Sustainable High-Performance Concrete: Exploring Laterite Soil As An Eco-Friendly Fine Aggregate Replacement

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ABSTRACT

Concrete is the most widely used composite material today. The constituents of concrete are coarse aggregate, fine aggregate, binding material, and water. A rapid increase in construction activities leads to an acute shortage of conventional construction materials. Conventionally, sand is being used as fine aggregate in concrete. The function of the fine aggregate is to assist in producing workability ad uniformity in the mixture. The river deposits are the most common source of fine aggregate. So there are great demands within the construction industries for river sand as fine aggregate used in the production of concrete. This has created a very difficult situation, also there is great fear from environmentalist and the ecology will be distorted. Hence, the need to find the materials which are affordable and available partially or totally replaced river sand in the production of concrete. Hence we are forced to think the alternative materials. This report aims to present the study done to establish scientific data regarding the compressive strength and tensile strength of concrete on partial replacement of fine aggregate with laterite soil in concrete mix of High Performance Concrete M100 grade. The sand shall be replaced gradually in the mentioned grade of concrete by 0%, 10%, 20%, 30%, 40% and 50% with laterite soil and the specimen shall be tested at curing intervals of 3days, 7days, and 28days. For compressive strength and at curing interval of 3days, 7days, and 28days for tensile strength for 28 days.

Keyword: Fine aggregate replacement, Concrete durability, Tensile strength, Environmental impact.

1. INTRODUCTION

The construction industry plays a pivotal role in global infrastructure development, with concrete being the most extensively used building material. However, the increasing demand for concrete, particularly in developing countries like India, has led to an acute shortage of conventional construction materials, particularly fine aggregate. Natural river sand, the primary source of fine aggregate, is rapidly depleting due to excessive extraction, resulting in environmental degradation, ecosystem imbalance, and escalating material costs. This crisis necessitates the exploration of sustainable and locally available alternatives that can ensure both economic feasibility and structural integrity.

Laterite soil, a naturally occurring material rich in iron and aluminum oxides, emerges as a promising alternative. Found abundantly in the Malabar region of Kerala and covering a significant portion of India, laterite has historically been used in various forms of construction, including masonry, road base layers, and foundation filling. However, its potential as a fine aggregate replacement in high-performance concrete (HPC) remains underexplored. Given its similar particle size distribution to river sand and its inherent physicochemical properties, laterite fines (<10mm particle size) offer a viable and sustainable solution for mitigating the sand shortage crisis.

This study investigates the feasibility of utilizing laterite fines as a partial replacement for fine aggregate in M100-grade HPC. The research aims to evaluate the compressive and tensile strength characteristics of concrete with varying proportions of laterite (0%, 10%, 20%, 30%, 40%, and 50%) as a fine aggregate substitute. The strength properties are assessed at curing intervals of 3, 7, and 28 days to determine the long-term performance and viability of laterite-incorporated HPC.

By integrating laterite fines into concrete production, this research contributes to the advancement of sustainable construction practices, promoting resource efficiency and reducing environmental impact. The study aligns with the global movement towards eco-friendly construction materials, ensuring a balance between infrastructural growth and environmental conservation.

2. LITERATURE SURVEY

Prasad and Parthasarath, (2018), studied the formation of laterite. The origin of laterite was connected with the physical and climatic of a particular region. Tzu hsing Ko (2014) studied the nature and properties of laterite soil derived from different sources in Taiwan. The study revealed that parent material plays an important role during soil weathering. The physical, chemical and mineralogy compositions affect the soil formation. The most difference among all laterite soil is their content of iron oxide and the soil age of formation.

Aginam et al. (2014) investigated the geotechnical properties of laterite from Nigeria. The higher the fines, the permeability increases for different samples from different locations and based on the physical properties suitable for sub grade and sub base but should not be used as base material in road construction. Chandran P et al. (2005), investigated the mineralogy, genesis of laterite soils in Kerala. The classification of soils depends upon the variability of organic matter, the clay content and particle size.

Nieuwenhuyse et al. (2000) in their study on the origin of laterite in Costa Rica observed that the degree of weathering and difference in clay mineralogy depends upon time. Umarany Mahalinga Iyer and David Williams (1991) studied engineering properties of laterite soil in Australia and found that properties depend on the local climate, vegetation and topography of the area.

Okagbue (1986) investigated the properties of laterite in Nigeria reveals that effects of parent rock are of secondary importance on the physical and mechanical nature of laterite gravels.

Deepa Joshi and Jain (2015) investigated the compressive behavior of unreinforced clay brick masonry. The experimental results of bricks, mortar and brick masonry prisms presented with a brief description of the testing procedure. The basic compressive stress of unreinforced masonry prisms determined experimentally has been compared with the basic compressive stress of the same obtained by using IS 1905-1987. The failure mechanism of prisms under uniaxial compressive load has been discussed.

Praveen Kumar and Radakrishna (2015) investigated the impact of replacement of natural and by manufactured sand in cement mortar 1:6 with various replacement levels. The study revealed the workability of the cement mortar increased with the increase in manufactured sand content and strength slightly increased with the increase with manufactured sand.

Asiedu Emmanuel and Agbenyega Allan (2014) investigated concrete bricks with a mix ratio of 1:6 and with water cement ratio of 0.50 with replacing sand by 0% (control specimens), 10%, 20%, 30%, 40% and 50% laterite fines and compared with those of conventional sandcrete bricks (control specimens). Laterite fines used satisfactorily replaced the sand up to 30% for the production of structural masonry units.

Harish Kizhakkumodom and Venkatanarayanan (2014) studied the effect of durability using supplementary cementing material as low carbon rice husk ash in cement mortar to evaluate the sulphate resistance in cement mortars. It was found that the sulphate resistance decreased with the increase in the rice husk ash dosage in the mortars at any given water-cement ratio.

Tasnia Hoque et al. (2013), studied the replacement of stone dust and found that mortar contain 25% of replacement by stone dust showed the higher strength. Tamara Kaaki (2013) studied the strength and behavior of masonry prisms with minimum height to thickness ratio requirement under compressive loading.

Venkatarama Reddy (2012) investigated the properties of brick masonry with table moulded bricks and wire cut bricks from India with different proportions of mortars. The elastic modulus and strength of brick masonry under compression are evaluated for strong brick -soft mortar and soft brick-strong mortar combinations. The failure mechanisms, size effect and bonding arrangements were studied.

Shyam Prakash and Haanumantha Rao (2016) studied the compressive strength of quarry dust in concrete showed up to 40% replacement of sand by quarry dust showed higher strength compared to normal M30 grade concrete.

Khairunisa Muthusamy et al.(2015) investigated the durability of laterite concrete with laterite in Malaysia, found that the concrete with upto 20% replacement of fine aggregate by laterite exhibits good durability against chloride ion penetration ,acid attack and water absorption

Olubisi (2013) carried out a study on the performance of concrete with laterite as fine aggregate under harsh environmental condition in Nigeria. The mix ratio used for this study was 1:2:4 with normal curing of 28 days. The compressive strength decreased with laterite replacement level when subjected to alternate wetting and drying and increased when subjected to alternate magnesium sulphate ($Mg2SO4$).

Olutage et al. (2013) observed that performance of laterised concrete gave satisfactory compared with ordinary concrete provided the laterite content is less than 25 percent.

Joseph Ukpata et al. (2012) investigated concrete characteristic using various combinations of lateritic sand and quarry dust as replacement of river sand. The result showed that concrete can be used for structural purpose provided the laterite content is below 50%.

Muthusamy and Kamaruzaman (2012) studied the Malaysian laterite as fine aggregate by replacing natural sand showed the 10% replacement produced the concrete with comparable results that of normal concrete

Ukpata and Epharaim (2012) compared with the flexural property of laterite with quarry dust in concrete with normal concrete showed the comparable result provided the laterite content does not exceed 50 percent.

Omotola Alawode and Idowu (2011) studied the compressive strength and workability of concrete and laterite mix concluded that the laterite concrete was not workable compared to normal concrete and not recommended for concrete .

Felix Udoeyo et al. (2010) studied the effect of the specimen geometry of concrete with the laterite on compressive and spilt tensile strength showed significant influence in the geometry of concrete.

Osadebe and Nwakonobi (2007) studied the structural characteristics of concrete with laterite at optimum mix proportion. Based on the result, the Modulus of elasticity, Modulus of rigidity, flexural strength, Poisson's ratio are higher at optimum mix proportion.

Ata and Adesanya (2007), based on the stress on cubes of size 150x150x150mm with mix ratios of (1:1½:3), (1:2:4) and (1:3:6), the elastic modulus and modulus of deformability decreases with the increases in the level of applied stress.

Udoeyo, Felix et al. (2006), studied the concrete with laterite as partial or full replacement of natural sand in the state of Nigeria. Natural sand in a concrete mix ratio 1:2:4 with water cement ratio of 0.56 was replaced with 0%, 20%, 40%, 60%, 80%, and 100% laterite. The results showed that 20 % replacement of laterite showed 98 % of the strength of that of controlled concrete. The results pointed out that up to 40 % replacement level of sand by laterite attained the desired strength of 20 N/mm2 , which indicated the possibility of using laterite as partial replacement for sand up to this level.

Osunade (2002) proved that the shear and tensile strengths increase in concrete with laterite increased as with curing age and grain size increases. Shear and tensile strengths were obtained as higher values for rectangular specimens than those obtained for cylinders.

Neville (1995) based on the investigation, pointed out that laterite rarely produce concrete stronger than 10 MPa.

Osunade and Babaloa (1991), in their study, established that the size of reinforcement and mix ratio have a significant effect on the anchorage bond stress of concrete with laterite. The cement content is richer in the mix ratio and the anchorage bond stress is higher of concrete with laterite.

Balogun and Adepegba (1982), reported based on the investigation that the most suitable mix of concrete with laterite of 0.65 as water cement ratio for structural purposes is (1:1½:3), provided the maximum 50 percent of laterite content with strength decreased with increase in laterite content and 50% laterite content shows the strength is above the desired strength.

Adepgaba (1975) first studied on concrete with the replacement of fine aggregate with laterite. The strength properties of controlled concrete compared with those of concrete with laterite and concluded that concrete with laterite can be used for structural purpose.

3. PROPOSED SYSTEM

The proposed system aims to explore the feasibility of using laterite soil as a partial replacement for fine aggregate in High-Performance Concrete (HPC) of M100 grade. The system is designed to address environmental concerns and resource depletion by evaluating the strength properties of laterite-incorporated concrete. The methodology involves experimental testing at different curing intervals to assess its viability in sustainable construction.

1. **Material Selection and Characterization:**
    - Identify and source high-quality laterite soil with fine particles (<10mm).
    - Analyze its physical and chemical properties to ensure suitability as a fine aggregate substitute.
2. **Concrete Mix Design:**
    - Develop an optimized M100 HPC mix with varying percentages of laterite soil (0%, 10%, 20%, 30%, 40%, and 50%).
    - Maintain consistency in water-cement ratios and binder compositions.
3. **Sample Preparation and Curing:**

- Prepare concrete specimens for each laterite replacement percentage.
- Cure samples at intervals of 3 days, 7 days, and 28 days.

4. **Mechanical Testing and Analysis:**
    - Conduct compressive strength tests at different curing intervals.
    - Perform tensile strength tests after 28 days of curing.
    - Compare results with conventional concrete to determine the impact of laterite substitution.
5. **Data Analysis and Validation:**
    - Analyze results to determine trends in strength properties.
    - Validate findings by comparing with existing literature on alternative fine aggregates.
6. **Environmental and Economic Feasibility:**
    - Assess the ecological benefits of reducing dependency on river sand.
    - Evaluate cost-effectiveness and availability of laterite as a large-scale alternative.

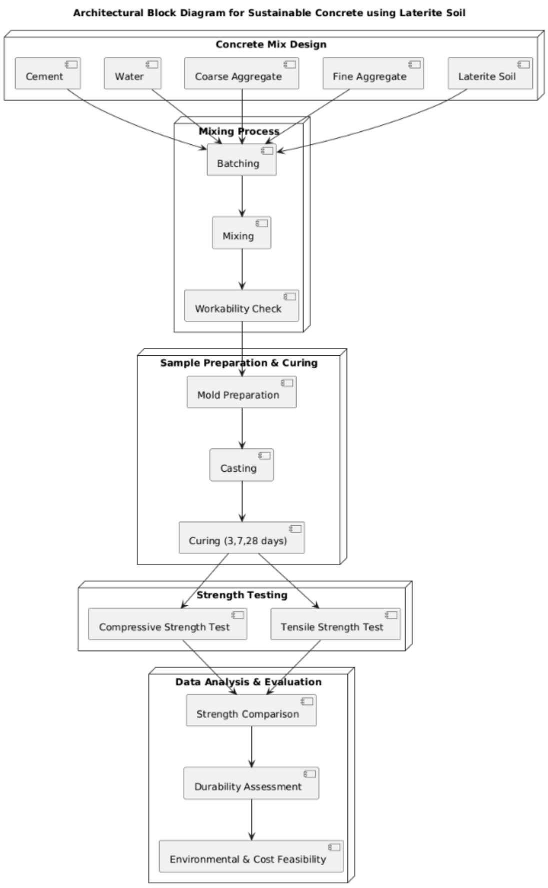

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

As per experimental programme results for different experiments were obtained. They are shown in table format and graph format, which is to be presented in this chapter.

4.1 Fresh properties of concrete (Workability Test)

4.1.1 Slump Test

The Slump test was performed on the laterite based concrete to check the workability of it at different replacements viz. 0 %, 10%, 20%, 30%, 40%, 50%, the following results were obtained, according to which it can be concluded that with the increase in % laterite from M1 to M6, workability increases. The results obtained for Slump test are shown below in Table 5.1.

Table 4.1: Results of Slump test

Mix No	Laterite (%)	Slump (mm)
M1	0	100
M2	10	103
M3	20	104
M4	30	107
M5	40	110
M6	50	115

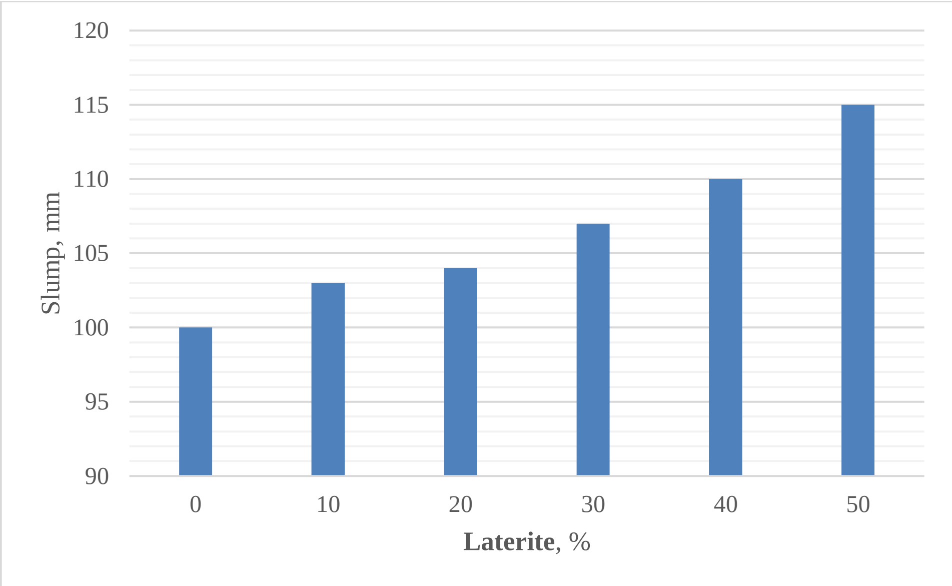

Fig 4.1 : Slump test results

The above figure 4.1 shows the slump results. It was observed that, the slumps increased from M1 to M6 mix with increased Laterite in the mix. It was varied from Medium Workability to High workability.

4.2 Harden properties of concrete

4.2.1 Compressive Strength Test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the compressive strength of Laterite based concrete and the results obtained are given in Table 4.2.

Table 4.2: Results of compressive strength test

Mix No	Laterite (%)	Compressive strength of cubes (N/mm^2)		
		7 days	14 days	28 days

M1	0	59	90	99
M2	10	64	97	107
M3	20	67	101	112
M4	30	65	98	108
M5	40	62	94	104
M6	50	61	92	102

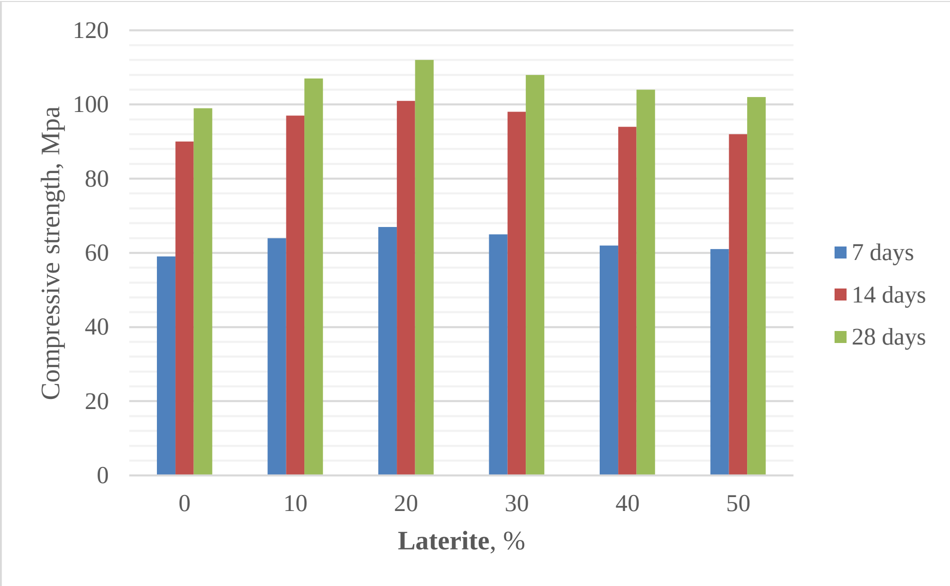

Fig 4.2: 7days Compressive strength test result graph

From the above results it was observed that with the increase in percentage of Laterite from M2 to M6 in concrete the compressive strength more than control mix M1. The highest compressive strength gained for 20% Laterite replacing with fine aggregate in the preparation of concrete. The optimum dosage suggested from this study was 20% Laterite as sand replacement.

4.2.2 Tensile Strength Test

The Tensile test was performed on the beams of size 300mm height x 150 diameter mm to check the Tensile strength of the concrete and the results obtained while performing the Tensile test on CTM are given in Table 4.3.

Table 4.3: Result of Tensile strength

Mix No	Laterite (%)	Tensile Strength for 28 days (N/mm^2)
M1	0	9.3
M2	10	9.72
M3	20	10
M4	30	9.8
M5	40	9.5
M6	50	9.43

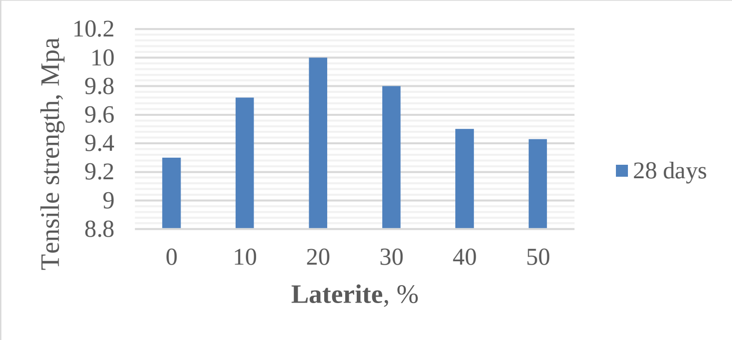

Fig 4.5: Tensile strength graph

From the above results it was observed that with the increase in percentage of Laterite from M2 to M6 in concrete the tensile strength more than the control mix M1. The highest tensile strength gained for 20% Laterite replacing with sand in the preparation of concrete. The optimum dosage suggested from this study was 20% Laterite as fine aggregate replacement.

4.3 Discussions

The workability was increasing with increasing Laterite replacement in the sand. The compressive and tensile strengths for Laterite replacement in the sand, was more than control mix. The maximum or highest strength was gained for 20% Laterite replacing with sand.

5. CONCLUSIONS

The experimental investigation on the partial replacement of fine aggregate with laterite soil in High-Performance Concrete (M100 grade) demonstrates its potential as a viable and sustainable alternative to conventional river sand. The study highlights key findings that reinforce the suitability of laterite as a fine aggregate substitute while maintaining the structural integrity of concrete.

The results indicate that laterite soil, due to its favorable mineral composition and absence of deleterious materials, can effectively replace natural sand without compromising performance. Notably, an optimal replacement level of 20% laterite yields the highest compressive and tensile strength gains, with an improvement of 13.13% and 7.52%, respectively, compared to conventional concrete. Furthermore, the enhanced workability observed with increasing laterite content suggests its potential benefits in improving concrete mix consistency and ease of placement.

The research contributes to sustainable construction practices by addressing the critical issue of sand depletion and promoting the use of locally available materials. The findings emphasize that laterite-based concrete not only enhances performance but also presents an economically feasible and environmentally responsible solution for modern infrastructure. Future studies can further explore the durability, long-term behavior, and real-world applications of laterite-incorporated concrete, ensuring its adoption in large-scale construction projects.

By integrating laterite soil into concrete production, this study aligns with global efforts to reduce environmental impact, conserve natural resources, and promote green building solutions, paving the way for a more sustainable and resilient built environment.

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