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Strength Characteristics Of Concrete With Partial Replacement Of Cement By Fly Ash And Rice Husk Ash

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Abstract: The current project aims to investigate the potential of sustainable alternatives to Ordinary Portland Cement (OPC) by partially replacing it with Fly Ash and Rice Husk Ash (RHA), both of which are widely available industrial and agricultural by-products. Specifically, the study focuses on developing and testing concrete in which 40% of the OPC is replaced—20% with Fly Ash and 20% with RHA—while the remaining 60% retains conventional cement. This approach not only seeks to reduce the dependency on cement, which is known for its high carbon emissions during production, but also to utilize materials that are often treated as waste, thereby contributing to environmental conservation and resource efficiency.

The primary objective of the study is to assess whether this blended concrete mix can match or exceed the performance of standard M20 grade OPC concrete in terms of mechanical strength and workability. A series of concrete specimens were prepared following IS code guidelines, using consistent mix proportions and locally sourced aggregates. Three main types of mechanical tests were performed: compressive strength at 3, 7, and 28 days; split tensile strength; and flexural strength at 28 days. All specimens were subjected to water curing, and no chemical activators or admixtures were used, making the process simpler and more suitable for rural or low-resource settings.

Fly Ash, a fine powder by-product of coal combustion in thermal power plants, and RHA, produced by controlled burning of rice husks, both possess pozzolanic properties that enhance the long-term strength and durability of concrete. Their inclusion not only aids in reducing the environmental footprint of construction materials but also offers an efficient method of waste management. Moreover, the proposed mix shows potential in cost reduction by decreasing the quantity of cement required, which is especially beneficial for developing countries where infrastructure growth is high and budget constraints are common.

This project contributes meaningfully to global sustainability efforts and is closely aligned with the United Nations Sustainable Development Goals (SDGs). It supports SDG 9 (Industry, Innovation, and Infrastructure) by introducing environmentally responsible materials into mainstream construction; SDG 11 (Sustainable Cities and Communities) by encouraging the development of resilient and cost-effective infrastructure; and SDG 13 (Climate Action) by addressing carbon emissions from cement usage and promoting the use of waste-derived alternatives. Overall, the findings from this project are expected to provide a practical foundation for future research and application of green concrete technology in the construction industry.

***Key Words* -** Ordinary Portland Cement (OPC), Fly Ash, Rice Husk Ash (RHA), Industrial By-products, Agricultural Waste.

I. INTRODUCTION

Concrete is the second most consumed material globally after water, serving as a cornerstone for modern infrastructure. However, the production of Ordinary Portland Cement (OPC), the primary binder in concrete, poses serious environmental challenges due to its high energy consumption and significant CO_2 emissions. For every kilogram of OPC produced, nearly an equal amount of CO_2 is released, making the cement industry a major contributor to global greenhouse gases. Moreover, the extraction of raw materials depletes natural resources and causes ecological degradation.

To address these issues, this study explores a sustainable alternative by partially replacing OPC with industrial and agricultural by-products—20% Fly Ash and 20% Rice Husk Ash (RHA). Both materials are rich in reactive silica and possess pozzolanic properties, making them effective supplementary cementitious materials. Using water as the only mixing medium, the research compares the performance of this blended mix with conventional OPC concrete, aiming to reduce environmental impact while maintaining strength and durability. This approach supports sustainable construction by promoting waste utilization, cost reduction, and resource conservation.

1.1 Objectives of the Study

The primary objectives of the study are as follows:

1. To evaluate the compressive strength of M20 grade concrete with partial replacement of cement by 20% Fly Ash and 20% Rice Husk Ash at 3, 7, and 28 days of curing.
2. To analyze the split tensile strength and flexural strength of the modified concrete mix and compare it with conventional OPC concrete.
3. To assess the workability of the concrete mixes using slump tests and examine the effects of pozzolanic materials on fresh concrete properties.
4. To promote sustainable construction by utilizing industrial and agricultural waste materials, thereby reducing cement consumption and environmental impact.

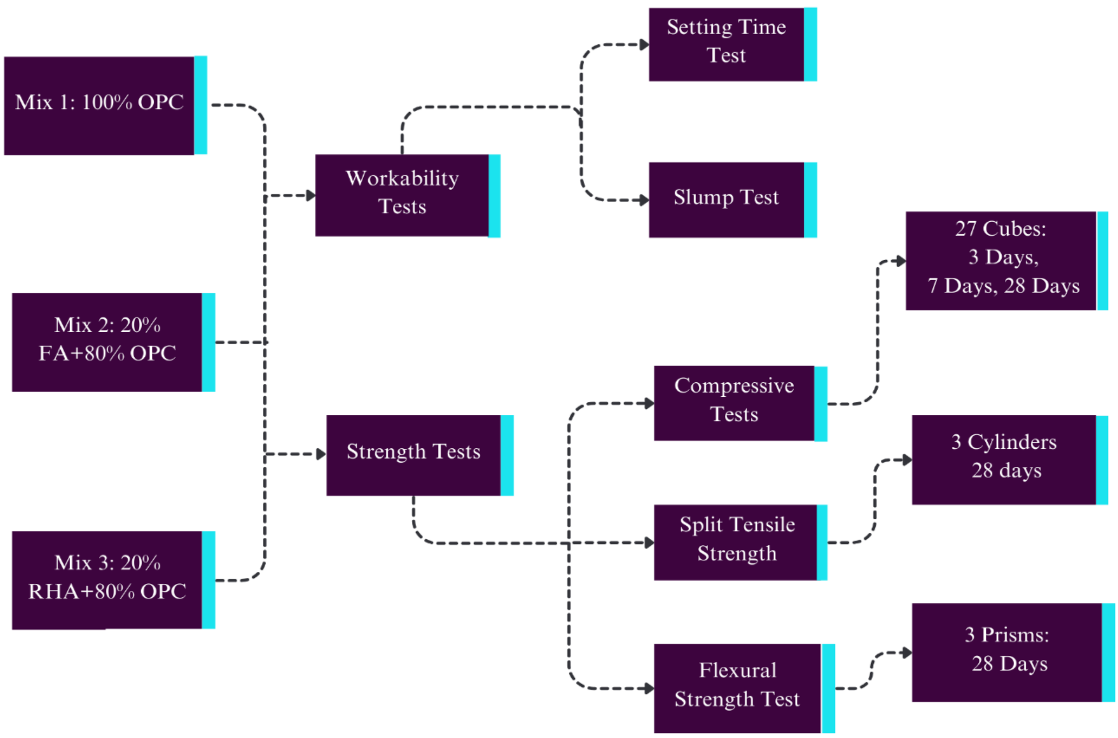

Fig-1: Workflow of Strength characteristics of concrete.

II. METHODOLOGY

This study aims to evaluate the strength properties of concrete with partial replacement of cement using fly ash and rice husk ash. The methodology adopted involves selection of materials, mix design, specimen preparation, curing methodology, and systematic testing of hardened concrete to assess its mechanical behavior.

2.1 Materials

The following materials were used in this experimental investigation:

1. **Cement**: Ordinary Portland Cement (OPC) of 43 Grade, conforming to IS 8112:2013, was used as the primary binder.
2. **Fly Ash (FA):** Low-calcium Class F fly ash obtained from a local thermal power station, complying with IS 3812 (Part 1):2003, was used as a supplementary cementitious material.
3. **Rice Husk Ash (RHA):** RHA was sourced from controlled burning of rice husk at around 600°C, followed by sieving to remove larger particles and ensure adequate fineness.
4. **Fine Aggregate:** Locally available river sand confirming to Zone II as per IS 383:2016 was used as fine aggregate.
5. **Coarse Aggregate:** Crushed angular granite aggregates of 20 mm and 10 mm size in a 60:40 proportion were used, confirming to IS 383:2016.
6. **Water:** Potable tap water free from impurities was used for both mixing and curing.
7. **Chemical Admixtures:** No chemical admixtures or superplasticizers were used in this study.
8. **Liquid Medium:** Ordinary water was used in place of conventional alkaline activators typically employed in geopolymer concrete.

2.2 Mix Design

The concrete mix design was developed for M20 grade concrete using the guidelines of IS 10262:2019 and IS 456:2000. The target mean strength was taken as 26.6 MPa considering standard deviation and margin for variability. A fixed water-binder ratio of 0.50 was maintained throughout the mixes. Three mixes were prepared:

- **Mix 1 (Control):** 100% OPC
- **Mix 2:** 80% OPC + 20% Fly Ash
- **Mix 3:** 80% OPC + 20% Rice Husk Ash

The binder content and total aggregate volume were kept constant across all mixes to ensure uniformity.

2.3 Preparation of Specimens

The dry materials were mixed in a mechanical mixer to ensure uniform blending. Water was then added gradually to achieve the desired workability. The fresh concrete was placed in standard molds:

- **Cubes:** 150 mm × 150 mm × 150 mm for compressive strength
- **Cylinders:** 150 mm diameter × 300 mm height for split tensile strength
- **Prisms:** 100 mm × 100 mm × 500 mm for flexural strength

Each layer of concrete was compacted using a table vibrator to eliminate entrapped air and achieve proper densification.

2.4 Curing Methodology

After 24 hours of casting, all specimens were demolded and transferred to a water-curing tank maintained at 27 ± 2°C. Curing durations were selected as per IS standards: 3, 7, and 28 days for compressive strength, and 28 days for split tensile and flexural strength tests.

2.5 Tests Conducted

A comprehensive suite of laboratory tests was performed to characterize both the fresh and hardened properties of the concrete mixes. All tests were carried out in strict accordance with the relevant Bureau of Indian Standards (IS) specifications.

1. **Setting Time Test (IS 4031 – Part 5:1988)**

Cement paste samples were prepared by mixing cement and water at the standard consistency ratio determined earlier. The Vicat apparatus was used to determine the initial and final setting times. After filling the Vicat mold, the plunger was allowed to descend under its own weight, and the time taken for the needle to penetrate to 5 ± 1 mm from the bottom of the mold was recorded as the initial setting time. Subsequently, the final setting time was recorded when the needle failed to make a complete imprint on the paste surface. Three trials were performed for each cement blend, and the mean values are reported.

2. **Slump Test for Workability (IS 1199:1959)**

The consistency (workability) of fresh concrete was assessed using the standard slump-cone method. The slump cone (300 mm height, 100/200 mm top and bottom diameters) was placed on a smooth, rigid baseplate. Freshly mixed concrete was filled in three layers, each tamped 25 times with a standard rod. The cone was then lifted vertically, and the vertical settlement (slump) of the concrete free surface was measured. A higher slump indicates greater workability; values were recorded to the nearest 5 mm.

3. **Compressive Strength Test (IS 516:1959)**

Concrete cubes (150 mm × 150 mm × 150 mm) were cast for each mix and cured under water at 27 ± 2 °C. Specimens were tested at 3, 7, and 28 days using a calibrated Compression Testing Machine (CTM) with a loading rate of 140 kg/cm²/min (approximately 0.2 MPa/s). For each age and mix, three cubes were tested and the average maximum load was used to calculate the compressive strength (load divided by cross-sectional area).

4. **Split Tensile Strength Test (IS 5816:1999)**

Indirect tensile strength was determined on 150 mm × 300 mm cylindrical specimens at 28 days. Each cylinder was capped to ensure plane ends, placed horizontally between the platens of a Universal Testing Machine (UTM), and loaded diametrically at a constant rate of 1.2 kN/s. The split tensile strength was calculated using:

$$f_r = \frac{2P}{\pi DL}$$

where P is the maximum applied load, D the cylinder diameter, and L its length. Two specimens per mix were tested and the mean value reported.

5. **Flexural Strength Test (IS 516:1959)**

Flexural (modulus of rupture) tests were performed on prismatic beams measuring 100 mm × 100 mm × 500 mm at 28 days. A two-point loading arrangement with a span of 400 mm was used. Load was applied at a uniform rate such that failure occurred within 2 to 5 minutes. The flexural strength was computed as:

$$f_r = \frac{PL}{bd^2}$$

where P is the maximum applied load, L the span length, and b and d the beam's width and depth. Two prisms per mix were tested and their average strength reported.

In total, 30 specimens were cast and tested, comprising 18 cubes (3 mixes × 3 curing ages × 2 replicates), 6 cylinders (3 mixes × 2 replicates), and 6 prisms (3 mixes × 2 replicates). The results from these tests provide a rigorous assessment of both the fresh characteristics and the long-term mechanical performance of concrete containing Fly Ash and Rice Husk Ash as partial cement replacements.

III. RESULTS AND DISCUSSION

3.1 Compressive Strength

Table 1 summarizes the compressive strength results for the three concrete mixes evaluated at 3, 7, and 28 days. The control mix (100% Ordinary Portland Cement) achieved the highest 28-day compressive strength of **23.6 MPa**. In comparison, mixes with **20% Fly Ash (FA)** and **20% Rice Husk Ash (RHA)** replacements showed slightly lower 28-day strengths of **20.4 MPa** and **18.8 MPa**, respectively.

Interestingly, early strength gain trends indicate that both FA and RHA mixes exhibited relatively **higher early-age strength development**. Mix 3 (RHA) reached **90.42%** of its 28-day strength by 7 days, suggesting rapid pozzolanic reactivity and potential for early-age applications. These findings highlight that, despite a slight reduction in ultimate strength, the partial replacement mixes offer competitive early strength characteristics.

Table 1: Compressive Strength of Concrete Mixes

Mix Type	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
100% OPC	12.5	18.5	23.6
20% Fly Ash	11.0	17.8	20.4
20% RHA	10.2	17.0	18.8

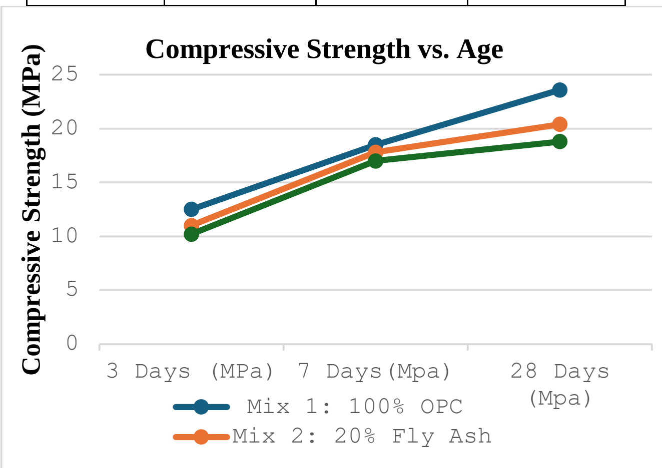

Fig. 2: Line Graph: Compressive Strength vs Curing Age

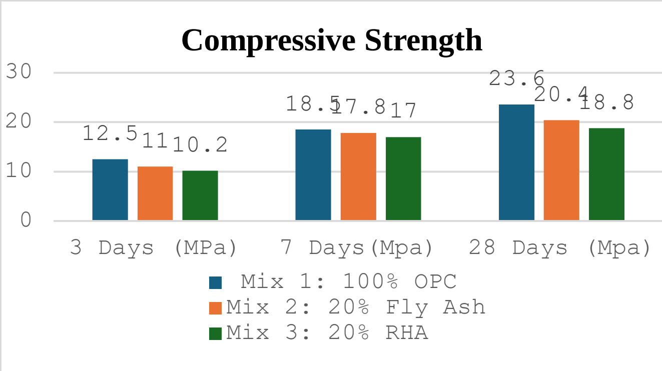

Fig. 3: Compressive Strength Test Results in Bar Graph

3.2 Split Tensile Strength

The 28-day split tensile strength values are presented in Table 2. The control mix achieved a maximum value of **2.3 MPa**, while mixes containing FA and RHA recorded **2.2 MPa** and **2.1 MPa**, respectively. This corresponds to approximately **95.7%** and **91.3%** of the control mix tensile strength. Although slightly reduced, these values remain structurally sufficient and highlight the continued integrity of concrete with supplementary cementitious materials.

Table 2: Split Tensile Strength at 28 Days

Mix Type	Split Tensile Strength (MPa)
100% OPC	2.3
20% Fly Ash	2.2
20% RHA	2.1

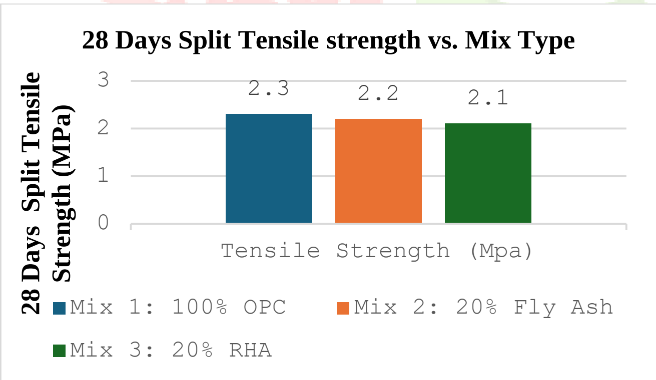

Fig. 4: 28-Day Split Tensile Strength

Fig-5: Specimen Preparation

Fig 6: Casting Procedure

Fig 7: Casting Procedure contn…

Fig-8: Slump Test Setup for Fresh Concrete

Fig-9: Compressive Strength Testing Machine

3.3 Flexural Strength

Table 3 shows the 28-day flexural strength results. The control mix displayed the highest strength of **3.4 MPa**, while mixes with FA and RHA yielded strengths of **3.3 MPa** and **3.2 MPa**, respectively. This represents **97.1%** and **94.1%** of the control mix's performance. The minor reduction in flexural capacity is attributable to differences in hydration kinetics and water absorption properties of FA and RHA but remains within permissible limits for structural concrete.

Table 3: Flexural Strength at 28 Days

Mix Type	Flexural Strength (MPa)
100% OPC	3.4
20% Fly Ash	3.3
20% RHA	3.2

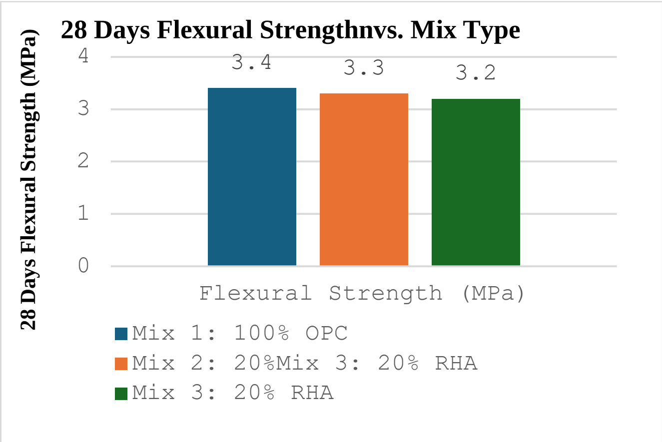

Fig. 10: 28-Day Flexural Strength

CONCLUSION

This experimental investigation examined the effects of partially replacing Ordinary Portland Cement (OPC) with 20% Fly Ash (FA) and Rice Husk Ash (RHA) on the performance of concrete. Three mixes were evaluated: Mix 1 (100% OPC), Mix 2 (20% FA + 80% OPC), and Mix 3 (20% RHA + 80% OPC). The results revealed that incorporating FA and RHA slightly reduced workability and increased water demand due to their fine, porous nature. Setting times were extended, particularly for RHA, indicating slower pozzolanic reactions beneficial for prolonged workability. Densities decreased marginally in FA and RHA mixes, reflecting the lower specific gravity of these materials.

In terms of mechanical performance, Mix 1 showed the highest compressive strength (23.6 MPa at 28 days), followed by Mix 2 (20.4 MPa) and Mix 3 (18.8 MPa). Split tensile and flexural strengths followed a similar trend but remained within acceptable structural limits. Overall, Fly Ash outperformed RHA across most parameters, though both proved to be viable supplementary cementitious materials. The findings suggest that partial replacement with FA and RHA can yield sustainable concrete with reduced environmental impact, particularly in terms of lower OPC usage and CO_2 emissions, without significantly compromising strength or durability.

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