% laterite and 1.15% superplasticizer promotes a dense microstructure, facilitates efficient hydration, and enhances the formation of strength-giving C-S-H gel, thereby maximizing the compressive strength of the lateritic concrete.

IV. DISCUSSION AND CONCLUSIONS

The strategic incorporation of 1.15 % HYDROPLAST 240GP polycarboxylate ether superplasticizer with 7.5 % laterite replacement successfully overcame the low fluidity and cohesion challenges typical of high-fines lateritic concrete. Workability improved significantly without over-dispersion or segregation, demonstrating that modest admixture dosages can replace bulk cement stabilization.

This finding is particularly significant when contrasted with traditional stabilization methods. While previous research on similar laterites demonstrated that 8% cement stabilization could achieve strengths of ~4.6 N/mm^2 for load-bearing earth bricks (Ogundiran & Akinmoladun, 2013), the optimized blend achieved a 28-day compressive strength of 22.6 N/mm^2 slightly higher than the 22.09 N/mm^2 control mix showing structural-grade performance at minimal cementitious cost. Response Surface Methodology (RSM) models exhibited strong predictive capability (R^2 = 0.9131 for slump), streamlining mix-design and reducing experimental iterations. This study shows that a much smaller dosage (1.15%) of a PCE superplasticizer enables the use of laterite as a sand replacement in structural concrete, achieving strength gains through improved particle dispersion and hydration rather than additional cementitious binding.

Microstructural characterization (SEM, EDX, XRD) confirmed a dense, low-porosity matrix rich in well-formed C–S–H gel and robust aggregate–paste interfaces. These observations link the macroscale strength gains to enhanced particle dispersion, improved hydration kinetics, and potential secondary pozzolanic activity of lateritic fines acting as microfillers.

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