Compressive Strength and Workability of Concrete Incorporating Laterite as Partial Replacement of Fine Aggregate

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ABSTRACT

The study examined laterite, an abundant and eco-friendly material, as a partial replacement for fine aggregate in concrete. It considered how laterite affected workability, compressive strength, and split tensile strength by using a mix of 1:1.5:3 (cement:fine aggregate:coarse aggregate). The laterite replaced 0%, 5%, 10%, and 15% of fine aggregate, both with and without 1% superplasticizer (based on the weight of cement). A total of 144 cubes (150mm) and 144 cylinders (150mm × 300mm) were cast and tested at various intervals: 3, 7, 10, 14, 28, and 42 days. The workability tests revealed that 5% laterite without superplasticizer achieved the highest slump at 55mm. Meanwhile, 10% and 15% dropped to 40mm, while the control was at 35mm. The presence of superplasticizer increased the slump by 109 to 271%, making all mixes practical for construction. At 28 days, the mix with 10% laterite and no superplasticizer showed the highest compressive strength at 31.19 MPa, which was better than the control at 29.26 MPa. When superplasticizer was added, 5% laterite reached 42.27 MPa, a 5% improvement over the control at 40.26 MPa. The split tensile strength also peaked at 3.01 MPa with 5% laterite plus superplasticizer, exceeding the control by 1.69%.. The mix at 5% laterite with superplasticizer gave maximum compressive strength of about 40 N/mm^2, making it suitable for structural applications. Laterite shows itself to be a viable alternative to sand. It is effective up to 10% without superplasticizer and 15% with it, supporting eco-friendly construction in areas rich in laterite.

Keywords: Laterite, Concrete, Compressive strength, Workability, Mix proportions

INTRODUCTION

Concrete is the main material used in construction due to its strength, durability, and versatility. However, its production relies heavily on natural aggregates and cement, contributing to resource depletion and greenhouse gas emissions (Mindess et al, 2003). Every year, more than 25 billion tonnes of concrete are needed, and fine aggregate like river sand makes up 30-40% of the mix. In Nigeria, sand mining has led to riverbed degradation, flooding, and loss of biodiversity in states like Ogun and Lagos. Fine aggregate is crucial in concrete for reasons including, (i) filling of voids between coarse aggregates, (ii) reduction of paste volume requirements and (iii) enhancing density, workability and durability (Branavan and Konthesingha, 2019, & Afolabi and Edidi 2025). Partial replacement of sand with laterite in concrete fine aggregates is relevant for sustainable construction and also that characteristics of laetrile soil cold satisfy the requirement of filler in concrete. The soil is typically rich in iron and aluminium oxide is a natural resource that is abundant in various regions of the world (Ogunleye, 2023). Laterite soils are produced by intensive and prolonged weathering of the underlying parent rock, usually under conditions of high temperatures and heavy rainfall alternating with dry periods in a process called laterization (Tardy, 1997). To address the issue of sustainable alternative of fine aggregate - Laterite a reddish, iron-rich soil abundant in tropical regions such as Nigeria - have gained attention. Laterite covers over 30% of Nigeria's landmass, with annual deposits exceeding 50 million tonnes in areas like Ikorodu, Ogun, and Anambra. Chemically, it contains 40-60% Fe_2O_3, 20-30% Al_2O_3, and 10-20% SiO_2, giving it pozzolanic potential when finely ground. Traditionally used in roadworks and rural housing, laterite's fine-grained nature suggests potential as a partial replacement for river sand in concrete. This study explores laterite's effect on concrete's workability, compressive strength, and split tensile strength at replacement levels of 0%, 5%, 10%, and 15%, with and without superplasticizer. The aim is to identify an optimal mix that balances performance and sustainability, leveraging Nigeria's rich laterite deposits. Limited access to quality sand in some areas underscores the need for local alternatives, though this study focuses on performance rather than scarcity. The objectives include assessing workability via slump tests, evaluating strengths at multiple curing ages (3, 7, 10, 14, 28, and 42 days), and determining the feasibility of laterite in structural concrete.

LITERATURE REVIEW

Research indicates laterite can enhance concrete performance at moderate replacement levels. Ettu et al. (2013) got compressive strengths over 20 MPa with 30% laterite replacement, and this was good enough for normal structural work. Their tests on blended cement showed that laterite as part of the cement kept strength high for walls and non-load-bearing parts, and it met BS 8110 rules for M20 grade concrete. Olutoge et al. (2013) tested up to 40% laterite and got strengths from 15.3 MPa to 35.7 MPa, with 25% being the best balance. In their beam tests, 25% laterite gave almost the same load capacity as normal concrete, with only 5-10% less bending strength, so it works for low buildings in hot areas. But above 40%, the strength dropped because of clay and bad particle shape unless superplasticizer was added. The clay in laterite (10-20%) takes more water and makes weak spots, which increases holes and lowers density – this was seen under microscope in other tests. Workability goes down as more laterite is added because of its sharp edges, high water soak, and clay. The sharp shape causes more friction inside, and the absorption (15- 25%) locks up free water, so slump drops 20-50% compared to river sand. Falade et al. (2017) showed that superplasticizers improve workability and makes strength better, especially with small aggregates. Their tests with polycarboxylate superplasticizer (0.5-2% dose) gave 15- 30% more slump and 10-15% more strength at 28 days, mainly when laterite was under 10 mm, because it spread cement better and cut water-cement ratio from 0.55 to 0.45. Udoeyo et al. (2006) got 17% more strength at 10% replacement because of better packing and pozzolanic reaction. They tested sand replacement up to 100% and found that at 10-40% laterite, the fine particles filled gaps in the stone, making it denser and pushing strength to 20 N/mm² or higher, while iron oxides helped extra hardening. Adepegba (1975) reached 25-30 MPa at 20% laterite and recommended it for cheap houses. He tested soft laterite in 1:3:6 mixes with water-cement 0.65, and 20-50% replacement gave strength like normal concrete (25 N/mm² at 28 days), with stiffness staying at 18-20 GPa - perfect for villages with no sand. Raheem et al. (2012) said 20% is best, with big drops after 30% because of holes, and they suggested washing the clay out. In their 1:2:4 mix tests, washing cut clay by 40% and raised 28-day strength from 18 MPa to 28 MPa at 20% replacement, and recommended pre-treatment for site use Adekunle et al. (2018) found that 10-15% laterite with 1% superplasticizer raised slump by 120% and strength by 12-18%. They used the same method as in Nigerian Journal of Technology, testing 1:1.5:3 mixes with water-cement 0.5, and at 10% replacement, slump went from 50 mm to 110 mm while strength hit 32 MPa - this was because the superplasticizer spread the clay better. Ogunbiyi et al. (2019) saw better durability at 5-15% laterite with superplasticizer, but more shrinkage over 20%. Their tests on sulfate attack and carbonation showed 5-15% laterite cut water absorption by 5-10% and made concrete tougher in bad conditions, but drying shrinkage went over 0.05% at high levels, suggesting adding fibers to control it.

METHODOLOGY

Raw materials included laterite (locally sourced, air-dried, sieved), river sand (passing 4.75 mm), Ordinary Portland Cement, crushed granite, clean water, and Costamix 600 - a fourth-generation polycarboxylate ether (PCE) superplasticizer - at 1% dose for 100 kg of cement used for select mixes. The mix design was 1:1.5:3 with a water-cement ratio of 0.50.

Raw Materials

Laterite was sourced from Ayobo, Lagos, air-dried, crushed, and sieved to pass 4.75 mm. River sand (fine aggregate) was sourced locally from a reputable supplier in Lagos and passed through 4.75 mm sieve. Ordinary Portland Cement, crushed granite (maximum size 20 mm), and clean potable water were used. Costamix 600, a fourth-generation PCE superplasticizer, was added at 1% dose for 100 kg of cement used (i.e., 1 kg per 100 kg cement) in half of the mixes to improve workability and strength development.

Mix Ratio

Laterite replaced fine aggregate at 0%, 5%, 10%, and 15% by weight. Half the mixes included 1% Costamix 600 (1 kg per 100 kg cement). Mixing occurred in a concrete mixer, producing 150mm cubes and 150mm × 300mm cylinders, compacted in molds. A total of 8 mix combinations were prepared. For each mix, 18 cubes and 18 cylinders were cast - 3 specimens per test at 6 curing ages (3, 7, 10, 14, 28, 42 days) - resulting in 144 cubes and 144 cylinders in total. Batching was done by weight, and mixing sequence was: dry materials (cement + fine aggregate + laterite + coarse aggregate) for 2 minutes, followed by water and Costamix 600 (where applicable, pre- diluted in mixing water) for 3 minutes, to ensure full dispersion and uniform consistency.

Specimens were demoulded after 24 hours and cured in water tanks at room temperature (27 ± 2°C) for 3, 7, 10, 14, 28, and 42 days. The curing tanks were covered to prevent evaporation, and water was maintained at a depth sufficient to fully submerge all specimens.

Testing of Concrete

Workability was assessed via slump tests (BS EN 12350-2). The slump cone was filled in three equal layers; each compacted with 25 strokes of a 16 mm diameter tamping rod. The slump was measured immediately after lifting the cone. Compressive strength was measured on 150mm cubes using a Universal Testing Machine (BS EN 12390-3) at a constant loading rate until failure. Split tensile strength was determined on 150mm × 300mm cylinders using the same machine (BS EN 12390-6). All tests were conducted in triplicate, and average values were reported.

RESULT AND DISCUSSION

Workability (Slump Test)

Workability of the fresh concrete was determined immediately after mixing using the slump test (BS EN 12350-2). Results are presented in Table 4.1 and Figure 4.1.

NS = No Superplasticizer, SP = With Superplasticizer

Table 4.1: Slump Values for All Mixes

S/N	Mix Designation	Laterite Replacement (%)	Superplasticizer	Slump (mm)
1	Control - NS	0	No	35
2	L5-NS	5	No	55
3	L10-NS	10	No	40
4	L15-NS	15	No	40
5	Control - SP	0	Yes	130
6	L5-SP	5	Yes	115
7	L10-SP	10	Yes	110
8	L15-SP	15	Yes	95

Figure 4.1 shows the slump test results. When no superplasticizer was used, the control mix gave a slump of 35 mm. The mix with 5% laterite reached 55 mm, which is 57.14% more than the control. At 10% and 15% laterite replacement, the slump was 40 mm, a 14.29% increase over the control. This means that 5% laterite makes the concrete flow much better, while 10% and 15% still give a small improvement in workability. When 1% superplasticizer was added, the slump values went up a lot. The control mix with superplasticizer gave 130 mm, which is 271.43% more than the control without superplasticizer. The 5% laterite mix with superplasticizer recorded 115 mm, a 109.09% increase over the same mix without superplasticizer. The 10% laterite mix with superplasticizer reached 110 mm, a 175.00% increase from the mix without superplasticizer. The 15% laterite mix with superplasticizer gave 95 mm, a 137.50% increase over the mix without superplasticizer. All the mixes with superplasticizer had slump above 95 mm, which is good for pumping concrete and placing it in tight spaces with reinforcement.

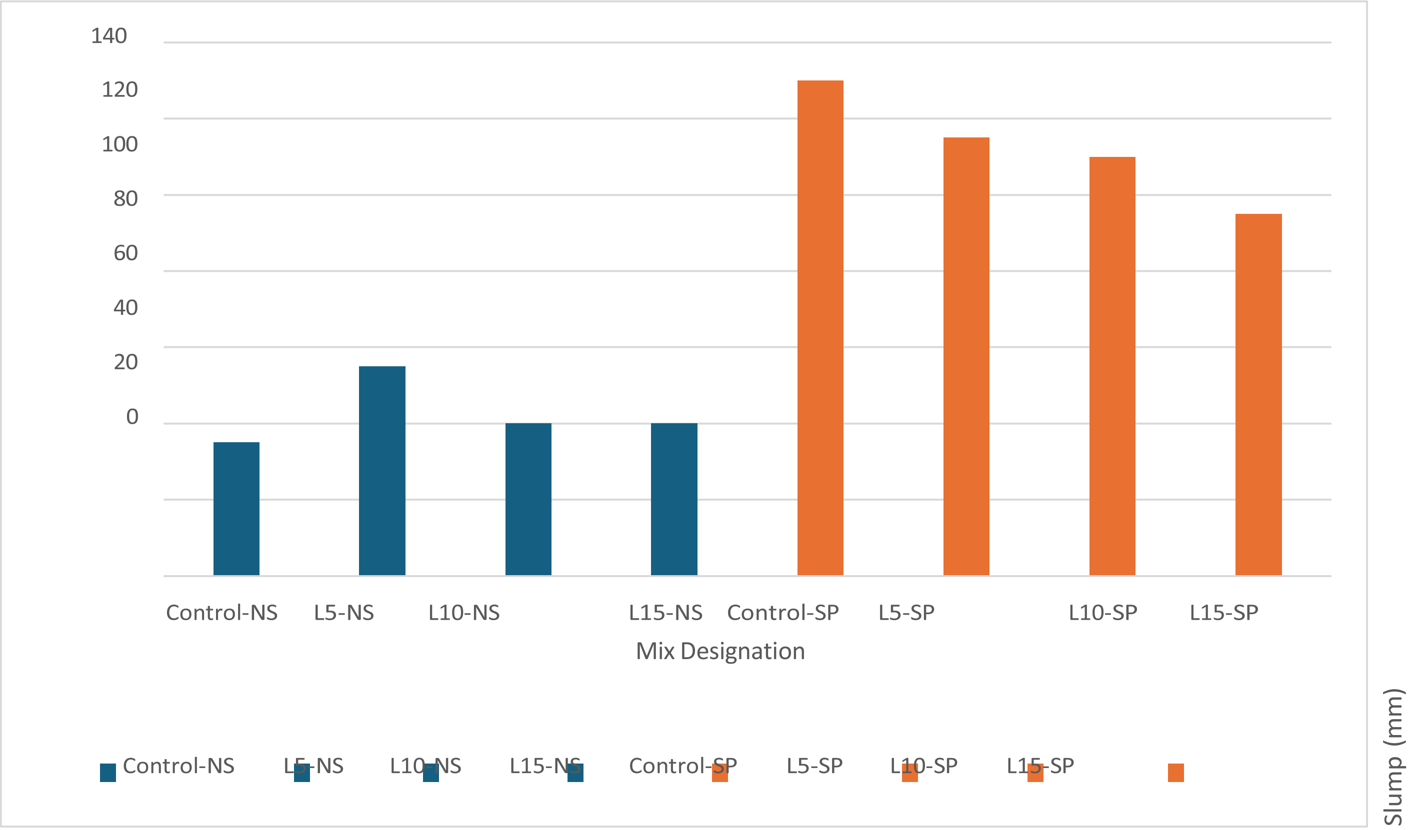

Figure 4.1: Effect of Laterite and Superplasticizer on Slump

Compressive Strength Development

The average values from triplicate specimens are reported in Table 4.2.

Table 4.2: Summary of Average Compressive Strength Results (for graphical analysis)

S/N	**Age (days)**	**Control- NS (N/mm^2)**	**L5%-NS (N/mm^2)**	**L10%- NS (N/mm^2)**	**L15%- NS (N/mm^2)**	**Control- SP (N/mm^2)**	**L5%-SP (N/mm^2)**	**L10%- SP (N/mm^2)**	**L15%- SP (N/mm^2)**
1	**3**	17.11	15.87	14.70	13.81	23.46	21.93	21.11	19.49
2	**7**	23.29	22.02	22.78	20.38	29.64	28.53	25.22	23.00
3	**10**	24.09	23.46	22.76	22.96	32.44	31.27	26.14	24.57
4	**14**	24.74	24.33	22.74	24.50	34.88	23.70	27.96	22.16
5	**28**	29.26	27.92	31.19	28.09	40.26	42.27	30.60	29.88
6	**42**	31.18	29.60	30.24	28.50	43.59	40.85	34.56	32.37

Table 4.2 and Figure 4.2, Concrete without superplasticizer, the control mix achieved 29.26 MPa. The 5% laterite mix reached 27.92 MPa, a 4.58% decrease from the control. The 10% laterite mix delivered 31.19 MPa, a 6.60% increase over the control - the highest in this group. The 15% laterite mix recorded 28.09 MPa, a 4.00% decrease from the control. With superplasticizer, the control mix achieved 40.26 MPa. The 5% laterite mix recorded the highest strength at 42.27 MPa, a 5.00% increase over the superplasticized control. The 10% laterite mix reached 30.60 MPa, a 23.99% decrease from the superplasticized control. The 15% laterite mix gave 29.88 MPa, a 25.76% decrease from the superplasticized control.

The results from the cube tests showed that when no superplasticizer was used, the mix with 10% laterite gave the highest compressive strength of 31.19 MPa because the particles packed better and filled the small gaps. At 5% and 15% laterite without superplasticizer, the strength was a little lower than the control mix, and this was probably because the clay in the laterite needed more water. When superplasticizer was added, the mix with 5% laterite gave the highest strength of 42.27 MPa, and this happened because the low amount of laterite helped the cement spread out better and lowered the water-cement ratio, making the concrete denser inside. At 10% and

15% laterite with superplasticizer, the strength dropped a lot, which means the clay and water absorption from the laterite took over and made the mix weaker.

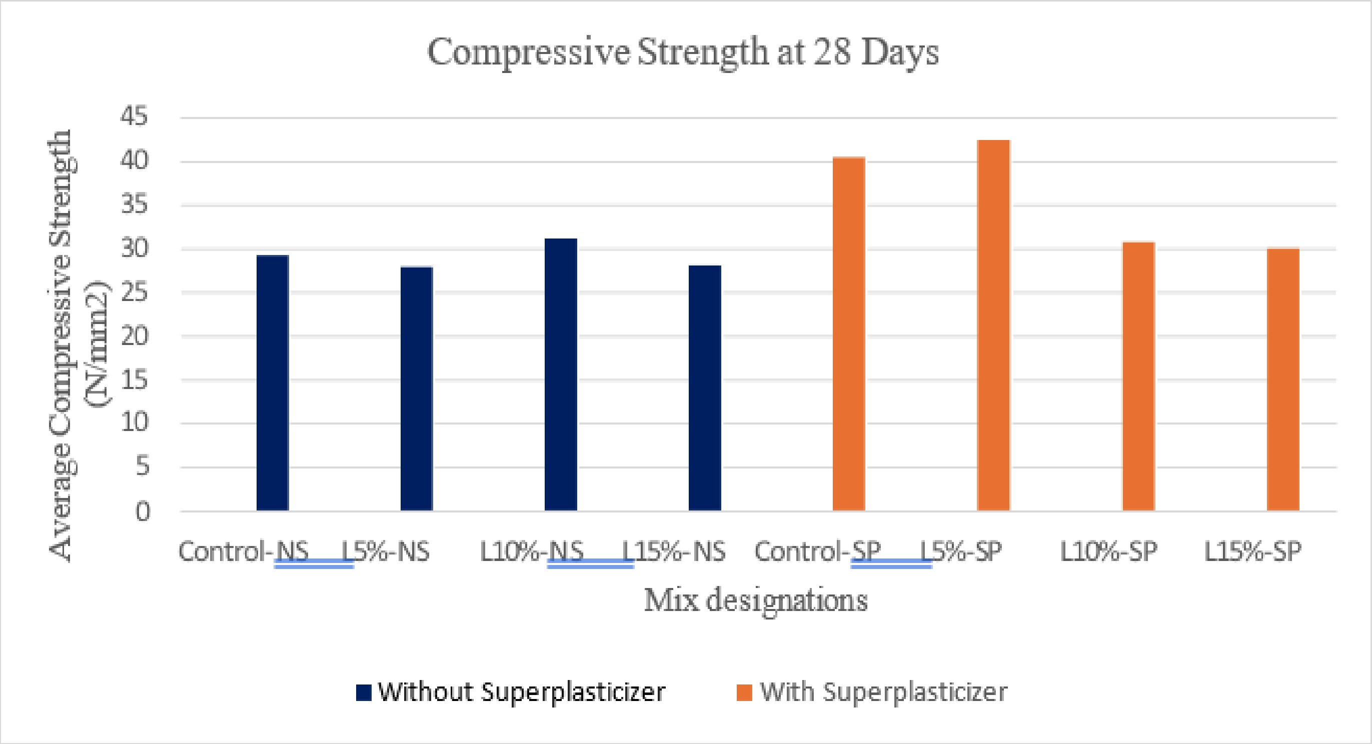

Figure 4.2: Compressive strength at 28 days

Split Tensile Strength

The Split tensile strength at 28 days was tested on 150 mm × 300 mm cylinders, with average values from triplicate specimens reported in Table 4.3.

Table 4.3: Summary of Average Split Tensile Strength (for graphical analysis)

S/N	Age (days)	Control-NS	L5%-NS	L10%-NS	L15%- NS	Control- SP	L5%-SP	L10%- SP	L15%- SP
1	**3**	1.42	1.41	1.43	1.16	2.01	1.74	1.56	1.37
2	**7**	2.09	2.07	2.07	2.07	2.16	1.86	1.94	1.41
3	**10**	2.13	2.22	2.24	2.12	2.29	2.29	2.13	1.68
4	**14**	2.19	2.40	1.88	2.28	2.33	2.95	2.35	2.14
5	**28**	2.29	2.25	2.28	2.41	2.96	3.01	2.47	2.45
6	**42**	2.59	2.53	2.29	2.23	3.21	3.08	2.67	2.17

Table 4.3 and Figure. 4.3, Concrete without superplasticizer, the control mix achieved 2.29 MPa. The 5% laterite mix reached 2.25 MPa, a 1.75% decrease from the control. The 10% laterite mix recorded 2.28 MPa, a 0.44% decrease. The 15% laterite mix gave 2.41 MPa, a 5.24% increase over the control - the highest in this group. With superplasticizer, the control mix achieved 2.96 MPa. The 5% laterite mix recorded 3.01 MPa, a 1.69% increase over the non-superplasticized control and a 1.69% increase over the superplasticized control. The 10% laterite mix reached 2.47 MPa, a 7.83% decrease from the superplasticized control. The 15% laterite mix gave 2.45 MPa, a 17.23% decrease from the superplasticized control. The results reveal that without superplasticizer, 15% laterite replacement yields the highest split tensile strength at 2.41 MPa, a 5.24% increase over the control, possibly due to enhanced bonding at higher clay content. At 5% and 10%, tensile strength is slightly below the control. With superplasticizer, 5% laterite achieves the peak tensile strength of 3.01 MPa, matching the 1.69% gain seen in compressive strength trends. This show that the mix with 5% laterite and superplasticizer gives the best bond between paste and aggregate, which helps both the compressive strength and the split tensile strength.

When more laterite is added with superplasticizer, the split tensile strength drops a lot, and this means the bond between the paste and aggregate is not as good.

Figure 4.3: Split Tensile Strength at 28 days

CONCLUSION AND RECOMMENDATION

The results from this study show that laterite can partially replace fine aggregate in concrete, and the best performance comes at certain replacement levels depending on whether superplasticizer is added to the mix.

The 28 days results indicate that, mix with 10% laterite and no superplasticizer gave the highest compressive strength of 31.19 MPa, which is 6.60% more than the control mix that had 29.26 MPa. At the same age, the mix with 15% laterite and no superplasticizer recorded the highest split tensile strength of 2.41 MPa, a 5.24% increase over the control value of 2.29 MPa.

Sump for both mixes stayed at 40 mm, which is good enough for normal construction work.

1% superplasticizer, with **5% laterite** consistently produced better results for all mixes, as stated

- 42.27 MPa compressive strength - a 5.00% increase over the superplasticized control (40.26 MPa)
- 3.01 MPa split tensile strength - a 1.69% increase over both controls
- 115 mm slump - highly pumpable and suitable for congested reinforcement

This optimal mix exceeds 40 MPa, qualifies as high-strength concrete, and meets structural requirements for beams, columns, and slabs.

The tests showed that laterite works well up to 10% replacement when no superplasticizer is used - this gives the highest compressive strength. At 15% laterit without superplasticizer, the split tensile strength reaches its highest value. When superplasticizer is added, 5% laterite gives the best overall result with good compressive strength and workability.

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