Eco Friendly -Efficient M25 Concrete: A Performance Study Incorporating Industrial and Agricultural By-products for Sustainable Construction.

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Abstract

This study investigates the combined effect of Egg Shell Powder (ESP), Class F fly ash, and rice husk ash (RHA) as supplementary cementitious materials in concrete. We will analyze their impact on the chemical and physical properties, consistency, setting times, pH, and compressive strength of blended cements and mortars. The research will also compare ESP concrete strength against a control mix and assess durability through water absorption, sorptivity, chloride ion penetration, and diffusion coefficient. The goal is to determine optimal replacement levels, promoting sustainable construction and waste utilization. Notably, the modified RA4 cement concrete mix showed significantly enhanced durability compared to the control RA0 mix, with reduced water permeability (61.8%), chlorine penetration (78.35%), and chloride diffusion (51%). The RA4 mix also demonstrated superior acid and sulfate resistance and reduced corrosion (86.82%), making it suitable for harsh environments.

Keywords: Egg Shell Powder, Rice Hush Ash, Durability, Performance

1 INTRODUCTION

Managing traffic and accidents in congest

urban areas is challenging due to limited, short-range views from ground-based solutions. This hinders comprehensive, real-time traffic information needed to avoid jams and ensure safety[1].

A literature review reveals significant research into sustainable concrete, focusing on supplementary cementitious materials (SCMs). Studies highlight the successful incorporation of fly ash (FA), rice husk ash (RHA), and eggshell powder (ESP) to improve concrete's strength and durability while reducing environmental impact.

Research demonstrates the significant potential of fly ash (FA) and rice husk ash (RHA) as supplementary cementitious materials (SCMs) in concrete[4]. The combined effect of FA, RHA, and eggshell powder has been explored, and RHA characteristics directly influenced long-term strength development. It was found that a 50% RHA substitution improved strength and durability due to reduced porosity. RHA has been suggested to replace up to 10% of cement[7].

Studies consistently show the benefits of RHA[8]. It has been noted that 10-20% cement substitution with RHA could lower greenhouse gas emissions and production costs[9]. Additionally, 20% RHA replacement yielded superior 90-day results in cement mortar, and increased flexural strength was observed with RHA in pavement concrete. Finer RHA particles enhance concrete properties, leading to lower water absorption and increased compressive strength[11].

RHA has a positive effect on early age compressive strength. A target strength of 50 MPa has been achieved with 5% RHA for lighter, less permeable concrete[13]. A blend of 22.5% FA and 7.5% RHA has been found to improve compressive, flexural, and split tensile strengths. RHA also enhances durability and mechanical strength in self-compacting concrete[15]. Furthermore, recycled concrete aggregate, quarry dust, and RHA have been investigated for environmentally friendly concrete.

The novelty and unique contribution of our study, "Eco-Friendly and Efficient M25 Concrete: A Performance Study Incorporating Industrial and Agricultural By-products for Sustainable Construction," will lie in a combination of several factors, considering the current research landscape in India and globally. While individual industrial (e.g., fly ash, GGBS) and agricultural (e.g., RHA, SCBA) by-products have been extensively studied as partial replacements in concrete, the **simultaneous and optimized combination of a specific set of both industrial and agricultural by-products for M25 grade concrete in the Indian context is often less explored comprehensively.** Many studies focus on either one type of by-product or different concrete grades.Our investigation will systematically investigate the **synergistic effects** of combining specific industrial and agricultural by-products on M25 concrete properties. This goes beyond simple individual replacements and aims to achieve a more optimized and holistic solution for sustainable M25 concrete, potentially leading to better performance and higher replacement levels than individual applications. The specific combination of by-products chosen, especially if it includes lesser-studied agricultural wastes prevalent in India, could also be a unique aspect.The selection of industrial and agricultural by-products will be driven by their **local availability and waste generation patterns within India**. For example, focusing on specific agricultural waste like rice hush ash abundant in particular regions of India makes the study highly relevant and practical for the Indian construction industry.

2 DISCUSSIONS ON LITERATURE:

The current study's findings, which highlight the benefits of using egg shell powder (ESP), Class F fly ash, and rice husk ash (RHA) as supplementary cementitious materials in concrete, align well with recent international literature emphasizing sustainable construction and waste utilization.

It also support the successful incorporation of fly ash, RHA, and ESP to improve concrete properties and reduce environmental impact. The observed enhanced durability, including reduced water permeability, chlorine penetration, and chloride diffusion in the modified RA4 cement concrete mix, is consistent with studies demonstrating RHA's ability to improve strength and durability due to reduced porosity. For example, bhanumati das noted that cement substitution with RHA could lower greenhouse gas emissions and production costs, further supporting the environmental benefits of such approaches. The superior acid and sulfate resistance, and reduced corrosion observed in the RA4 mix, are also in line with international findings on the positive effects of these by-products on concrete durability in harsh environments.

The scalability of this approach appears promising given the abundant availability of industrial and agricultural by-products like fly ash, rice husk ash, and eggshells globally. Utilizing these waste materials at a larger scale can significantly contribute to sustainable construction practices by reducing landfill waste and decreasing the demand for virgin cement production. The methodology employed in this study, which involves systematic testing of fresh and hardened concrete properties, can be replicated and adapted for various regional contexts and material availabilities. Furthermore, the detailed mix propositions and test results provide a clear framework for implementing these eco-friendly concrete mixes in practical applications. As demonstrated by the optimal performance of the RA4 mix, identifying specific blend ratios is crucial for maximizing the benefits of these supplementary cementitious materials. Continued research and pilot projects can further refine the application and optimize the performance of these sustainable concrete solutions on a wider scale.

3.0 METHODOLOGY & MATERIALS TESTING

The purpose of this study is to examine the effects of partially substituting cement in M25 grade concrete with fly ash (FA), rice husk ash (RHA), and eggshell powder (ESP). The main objective is to assess the amended concrete's strength and durability properties.

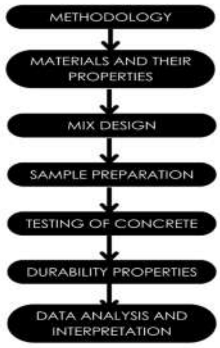


Table 1 physical property of materials

Materials	Name of properties	obtained Value
Ordinary Portland Cement	Specific gravity	3.16
	Fineness	338m^2/kg
	Consistency	30 (%)
	Initial setting time	40(minutes)
	Final setting time	230 (min)
	Soundness	1 mm
Fine aggregates	Specific gravity	2.4
	Finesse modules	2.63
	Bulk density	1598 Kg/m^3
Coarse aggregates	Specific gravity	2.6
	Finesse modules	6.31
	Bulk density	1498 Kg/m^3

Materials	Name of properties	obtained Value
RHA grain size of 3.8 µm	Specific gravity	2.11
	Fineness	3510 m^2/kg
	Bulk Density	688 kg/m^3
Egg Shell Powder (ESP)	Specific gravity	1.84
	Fineness	286 m^2/kg
	Bulk Density	1141kg/m3
fly ash – F	Specific gravity	2.04
	Fineness	516m^2/kg
	Bulk Density	1168kg/m^3

4.0 MIX PROPOSITION

The quality of concrete is primarily determined by the proportioning of its components, with the design mix dictating its precise behavior. For this study, an M25 grade control concrete was prepared according to IS 10262-2009, using a water-to-cement (W/C) ratio of 0.5 and a design cube compressive strength of 25 MPa. The mix ratios for the control concretes were 1:1.604:2.94. Ordinary Portland Cement (OPC) of 43 Grade was partially replaced with double pozzolans (fly ash and rice husk ash) at dosages from 0 to 40% by weight of cementitious materials; while 5% egg shell powder (ESP) was added at each replacement level. **Table 2** Mix proposition

Mix designation	Symbol	Cement (%)	Replacement (%)		Additive (%)
			FA	RHA	ESP
RA_0	OPC	100	-	-	-
RA_1	2.5FA2.5RH	95	2.5	2.5	5

	A5ESP				
RA_2	5FA5RHA5 ESP	90	5	5	5
RA_3	10FA10RH A5ESP	80	10	10	5
RA_4	15FA15RH A5ESP	70	15	15	5
RA_5	20FA20RH A5ESP	60	20	20	5
FA – Fly Ash, RHA – Rice Husk Ash & ESP – Egg Shell Powder					

5.0 RESULT AND DISCUSSION.

In our experimental investigations, we used the cubes of 150mm x 150mm for compressive strength and durability studies of acid and sulphate attacks and for split tensile strength we used cylinders of size 150mm diameter with 300mm length. For Flexural strength , we used the beams of size 150mm x 150mm x700mm. For RCPT we used the cylindrical disks 100mm dia and 50mm thickness.

5.1 FRESH CONCRETE TESTS

The fresh properties of concrete determine its workability, consistency, cohesiveness, and ease of placement. The following tests will be conducted to evaluate the fresh concrete characteristics when incorporating Fly Ash (FA), Rice Husk Ash (RHA), and Egg Shell Powder (ESP):

Table 3 Fresh concrete test results

Mix	Consistency (%)	Setting time (min)		Soundness value (mm)
		Initial	Final	
RA_0	30	60	255	1
RA_1	32	90	275	3
RA_2	34	110	285	3
RA_3	36	115	300	2.5
RA_4	38	125	325	1.5
RA_5	40	135	350	2.5

5.2 HARDENED CONCRETE TESTS

Once the concrete has hardened, various tests are conducted to evaluate its **strength, durability, and structural performance**. The key hardened concrete tests include:

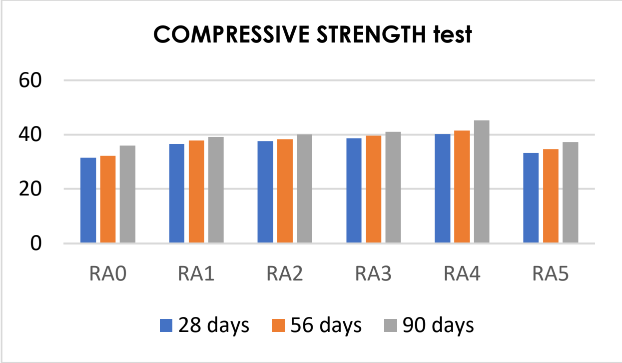
5.2.1 COMPRESSIVE STRENGTH TESTS

The compressive strength of ESP cement mortars increases with curing time, reaching RA4. The optimum mix proportion is RA4, which yields high compressive strength at all ages. This is due to the gradual increase in compressive strength in the absence of carbon content in RHA & FA showing table 4

Table 4 Compressive strength test results

Mix designation	Curing Periods		
	28 days	56 days	90 days
RA_0	36.08	39.53	41.33
RA_1	41.78	45.78	47.86

RA_2	42.97	47.08	49.23
RA_3	44.28	48.51	50.72
RA_4	46.01	50.41	52.71
RA_5	38.01	41.65	43.55

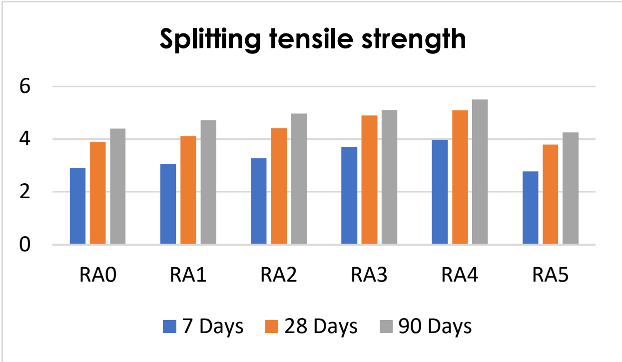


5.2.2 SPLITTING TENSILE STRENGTH

The splitting tensile strengths of ESP blended concrete after curing show table 5 a peak at RA4 content, which is the finest limit, with RA4 content being the maximum strength compared to RA0.

Table 5 Splitting tensile strength test results

Mix designation	Curing periods		
	7 Days	28 Days	90 Days
RA_0	3.04	3.15	3.39
RA_1	3.19	3.30	3.55
RA_2	3.42	3.54	3.81
RA_3	3.87	4.01	4.31
RA_4	4.16	4.31	4.64
RA_5	2.90	3.00	3.23



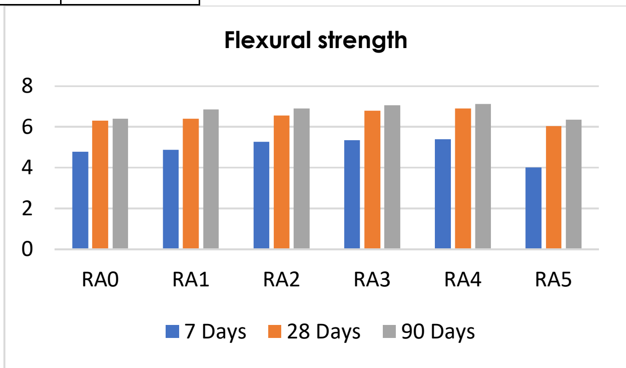
5.2.3 FLEXURAL STRENGTH TESTS

The study shows that the table 6 highest flexural strength of ESP concrete is achieved at RA4, and it reaches roughly identical strength to OPC concrete at RA5.

Table 6 Flexural strength test results

Mix designation	Curing Periods		
	7 Days	28 Days	90 Days
RA_0	4.82	5.35	6.06

RA_1	5.05	5.61	6.35
A_2	5.42	6.01	6.81
RA_3	6.13	6.80	7.70
RA_4	6.60	7.31	8.29
RA_5	4.59	5.09	5.77



5.3 DURABILITY TESTS

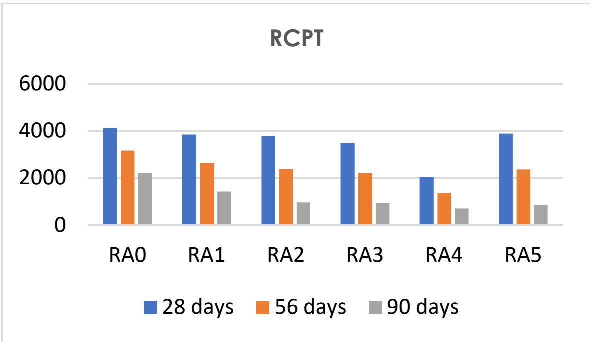
Durability testing is essential to ensure that the concrete maintains its **strength and performance** over time, especially when exposed to harsh environmental conditions. Below are the key durability tests conducted as per **Indian Standards (IS) and ASTM** for assessing concrete's resistance to water, chemicals, and environmental effects.

5.3.1 RAPID CHLORIDE ION PERMEABILITY TESTS

The study reveals that the resistance to chloride ion penetration in ESP concrete specimens decreases with increasing ash substitution content up to RA4 at all ages, with total charge passing through OPC mortar decreasing show in table 7.

Table 7 Rapid Chloride Permeability test results

Mix designation	RCPT Charge passed / coulombs		
	28 days	56 days	90 days
RA0	4342.75	3340.15	2382.24
RA_1	4068.39	2790.22	1540.95
RA_2	3997.84	2510.57	1042.86
RA_3	3684.29	2337.50	1009.65
RA_4	2172.35	1453.79	749.27
RA_5	4114.23	2508.14	919.29

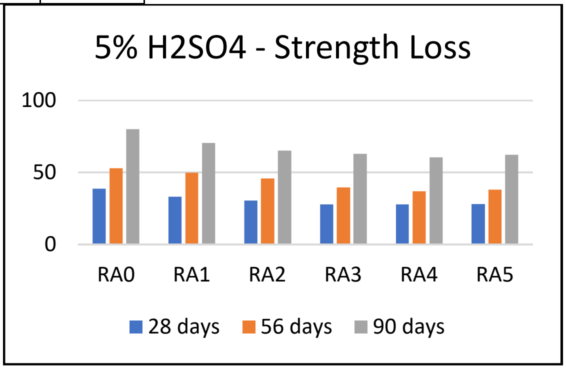


5.3.2 CHEMICAL EXPOSURE TO SULPHURIC ACID TESTS

The study reveals that concrete containing FA and RHA (RA4) exhibits higher acid resistance and lower weight loss and strength loss compared to OPC concrete show in table 8. This is due to the denser packing of the mixture and the stable product formed by FA and RHA.

Table 8 Sulphuric acid test test results

Mix designation	5% H_2SO_4 - Strength Loss		
	28 days	56 days	90 days
RA0	39.53	54.94	87.36
RA_1	33.91	51.63	76.89
RA_2	31.21	47.67	70.91
RA_3	28.70	41.10	68.60
RA_4	28.53	38.34	65.95
RA_5	28.75	39.62	67.86

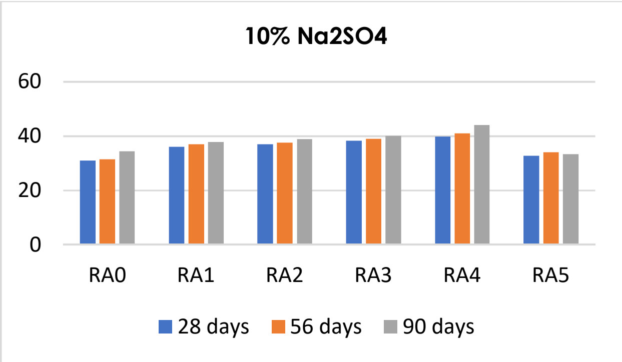


5.3.3 STRENGTH OF CONCRETE SPECIMENS DUE TO SULPHATE ATTACK

The study used sulphate attack to measure the chemical reaction between sulphate ions and hydration products, resulting in ettringite, which reduces bond strength and internal disintegration of concrete. After curing, concrete specimens were immersed in sulphate solution for 28, 56, and 90 days in table 10. The weight loss from conventional concrete decreased over time, while ESP blended mix saw gradual reduction.

Table 10 Sulphate attack test results

Mix designation	10% Na_2SO_4		
	28 days	56 days	90 days
RA0	32.37	33.21	36.67
RA_1	37.57	39.17	40.29
RA_2	38.74	39.72	41.43
RA_3	40.00	41.21	42.60
RA_4	41.60	43.28	46.87
RA_5	34.22	35.96	35.52

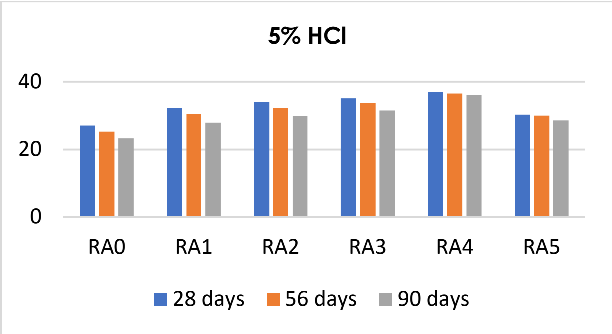


5.3.4 CHEMICAL EXPOSURE TO HYDROCHLORIC ACID TESTS

Acid affects hardened concrete by converting calcium compounds into calcium salts. The chemical resistance of concrete was evaluated using weight loss and compressive strength loss. Control concrete showed 13.89%, 21.43%, 35.19%, and 60.54% strength loss, while concrete prepared with fly ash, rice husk ash, and egg shell powder showed 8.24% and 20.31% strength loss show in table 11.

Table 11 Hydrochloric acid test results

Mix designation	5% HCL		
	28 days	56 days	90 days
RA0	27.73	26.12	24.28
RA_1	32.84	31.55	29.07
RA_2	34.76	33.26	31.18
RA_3	35.92	35.00	32.85
RA_4	37.68	37.74	37.54
RA_5	30.97	31.02	29.81



Compressive, tensile, and flexural strength tests are destructive, making re-testing impossible, and sample representativeness for in-situ concrete is a common limitation. Confounding factors include specimen size/shape, loading rate, moisture content, and curing conditions, all significantly influencing strength outcomes. Tensile strength tests face challenges with direct measurement and alignment, often relying on indirect methods that overestimate actual values, while material composition and temperature are key confounders. Flexural strength testing is limited by fragile beam specimens and non-uniform real-world temperatures, with strain rate and concrete age being critical influencing factors. Durability tests struggle to replicate complex real-world conditions, often focusing on single deterioration mechanisms, with the water-cement ratio and curing being major confounding factors. The RCPT, an indirect measure, is limited by heat generation overestimating permeability and the influence of all pore solution ions, not just chlorides, on results.

6 CONCLUSIONS

Material Properties

Fly ash-F (FA) and **rice husk ash (RHA)** are effective pozzolanic materials, characterized by a relatively low ignition value and rich in unstructured silica content (87.65% and 58.68% respectively). **Eggshell powder (ESP)** primarily consists of calcium carbonate, making up 93.70% of its composition.

Key Findings on Concrete Properties

- The **blend ratio values** of blended concrete mixes, ranging from RA1 (2.5% FA, 2.5% RHA, 5% ESP) to RA5 (20% FA, 20% RHA, 5% ESP), consistently fell between 12.16 and 13.41, indicating that the RA4 mix (15% FA, 15% RHA, 5% ESP) is particularly suitable for concrete exposed to corrosive environments.
- **Compressive strength** generally increased with higher blend ratios, peaking at RA4 (15% FA, 15% RHA, 5% ESP), which showed an approximate 30% increase at 28 days of curing and a 28% increase at

56 days compared to ordinary Portland cement (OPC) concrete. Beyond this point, further increases in the blend ratio, as seen in RA5 (20% FA, 20% RHA, 5% ESP) and RA6 (25% FA, 25% RHA, 5% ESP), led to a decrease in strength. Compared to the OPC control specimen, the concrete with the **RA4 blend mix** (15% FA, 15% RHA, 5% ESP) exhibited significantly improved mechanical properties, showing a 32% greater split tensile strength, 11.2% more flexural strength, and 16.4% more bond strength.

- **Water absorption** data indicated that RA4 concrete mixes effectively reduced water absorption by approximately 12% at 28 days and 21% at 90 days when compared to the control system.
- **Sorptivity** consistently decreased as the blend mix improved from RA1 to RA4 at both 28 and 90 days of curing. While sorptivity increased at RA5, these values remained lower than those of the control concrete.
- Regarding **chloride penetration**, the RA4 mix demonstrated lower chloride ion penetrability values compared to the control concrete.
- The **chloride diffusion coefficient** for RA4 significantly decreased by 73% at 28 days and 75% at 90 days of curing.
- **Water permeability** findings revealed that the RA4 mix reduced water permeability by approximately 31% at 28 days and 54% at 90 days of curing when compared to the control OPC concrete.
- **ESP concrete** displayed excellent **acid resistance** (to both HCl and H2SO4) across all tested mix proportions (RA0 to RA5). This enhanced acid resistance is attributed to the denser and more impermeable hardened concrete matrix formed in ESP concrete mixtures when compared to control OPC concrete.

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