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Sustainable Utilization of Agricultural Waste Ashes in Concrete through Experimental Evaluation of Rice Husk Ash and Sawdust Ash as Partial Cement Replacements

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Abstract

Concrete remains the most widely used construction material worldwide, yet the production of its key component, cement, contributes significantly to global carbon emissions. This study investigates the potential of agricultural waste materials, specifically rice husk ash (RHA) and sawdust ash (SDA), as partial substitutes for cement in concrete production. Both ashes are rich in silica and possess pozzolanic properties that can enhance the mechanical performance of concrete while reducing environmental impact. M30 grade concrete mixes were prepared with RHA and SDA replacing cement at varying percentages (5%, 10%, 15%, 20%, and 25%), and combinations of RHA and SDA were also tested.

A total of forty-two specimens were examined for compressive, flexural, and split tensile strengths after 7 and 28 days of curing. The results showed that RHA improved compressive strength up to a 10 percent replacement, while SDA performed optimally at 5 to 10 percent. Beyond these levels, a decline in strength was observed. The combined use of RHA and SDA also yielded satisfactory results within similar ranges. These findings indicate that limited incorporation of agricultural waste ashes can produce cost effective, sustainable, and structurally reliable concrete suitable for modern construction needs.

Keywords Rice Husk Ash, Sawdust Ash, Sustainable Concrete, Pozzolanic Material, Compressive Strength, Flexural Strength, Split Tensile Strength, Cement Replacement

INTRODUCTION

Concrete remains one of the most widely used building materials worldwide due to its versatility, structural strength, and ease of shaping. It is essentially a composite material composed of cement, aggregates (both fine and coarse), water, and admixtures. Its adaptability allows it to meet a broad range of design requirements, making it indispensable in almost all types of construction, from residential to large-scale infrastructural projects. Cement, as the primary binding component, plays a critical role in the hydration process, providing the necessary strength and durability to concrete structures. However, conventional concrete production poses significant environmental challenges. The extraction of raw materials, such as limestone, sand, and aggregates, contributes to resource depletion and environmental degradation, while the production process itself generates air pollution, noise, vibrations, and cement dust. Emissions from cement manufacturing predominantly consist of carbon dioxide (CO_2), nitrogen (N_2), oxygen (O_2), sulfur dioxide (SO_2), water vapor, and trace gases such as carbon monoxide (CO) and nitrogen oxides (NO_x).

The cement industry is one of the largest anthropogenic sources of CO_2, contributing approximately 8% of global carbon emissions. Around half of these emissions result from chemical reactions during cement production, while the remainder arises from fuel combustion. Structural concrete alone is estimated to produce about 410 kg of CO_2 per cubic meter. On a per-ton basis, roughly 900 kg of CO_2 is released for every ton of concrete produced. CO_2 is a major greenhouse gas, and its accumulation in the atmosphere significantly contributes to global climate change. The carbon footprint of cement arises both from the calcination of calcium carbonate, which releases CO_2, and from the considerable energy requirements of the production process, often sourced from fossil fuels. Consequently, there is a pressing need to identify alternative or supplementary materials that can partially replace cement in concrete, thereby reducing its environmental impact without compromising its essential properties such as strength and durability.

Research has explored the use of various industrial byproducts and agricultural wastes as partial substitutes for cement. These supplementary cementitious materials, which include fly ash, silica fume, granulated blast furnace slag, and rice husk ash (RHA), not only enhance the properties of concrete but also mitigate waste disposal issues and reduce carbon emissions. Rice husk ash, an agricultural byproduct obtained from the combustion of rice husks at high temperatures, has emerged as a particularly promising material. Its pozzolanic properties enable it to react with calcium hydroxide in cement to form additional cementitious compounds, thereby improving concrete strength and durability.

The environmental and economic benefits of using RHA are substantial. India alone produces an estimated 20 million tons of rice husk ash annually from rice mills, which often goes unused and contributes to environmental pollution. Incorporating RHA into concrete as a partial replacement for cement can reduce cement consumption, thereby lowering CO_2 emissions associated with cement production. Additionally, utilizing RHA addresses waste management concerns by diverting agricultural residues from landfills and open burning, which are significant sources of environmental pollution. The substitution of cement with RHA also has the potential to reduce construction costs, as both cement and agricultural byproducts like RHA are locally available and inexpensive, making concrete production more economical while simultaneously improving its environmental sustainability.

Research by K. Rakesh and A. V. Rao (2023) focused on evaluating the performance of geopolymer concrete with partial substitution of cement by RHA. The study demonstrated that replacing up to 8% of cement by weight with RHA resulted in significant improvements in the physical and mechanical properties of concrete, including enhanced compressive strength and durability. Moreover, the inclusion of RHA contributed to a reduction in overall construction costs by approximately 30%, particularly in regions where cement availability is limited or logistics are challenging. The environmental benefits were equally notable, as the use of RHA minimized the need for waste disposal and decreased CO_2 emissions associated with cement production.

In addition to RHA, synthetic fibers such as polypropylene fiber (PPF) have been investigated as partial replacements for fine aggregate in concrete. Md Munazirul Haque et al. (2023) conducted a study to assess the effects of incorporating waste polypropylene fibers into concrete on its mechanical properties. Various fiber contents, ranging from 0% to 1% by volume, were tested, and the resulting fiber-reinforced concrete (FRC) specimens were evaluated for compressive strength, split tensile strength, and density at different curing ages. The results indicated that the addition of polypropylene fibers had a minimal effect on the density of the concrete, slightly reducing it from 2397 kg/m^3 to 2393 kg/m^3. Importantly, the inclusion of fibers up to an optimal content of 0.5% led to significant improvements in mechanical performance, with compressive strength increasing by 10% and split tensile strength by 17% compared to the control. Beyond this optimal fiber content, the strength gains decreased, suggesting a limit to the beneficial effects of fiber reinforcement.

Overall, these studies highlight the dual benefits of incorporating industrial and agricultural waste materials into concrete: improved mechanical and durability performance, alongside reduced environmental impact. The partial replacement of cement with RHA and the inclusion of polypropylene fibers exemplify practical strategies for developing sustainable, cost-effective, and high-performance concrete. Such innovations are particularly relevant in the context of a rapidly growing construction sector, where traditional cement-based concrete continues to pose significant environmental and economic challenges. By adopting these sustainable materials, it is possible to produce stronger, more resilient, and environmentally friendly concrete while simultaneously addressing the pressing issue of agricultural and industrial waste management.

MATERIALS AND METHOD

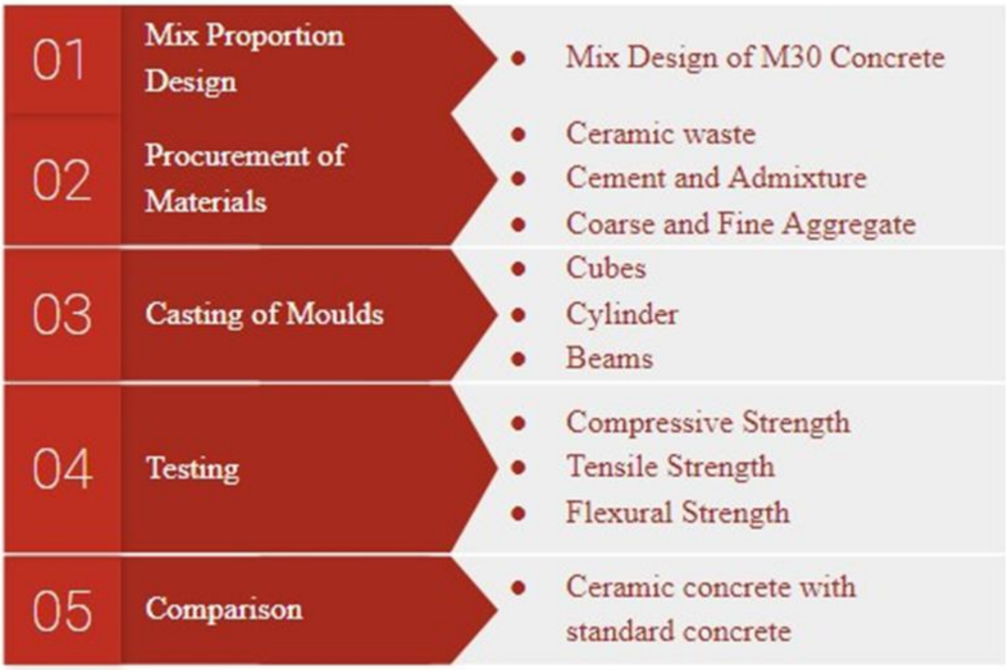

Figure 1: Scope of Experiment

MIX PROPORTION

A mix M30 grade was designed as per Indian Standard method (IS 10262-2009) and the same was used to prepare the test samples with water cement ratio w/c 0.43.

Table 1: Mix Ratio

	W (Ltr)	C (Kg/m3)	F.A. (Kg/m3)	C.A. (Kg/m3		Chemical Admixture
				20mm	10mm	
By Weight (kg)	183.5	422.45	644.25	728.25	485.5	3.4
By Volume (m3)	0.43	1	1.48	1.7	1.11	-

W- Water
C- Cement
F.A - Fine Aggregate
C.A- Coarse Aggregate

Table 2: Concrete design mix proportions

Partial Replacement	Cement	Fine aggregate	Coarse Aggregate	W/C	Water	Partial Replacement Quantity
Conventional Concrete	9.759	17.506	22.694	0.45	4.391	0
05% RHA	9.271	17.506	22.694	0.45	4.391	0.487
10% RHA	8.783	17.506	22.694	0.45	4.391	0.975
15% RHA	8.295	17.506	22.694	0.45	4.391	1.463
20% RHA	7.807	17.506	22.694	0.45	4.391	1.951
25% RHA	7.319	17.506	22.694	0.45	4.391	2.439
05% SDA	9.271	17.506	22.694	0.45	4.391	0.487
10% SDA	8.783	17.506	22.694	0.45	4.391	0.975
15% SDA	8.295	17.506	22.694	0.45	4.391	1.463
20% SDA	7.807	17.506	22.694	0.45	4.391	1.951
25% SDA	7.319	17.506	22.694	0.45	4.391	2.439
5%	7.807	17.506	22.694	0.45	4.391	1.467
RHA+15%SDA						
10% RHA+10%SDA	7.807	17.506	22.694	0.45	4.391	0.975
15% RHA+5%SDA	7.807	17.506	22.694	0.45	4.391	0.489

In total 42 samples were prepared to investigate the material strength on the parameters of compressive strength, flexural strength and split tensile strength.

RESULTS

Compressive Strength

The cube size of 150mm x 150mm x150mm is used in this experimental study to identify the compressive strength of concrete. For each type of mix cubes were casted for 7days and 28 days. 14 Cubes were casted for two different waste materials and its combination and placed in curing tank up to testing date.

Table 3: Compressive Strength in N/mm2

Compressive Strength in N /mm2		
Concrete Mix	7 Days	28 Days
0%	18.94	34.51
5% RHA	17.55	36.24
10% RHA	15.18	34.81
15% RHA	9.91	27.23
20% RHA	9.12	19.15
25% RHA	8.24	14.49
5% SD	18.7	34.57
10% SD	21.49	37.1
15% SD	19.76	34.1
20% SD	17.21	31.02
25% SD	14.41	27.73
5% RHA+15%SDA	15.18	31.67
10% RHA+10%SDA	18.59	36.66
15% RHA+5%SDA	13.17	28.42

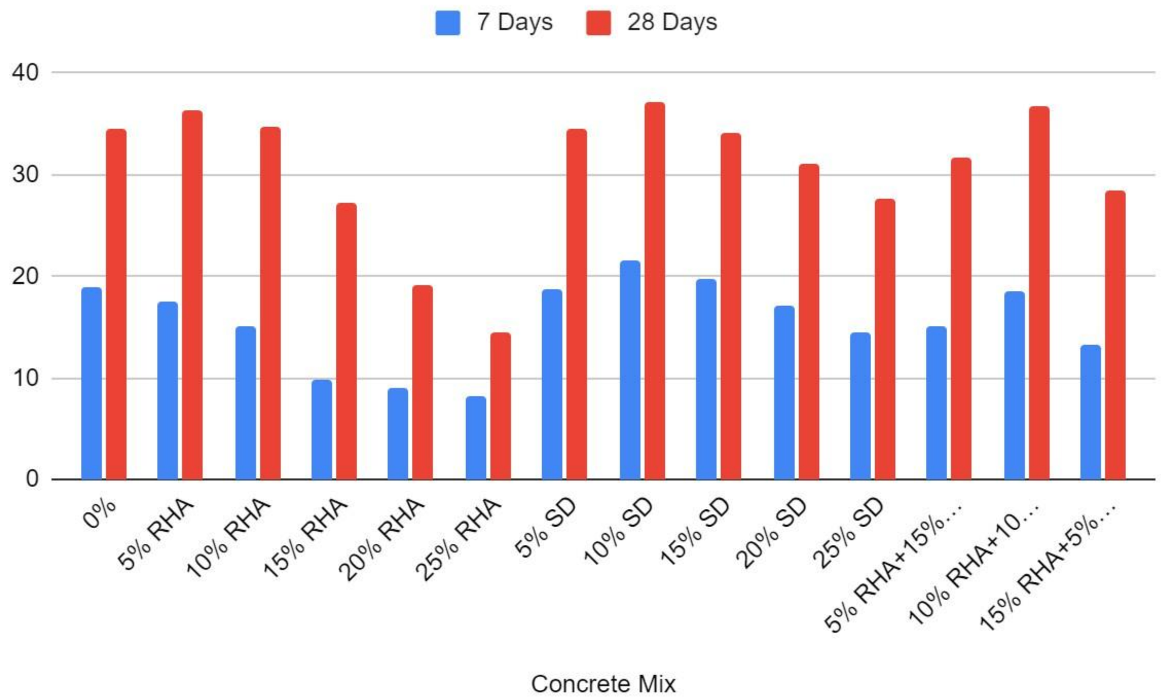

Figure 2: Compressive Strength in N/mm2

Inference-. With an increase in the percentage of rice husk ash in the concrete mixes, the compaction factor value falls. The fact that the compacting factor value has decreased indicates that the concrete is less workable. The fact that the percentage of rice husk ash has increased indicates that the mixture is becoming more workable as additional water is added. Because there is more silica in the mixture, rice husk ash concrete requires more water. Up to a 10% replacement of rice husk ash in the concrete mix boosts the mix's compression strength; after that, a progressive decline in compressive strength is observed. Test results shows that the compressive strength of the material is increased by the addition of sawdust ash.

Flexural Strength

The unreinforced beam of 100 x 100mm x 500mm is used. Because of the concrete brittleness, the failure occur suddenly and single crack will be obtained at the time of failure of a beam. This test is conducted under Universal Testing Machine. The average load carrying capacities of unreinforced sawdust ash concrete with conventional is little bit high at different mix.

Table 4: Flexural Strength in N/mm2

Flexural Strength in N/mm2		
Concrete Mix	7 Days	28 Days
0%	2.38	4.45
5% RHA	2.95	4.61
10% RHA	2.15	4.53

15% RHA	1.65	3.48
20% RHA	1.36	2.23
25% RHA	1.2	1.8
5% SD	2.58	3.87
10% SD	2.58	3.92
15% SD	2.671	4.407
20% SD	2.5	3.8
25% SD	2.1	3.4
5% RHA+15%SDA	2.21	3.4
10% RHA+10%SDA	2.8	3.9
15% RHA+5%SDA	2.5	3.4

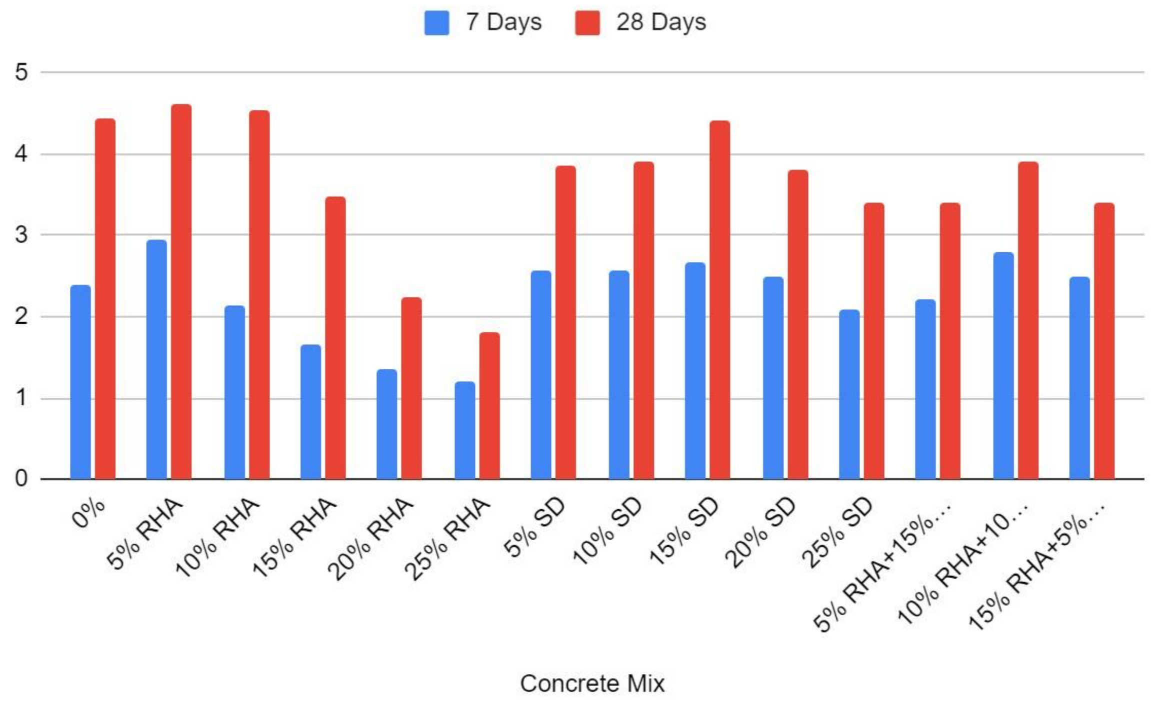

Figure 3: Flexural Strength in N/mm2

Inference- The rice husk ash concrete's flexural strength indicates an increase in RHA concrete's strength. The conventional mix's flexure strength after seven days is 2.38, but the addition of 5% rice husk ash results in a 2.95 strength increase. All other mixes then exhibit a decrease in flexural strength and a linear down of the curve. And the flexural strength after 28 days yields good results. The strength, or the replacement of 5% and 10% of rice husk ash, increases the concrete mix's strength as compared to the conventional mixture's strength of 4.45. For 5 and 10% replacement, the two mixes' flexural strengths increase to 4.61 and 4.53, respectively, while the other mixes' flexure strength decreases after the 10% replacement. Therefore, up to 10% of the concrete mix can be replaced with rice husk ash as a replacement martial. Furthermore, adding more rice husk ash than 10% of the original mix tends to reduce the concrete's flexural strength.

Split Tensile Strength

Tensile strength of concrete was determined by using UTM. The split tensile strength of concrete was tested using 100mm x 300mm cylinder specimens are carried out by placing a specimen between the loading surfaces of UTM and the load was applied until the failure of the specimen. The average value of specimens for each mix at the age of 7 days and 28 days.

Table 5: Split Tensile Strength

Split Tensile Strength in N/mm2		
Concrete Mix	7 Days	28 Days
0%	2.23	2.85
5% RHA	2.97	3.39
10% RHA	2.25	2.95
15% RHA	2.07	2.44
20% RHA	1.81	2.02
25% RHA	1.11	1.85
5% SD	1.74	2.61
10% SD	1.69	2.57
15% SD	1.848	2.87
20% SD	1.8	2.7
25% SD	1.73	2.64
5% RHA+15%SDA	1.97	2.84
10% RHA+10%SDA	2.07	3.1

15% RHA+5%SDA	2.03	2.87

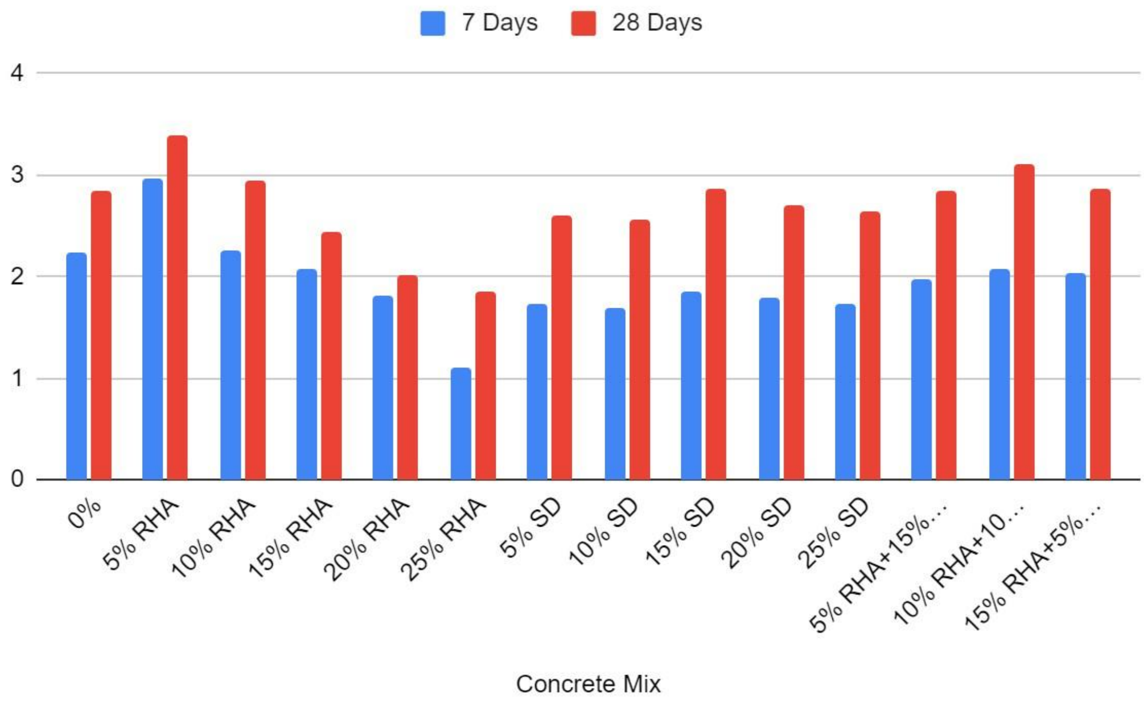

Figure 4: Split Tensile Strength in N/mm2

Inference- the concrete with 15% Saw Dust showed maximum strength as 2.87 N/mm2 and 10% Rice Husk Ash as 2.95 N/mm2.

CONCLUSION

The research established that utilizing Saw Dust Ash (SDA) and Rice Husk Ash (RHA) in concrete is both economical and cost-free, securing essential resources like cement and ensuring the long-term sustainability of the concrete construction sector. Incorporating these agricultural wastes also benefits the environment by reducing toxic gas emissions generated during cement's hydration process and mitigating waste disposal issues. However, the study noted a trade-off: the addition of these alternative materials, particularly RHA due to its high silica content, decreased the concrete's workability and consequently increased its water demand compared to conventional concrete. The findings indicate that cement can be partially replaced by RHA and SDA up to a certain threshold. For RHA, replacement is permitted up to 20%; however, to achieve optimal strength, the replacement should be capped at 5%. Specifically, compressive strength saw a boost up to 10% RHA replacement before a progressive decline began. Flexural strength similarly yielded good results at 28 days, increasing at both 5% and 10% RHA replacement compared to the conventional mix, but decreased when RHA exceeded the 10% threshold, suggesting 10% as the practical limit for this property. When considering SDA, replacement is allowed up to 10%, but only up to 5% is advised for ensuring good strength, with its addition generally shown to increase compressive strength. Overall, because RHA provides superior strength performance, it is deemed preferable over SDA for partial cement replacement. The concrete's strength, across all measured properties, may diminish if these limits are exceeded. Looking ahead, the research recommends future studies to examine the effects of various curing conditions on hardened concrete properties, the impact of RHA on Ordinary Portland Cement (OPC) concrete using different coarse aggregate types, and the influence of unburnt carbon content and internal water curing on cement paste hydration and microstructure. Further investigation is also needed on the chloride diffusion resistance of RHA concrete, the effect of RHA on the durability of OPC concrete at low water-to-binder ratios, and the effect of combustion temperature on the ultimate reactivity of the ash.

Conflicts of Interest: All authors declare that they have no conflict of interest associated with this research work.
CRedIt: **Temitope Oseni (Lead Author)** – conceptualization and drafting, and chemical characterization; **David Ajayi** – material acquisition and rigorous chemical characterization; **Chukwudi Nwankwo** – Compressive Strength testing and concrete mix protocols; **Femi John Ibitayo** – Flexural Strength testing and manuscript editing; **Emmanuel Ajibola** – long-term hardened property testing; **Adetona Oluwatosin** – specialized statistical analysis and modeling; **Paul Olatunji** – Split Tensile Strength testing and manuscript editing.

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