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Enhancement Of Concrete Strength Through Integration Of Weathered Soil And Industrial Byproducts

Chethan Kumar N T[1], K E Prakash[2], B R Shilpa[3], Bhavya S[4]

[1]Research Scholar, Department of Civil Engineering, Shree Devi Institute of Technology,
Mangalore–575 003, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.
[2]Professor, Department of Civil Engineering, Shree Devi Institute of Technology,
Mangalore – 575 003, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.
[3]Assistant Professor, Department of Civil Engineering, R R Institute of Technology,
Bangalore - 560 090, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.
[4]Assistant Professor, Department of Civil Engineering, SJC Institute of Technology,
Chickballapur – 562 101, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.

Abstract

Rigid pavements are increasingly being adopted across India, including for the development of rural road infrastructure. In this study, an effort has been made to utilize weather soil (laterite waste) and fly ash as alternative materials in rigid pavement construction, specifically as partial replacements for conventional coarse aggregates and cementitious components, respectively. The laterite waste was used as a substitute for coarse aggregate, while fly ash functioned as a supplementary cementitious material [1]. The replacement levels ranged from 0% to 30%, incrementally adjusted to study their effects on the mechanical performance of the concrete.

Comprehensive lab tests were conducted on all mix designs to evaluate their strength properties. The results indicated that up to 20% replacement of natural coarse aggregate with laterite waste, in combination with appropriate proportions of fly ash, did not adversely affect the strength parameters of the concrete. In fact, the mixes maintained satisfactory strength levels in accordance with the requirements for rigid pavement applications. Beyond 20% replacement, a gradual decline in compressive strength was observed, highlighting the optimal limit for sustainable replacement without compromising structural integrity.

These findings suggest that judicious use of laterite waste and fly ash can contribute significantly to sustainable constructions by reducing the use of virgin materials, lowering construction costs, and minimizing environmental impact.

Keywords: Weathered soil (Laterite), Fly ash

1. Introduction

Rigid pavement construction has witnessed a significant surge in recent years, particularly in urban infrastructure where it is preferred due to its high load-bearing capacity and long-term durability. Designed to withstand heavy wheel loads, rigid pavements offer a sustainable solution for urban roads. This trend has now extended to rural areas as well, where rigid pavements are increasingly being adopted to accommodate growing vehicular demands and ensure all-weather connectivity.

Rigid pavements, or concrete pavements, typically consist of 60% to 70% aggregates by volume. This creates a substantial demand for natural materials such as river sand and crushed stone. Unfortunately, the availability of these natural resources is rapidly declining. The extraction and transportation of river sand and aggregates are becoming increasingly uneconomical and environmentally damaging. Furthermore, river sand availability is unpredictable due to regulatory restrictions and ecological concerns, posing additional challenges for large-scale concrete production.

In light of these limitations, there is a need to explore sustainable alternatives for natural aggregates in concrete production. Although rigid pavements offer enhanced durability, the environmental impact of sourcing conventional materials makes their widespread use less viable. This has led to a growing interest in utilizing alternate materials that are abundant and often considered waste in the surrounding environment.

Several waste materials have demonstrated promising potential as partial replacements for fine or coarse aggregates in concrete. These include demolition waste, fly ash, rice husk ash, sawdust, marble dust,

coal dust, and glass powder. Among these, fly ash—a byproduct of coal combustion—stands out as a supplementary cementitious material with proven pozzolanic properties, capable of enhancing the performance and sustainability of concrete mixes [1]. Incorporating such industrial and agricultural waste materials into rigid pavement construction not only reduces dependence on natural resources but also addresses the issue of waste disposal, thereby contributing to a circular economy and environmentally responsible construction practices.
Partial replacement of conventional materials is widely accepted when supported by appropriate mix design parameters. Previous studies have concluded that up to 10% of laterite waste can be effectively used as a replacement for coarse aggregate, yielding favorable results [3]. Further research has demonstrated that ground granulated blast furnace slag (GGBS) in the range of 15% to 30%, and fly ash between 10% to 15%, can be effectively utilized as supplementary cementitious or pozzolanic materials in concrete mixtures [4]. In addition to material optimization, it is important to note that the production of ordinary Portland cement contributes significantly to environmental degradation, including carbon emissions and resource depletion. This underlines the necessity of identifying and utilizing alternative materials with lower environmental impact.

2. Materials

Aggregates

Aggregates, both coarse and fine, are essential constituents in concrete and play a critical role in determining its strength, durability, and overall performance. Typically, coarse aggregates are derived from crushed stone obtained from stone quarries and are required to meet specific gradation and quality standards to ensure proper interlocking and load distribution in the hardened concrete. In this study, coarse aggregates were sourced from a nearby stone quarry and subjected to a series of standard laboratory tests to evaluate their physical properties. These tests included specific gravity, water absorption, impact value, and crushing strength. The results confirmed that the aggregates conformed to the requirements specified in code. [8] The gradation of the aggregates was within permissible limits, making them suitable for use in rigid pavement applications.
Fine aggregates, commonly referred to as sand, were obtained from a natural riverbed. For use in concrete, fine aggregates are free from impurities such as silt, clay, organic matter, and other deleterious substances, as these can adversely affect the bond strength and durability of the concrete. In this research, the river sand was tested for key physical properties including fineness modulus, specific gravity, silt content, and bulk density. These properties were evaluated following the standard procedures outlined in IS: 2386 (Part I & III).
The test results indicated that the fine aggregate was well-graded and free from any significant contamination, thus confirming its suitability for use in the concrete mixes developed for rigid pavement construction. By ensuring the quality and compatibility of both coarse and fine aggregates, the study established a strong foundation for reliable concrete mix design incorporating alternative materials like fly ash and laterite waste.

Cement

In this study, Ordinary Portland Cement (OPC) of 53 grade was used as the primary binding material for the preparation of concrete mixes. The selection of 53-grade cement was based on its high early strength characteristics, which are particularly beneficial in rigid pavement applications where early load-bearing capacity is often desirable. The cement used conformed to the specifications of IS: 12269-2013, which outlines the requirements for 53-grade OPC in terms of chemical composition, physical properties, and performance criteria.
A series of standard laboratory tests were conducted to evaluate the physical properties of the cement. The specific gravity of the cement was determined to be 3.16, indicating its suitability for use in concrete mix design calculations, particularly for determining the mix proportions and unit weight of the mix.
The standard consistency of the cement was found to be 31%, as determined using the Vicat apparatus in accordance with IS: 4031 (Part 4). This value represents the amount of water required to produce a cement paste of standard consistency, which is essential for assessing setting time and other related properties.
Further, the initial setting time of the cement was recorded at 60 minutes, while the final setting time was observed at 320 minutes. These values were obtained through standard procedures as per IS: 4031 (Part 5). The setting time results fall within the permissible limits specified in IS codes, confirming that the cement possesses adequate workability time during mixing, placing, and finishing, as well as sufficient early strength development for rigid pavement construction.

Weathered soil (Laterite)

Laterite is a naturally occurring material formed through the prolonged weathering of rocks and is abundantly available in the western part of Karnataka. It is a heterogeneous mixture comprising soil and rock fragments and typically contains high concentrations of iron and aluminum oxides. For the purpose of this research, laterite waste samples were collected from the Dakshina Kannada District of Karnataka.

According to literature, laterite is generally not suitable for agricultural applications due to its poor nutrient-holding capacity and high iron content. To render it fit for agricultural use, additional treatment or supplementation with organic material is required. Consequently, in regions such as western Karnataka, laterite is predominantly used for construction purposes rather than in farming.

Its common applications include the construction of walls, cladding works, and as a partial replacement for coarse aggregates in concrete. Several studies have demonstrated that laterite waste can be effectively incorporated into concrete mixes, with replacement levels ranging from 10% to 20%, without compromising structural performance [2]. In fact, some studies have even explored the use of laterite waste as a sole fine aggregate in structural concrete, yielding promising results.

Based on these findings and its local availability, this research work utilizes laterite waste as a partial replacement for coarse aggregates in concrete. The decision to use laterite waste not only aligns with sustainable construction practices but also addresses the issue of natural aggregate scarcity by repurposing a regionally abundant material [5].

Fly ash

Fly ash is an industrial byproduct primarily generated from the combustion of pulverized coal in thermal power plants. It is also produced in smaller quantities by certain paper manufacturing industries that utilize coal-fired boilers. Fly ash is composed mainly of fine, powdery particles that are carried away with flue gases and later collected using electrostatic precipitators or filter bags.

For the present study, fly ash was sourced from a paper mill located in Bhadravathi, Shimoga District, Karnataka. This specific type of fly ash, being a byproduct of the paper industry, was collected, tested, and assessed for its suitability as a partial replacement for cement in concrete mixes[7]. Fly ash is widely recognized for its pozzolanic properties, which allow it to react with calcium hydroxide in the presence of water to form additional cementitious compounds. This contributes to improved workability, reduced heat of hydration, and enhanced long-term strength and durability of concrete. It also plays a significant role in reducing the carbon footprint associated with Portland cement production.

The use of fly ash as a supplementary cementitious material is endorsed by several national and international standards[9]. Relevant literature [3] also supports its application in cementitious systems, especially in sustainable infrastructure projects.

In this research, fly ash was utilized as a partial replacement for cement, with the aim of enhancing the sustainability and economic efficiency of the concrete mix while maintaining or improving its performance. Its incorporation aligns with current green building practices and contributes to the effective utilization of industrial waste materials.

Water

The water used for concrete work should be potable, i.e., suitable for drinking. The workability and strength characteristics of concrete are significantly influenced by the quality of water used in the mixing process

Fig. 1. Natural aggregates, River sand, Laterite brick, Fly ash.

3. Proportioning of Materials

In this research work, laterite waste was utilized as a partial replacement for coarse aggregates to develop a more economical and sustainable concrete mix compared to conventional concrete. Specifically, replacement levels were selected based on a review of previous studies and preliminary trials. The primary objective was to assess the feasibility of incorporating laterite waste in structural concrete without compromising key mechanical properties.

For the concrete mix design, a target grade of M30 was chosen, which is commonly used in rigid pavement applications due to its adequate compressive strength and durability. A water-to-cement ratio (w/c) of 0.5 was maintained for all mixes to ensure a consistent basis for comparison. The density of concrete was assumed to be 2400 kg/m³, which is the standard value for conventional concrete and was used in mix proportion calculations. To evaluate the mechanical performance of the concrete, optimum percentages of supplementary materials such as fly ash and laterite waste were considered based on previous literature and standard guidelines. The concrete specimens were prepared by casting 150 mm × 150 mm × 150 mm cubes, following the procedures specified in IS: 516 – 1959 for strength testing of concrete. After casting, the concrete cubes were subjected to curing under controlled conditions to ensure proper hydration and strength development. The curing period was maintained as per standard requirements, typically for 28 days, to simulate field conditions and ensure uniformity across all test specimens.

As mentioned earlier, this research focuses on the utilization of industrial waste materials, such as fly ash (a pozzolanic cementitious additive) and laterite waste, in an effort to reduce reliance on natural resources while promoting environmentally friendly construction practices. The experimental results obtained from this study provide insights into the mechanical behavior and feasibility of using such materials in rigid pavement concrete.

4. Results

Compressive Strength

Table 1 represents mix proportions considered for test purpose and obtained compressive strength test results for 28 days of curing. Figure 2 represents the graphical representation of the compressive test results.

Table. 1 Mix proportions & Compressive strength test results

Mix Designation	Materials	Compressive strength, N/mm²
M1	Nominal mix	34.5
M2	Laterite Waste (10%)	32.8
M3	Laterite Waste (20%)	33.4
M4	Laterite Waste (30%)	33.1
M5	Fly Ash(10%)	34.2
M6	Fly Ash(20%)	33.8
M7	Fly Ash(30%)	33.5
M8	Laterite Waste (10%) + Fly Ash(10%)	33.8
M9	Laterite Waste (10%) + Fly Ash(20%)	34.1
M10	Laterite Waste (10%) + Fly Ash(30%)	33.6
M11	Laterite Waste (20%) + Fly Ash(10%)	35.1
M12	Laterite Waste (20%) + Fly Ash(20%)	35.6
M13	Laterite Waste (20%) + Fly Ash(30%)	35.4
M14	Laterite Waste (30%) + Fly Ash(10%)	34.2
M15	Laterite Waste (30%) + Fly Ash(20%)	34.8
M16	Laterite Waste (30%) + Fly Ash(30%)	34.4

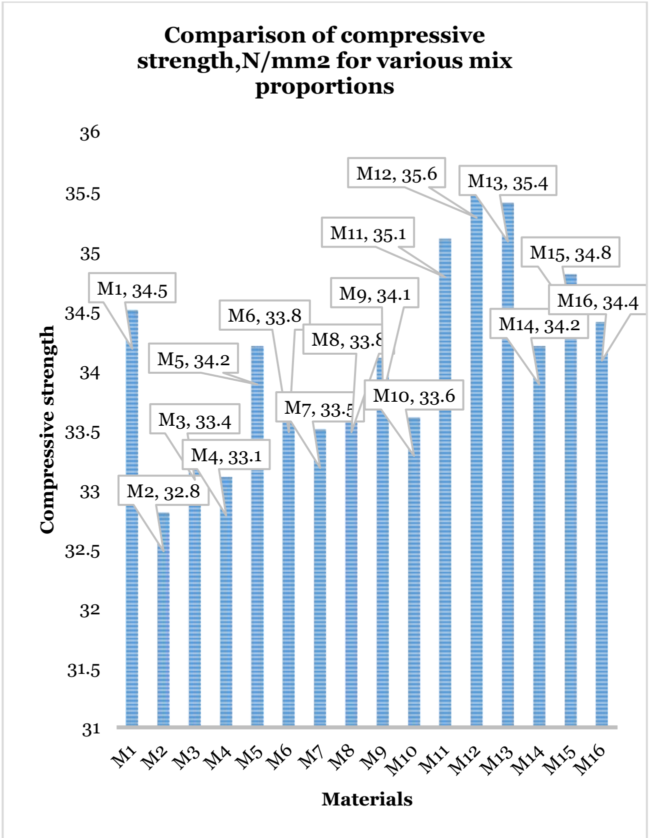

Fig. 2. Graphical representation of compressive strength of various mix proportions

Discussions on compressive strength test results

IS 456:2000 allows partial replacement of cement with fly ash (within 35%). Studies suggest fly ash improves long-term strength, and laterite can partially replace coarse aggregates up to 20–30% (as seen in works by Akinmusuru, 1991; Olugbenga et al., 2015). Pozzolanic materials like fly ash refine the pore structure and improve density, especially in mixes with marginal aggregates like laterite. 20% Laterite + 20% Fly Ash is validated as the optimum mix, exceeding nominal

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compressive strength by 3.19%. All other combinations maintain strength above ~32 MPa, meeting M30 criteria. Your use of locally available laterite and industrial byproduct fly ash is sustainable, economical, and technically sound. These results support further field application in rural rigid pavement construction.

Split tensile strength

The Split Tensile Strength Test measures the indirect tensile strength of concrete. Since concrete is weak in direct tension, this test helps assess its crack resistance and tensile load-carrying capacity, which are critical for elements like pavements, slabs. Test is conducted as per IS 5816:1999, and the concrete cylinders of 150 mm diameter × 300 mm height were casted. Type of test is indirect tensile loading by compression along the diameter of the cylinder.

Table 2 represents the split tensile test results for 28 days of curing. Figure 3 represents the graphical representation of the split tensile test results

Table 2. Split tensile test results

Mix Designation	Split tensile strength, N/mm2
M1	3.41
M2	3.31
M3	3.34
M4	3.41
M5	3.51
M6	3.48
M7	3.41
M8	3.41
M9	3.28
M10	3.37
M11	3.41
M12	3.52
M13	3.28
M14	3.21
M15	3.28
M16	3.26

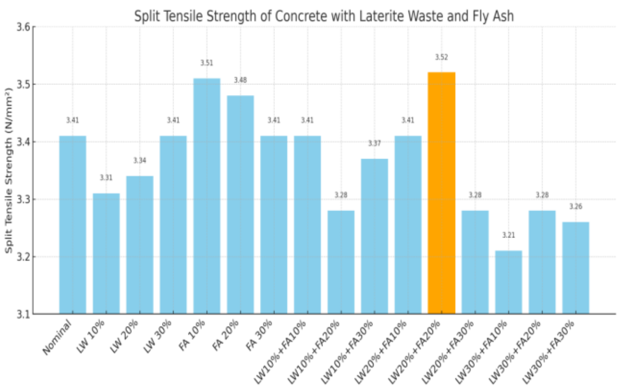

Fig. 3. Graphical representation of split tensile strength of various mix proportions

Discussions on split tensile test results

Fly Ash is rich in silica and alumina. It reacts with calcium hydroxide (from cement hydration) to form additional calcium silicate hydrate (C–S–H) gel. This gel fills micro-pores and enhances bonding in the matrix, leading to increased tensile strength—especially at 10–20% replacement. At 30% replacement, the cement content becomes too low, slowing hydration and reducing early strength gain. Fly Ash and Laterite Waste have finer particles than conventional aggregates. Their addition improves particle packing, filling voids in the concrete matrix, and can enhance density and tensile strength. However, excessive replacement can disturb the optimal grading, increasing porosity and reducing strength.

Flexural test

It is the ability of concrete to resist failure in bending. It reflects how well concrete can withstand tensile stress developed at the bottom fibers when subjected to bending, such as in pavements, beams, and slabs. Test is conducted as per IS 516:1959. Specimens of standard beam of 100 mm × 100 mm × 500 mm or 150 mm × 150 mm × 700 mm were casted for testing purpose. Two-point loading is used for loading pattern.

Table 3 represents the split tensile test results for 28 days of curing. Figure 4 represents the graphical representation of the split tensile test results.

Table 3. Flexural test results

Mix Designation	Flexural strength, N/mm2
M1	4.12
M2	4.28
M3	4.32
M4	4.21
M5	4.55
M6	4.52
M7	4.38
M8	4.27
M9	4.35
M10	4.51
M11	4.61
M12	4.5
M13	4.37
M14	4.28
M15	4.35
M16	4.28

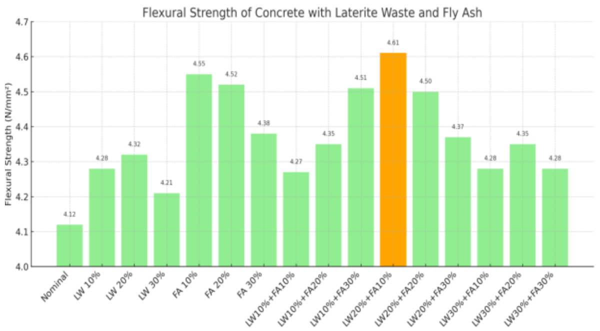

Fig. 3. Graphical representation of flexural test of various mix proportions

Discussion of flexural test

Fly Ash at 10–20% consistently enhances flexural strength due to pozzolanic reaction and densification. Laterite Waste alone improves strength slightly up to 20% but doesn't exceed the performance of Fly Ash. Optimal combination is found at 20% Laterite + 10% Fly Ash yielding 4.61 N/mm², the maximum among all mixes. Strength drops or levels off when Laterite exceeds 20% or Fly Ash exceeds 30%. Fly Ash plays a major role in enhancing flexural strength due to its pozzolanic and filler effects. Laterite Waste contributes positively up to 20%, but higher levels may weaken the matrix. Combination of 20% LW + 10% FA provides optimal synergy, achieving the highest flexural strength. Excessive replacement (≥30% total) tends to reduce performance due to reduced cementitious content and poor paste-aggregate bond.

5. Conclusions & Discussions

In summary, this study emphasizes the importance of utilizing locally available materials for the construction of rigid pavements, particularly for rural road infrastructure. Considering the optimal replacement levels established through experimental investigations, laterite waste was incorporated up to 20% as a partial substitute for coarse aggregates in the concrete mix. Additionally, fly ash was used as a supplementary cementitious material at a replacement level of 20% of the cement content.

The compressive strength results obtained from the concrete specimens containing this combination of laterite waste(LW) and fly (FA) were found to be satisfactory and met the performance criteria for rigid pavement applications. These findings confirm that fly ash serves as an effective additive in improving the overall quality and durability of concrete when used alongside laterite waste. The combined use of these materials not only enhances the mechanical properties but also contributes to the production of eco-friendly and sustainable concrete, aligning with current environmental and resource conservation goals.

Laterite waste, a readily available industrial byproduct, demonstrated significant potential as a partial coarse aggregate replacement without adversely affecting concrete strength. Figure 2 illustrates the comparison of compressive strength results across various mixes containing different percentages of these alternative materials. Notably, the mix combining laterite waste and fly ash exhibited superior performance compared to mixes containing only one of the substitutes, highlighting the synergistic effect of these materials.

Furthermore, fly ash contributes to strength gain at later ages due to its pozzolanic properties[5], which help reduce micro-crack formation and improve the long-term durability of concrete. This characteristic is particularly advantageous for rigid pavements subjected to cyclic loading and environmental stresses.

Overall, the research validates the effective use of industrial waste materials such as laterite waste and fly ash in the construction of rural roads. The findings underscore the significance of prioritizing locally available resources to reduce environmental impact, lower construction costs, and promote sustainable infrastructure development. This approach not only conserves natural aggregates and cement but also supports waste management strategies by repurposing industrial byproducts in the construction sector.

The use of Laterite Waste and Fly Ash, particularly in 20%+20% combination, is validated as both technically viable and eco-friendly. This combination can be confidently adopted for rigid pavement and rural road construction, supporting sustainability without compromising strength. Notably, the combination of 20% Laterite + 20% Fly Ash achieves the highest compressive strength of 35.6 N/mm², surpassing the nominal mix. The combination of 20% Laterite + 10–30% Fly Ash consistently outperforms all other mixes. Even at 30% Laterite + Fly Ash, the strength remains above or near the nominal, suggesting no strength compromise. Table 4 represents the mechanical properties of various mix proportions adopted for the test.

Table 3. Mechanical properties of prepared samples

Mix	Description	Compressive Strength, N/mm²	Split Tensile Strength, N/mm²	Flexural Strength, N/mm²
M1	Nominal mix	34.5	3.41	4.12
M2	Laterite Waste (LW) (10%)	32.8	3.31	4.28
M3	LW (20%)	33.4	3.34	4.32
M4	LW (30%)	33.1	3.41	4.21
M5	Fly Ash(10%)	34.2	3.51	4.55
M6	Fly Ash(20%)	33.8	3.48	4.52
M7	Fly Ash(30%)	33.5	3.41	4.38
M8	Laterite Waste (LW) (10%) + FlyAsh(FA) (10%)	33.8	3.41	4.27
M9	LW (10%) + FA(20%)	34.1	3.28	4.35
M10	LW (10%) + FA(30%)	33.6	3.37	4.51
M11	LW (20%) + FA(10%)	35.1	3.41	4.61
M12	LW (20%) + FA(20%)	35.6	3.52	4.50
M13	LW (20%) + FA(30%)	35.4	3.28	4.37
M14	LW (30%) FA(10%)	34.2	3.21	4.28
M15	LW (30%) + FA(20%)	34.8	3.28	4.35
M16	LW (30%) + FA(30%)	34.4	3.26	4.28

Trend Analysis of Mechanical Properties

The mechanical performance of concrete modified with varying proportions of Laterite Waste (LW) and Fly Ash (FA) was evaluated through compressive, flexural, and split tensile strength tests. The nominal mix served as a control, recording 34.5 N/mm², 4.12 N/mm², and 3.41 N/mm² for compressive, flexural, and split tensile strength, respectively. Among the individual replacements, 10% FA exhibited the most favorable improvement across all parameters, achieving a flexural strength of 4.55 N/mm² and a split tensile strength of 3.51 N/mm², while maintaining compressive strength near the nominal value. In contrast, the incorporation of LW alone at 10–30% provided marginal improvements, with slightly lower values for split tensile and compressive strengths, though flexural performance peaked at 20% LW with 4.32 N/mm².

The most significant enhancement was observed in the combined mixes. The mix containing 20% LW and 20% FA achieved the highest compressive strength of 35.6 N/mm² and the highest split tensile strength of 3.52 N/mm², reflecting a synergistic effect of the hybrid blend. Similarly, the flexural strength reached its peak (4.61 N/mm²) in the mix with 20% LW and 10% FA. These results suggest that moderate incorporation of LW and FA—specifically within the range of 20% LW and 10–20% FA—can improve the mechanical behavior of concrete. Conversely, higher total replacement levels (30% LW + 30% FA) led to a decline or plateau in strength, likely due to dilution of the cement matrix and reduced particle packing efficiency. This trend analysis supports the feasibility of using laterite waste and fly ash as sustainable partial replacements in concrete, particularly when used in carefully optimized proportions.

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