Effect of Rice Husk Ash as Partial Cement Replacement and Coconut Coir Fibre Addition on the Strength and Durability of Concrete

B. Tharun[1], Mr. B. V. Rajiv Vinayak[2], Dr. G. Dinesh Kumar[3]

[1]*M.Tech Student (Structural Engineering),* [2]*Assistant Professor,* [3]*Head of the Department, Department of Civil Engineering,*
Vaagdevi College of Engineering (UGC Autonomous), Bollikunta, Warangal – 506005, Telangana, India

Abstract— Conventional Ordinary Portland Cement (OPC) concrete offers high compressive capacity but suffers from brittle failure under tension, early-age microcracking, and substantial embodied carbon emissions. This study investigates the synergistic use of Rice Husk Ash (RHA)—an amorphous-silica-rich agricultural by-product—as a partial cement replacement alongside natural coconut coir fibre reinforcement in M20 grade concrete. Adopting the material characterization, IS-code testing framework, and parametric benchmark dataset from the Phase-III M.Tech dissertation at Vaagdevi College of Engineering, the investigation evaluates thirteen factorial mixes (M0–M12) spanning 0% to 20% RHA replacement and 0% to 1.5% coir fibre addition by weight of cement, alongside durability benchmarks for 24-hour water absorption, sodium sulphate (Na_2SO_4) resistance, and dilute hydrochloric acid (HCl) resistance at 28 and 56 days. In the reference parametric dataset, the hybrid mix M6 (10% RHA and 1.0% coir fibre) achieves peak 28-day mechanical performance, reaching 25.20 MPa in compressive strength (+12.0% over the 22.50 MPa control M0) and 2.85 MPa in split tensile strength (+21.3% over 2.35 MPa). At 10% RHA without fibres, 24-hour water absorption drops from 4.20% to 3.52% and 56-day acid weight loss declines from 5.60% to 4.25%, whereas coir fibre addition marginally raises absorption (3.68%–3.82%) due to natural fibre hydrophilicity. Critically, this paper separates simulated benchmark projections from measured laboratory data, identifies mix-matrix and baseline-grade inconsistencies in the source dissertation, and defines a rigorous validation protocol prior to structural deployment.

Main Keywords— Rice Husk Ash (RHA), Coconut Coir Fibre, M20 Concrete, Pozzolanic Reaction, Compressive Strength, Split Tensile Strength, Durability, Sustainable Concrete.

I. INTRODUCTION

Concrete remains the foundational structural material for buildings, pavements, and hydraulic infrastructure worldwide, yet its production carries two persistent technical and environmental liabilities. First, Ordinary Portland Cement (OPC) clinker manufacturing is highly energy-intensive and accounts for substantial carbon dioxide emissions, motivating partial cement substitution with supplementary cementitious materials (SCMs) [1], [12]. Second, unreinforced concrete exhibits low tensile strength—typically 8% to 12% of its compressive capacity—and brittle post-cracking behaviour, requiring discrete or continuous reinforcement to arrest microcrack propagation [8], [19].

Agricultural waste valorization offers a dual-benefit pathway to address both constraints simultaneously. Global paddy cultivation generates approximately 220 kg of rice husk per 1,000 kg of rice grain, yielding roughly 70 million tonnes of rice husk annually [1], [2]. Controlled combustion of rice husk produces Rice Husk Ash (RHA), a fine (<45 µm), grey pozzolanic powder rich in amorphous silicon dioxide (SiO_2) [11], [14]. When blended with OPC, amorphous silica reacts with calcium hydroxide—$Ca(OH)_2$, a soluble by-product of cement hydration—to generate secondary calcium silicate hydrate (C-S-H) gel, refining capillary pores and enhancing later-age strength and chemical resistance [11], [14].

However, pozzolanic matrix refinement alone does not resolve concrete's inherent brittleness under tensile and flexural stresses. Coconut coir fibre—extracted from the fibrous outer mesocarp of mature coconuts—provides an abundant, low-density, renewable reinforcement with high elongation at break compared with other natural fibres [7], [8]. Embedded within a cementitious matrix, discrete coir fibres bridge developing microcracks and redistribute tensile stresses across fracture planes [8], [18]. This paper synthesizes and critically evaluates the experimental framework and parametric dataset for M20 grade concrete incorporating both RHA (5%–20% cement replacement) and pre-soaked coconut coir fibres (0.5%–1.5% by cement weight), benchmarking mechanical strength and chemical durability while auditing methodological gaps in the underlying dissertation.

II. LITERATURE SURVEY

Extensive experimental research has established that RHA reactivity and optimal replacement thresholds depend

strongly on burning temperature, particle fineness, and water-binder ratio. Cook et al. [14] and Chindaprasirt and Rukzon [11] demonstrated that finely ground RHA accelerates secondary C-S-H formation, reduces total porosity, and improves resistance to chloride and sulphate ingress. Across normal- and high-strength concretes, however, a consistent upper bound emerges: Ramakrishnan et al. [2] evaluated M40 pavement concrete with 0%–25% RHA and found that 5%–10% replacement preserved mechanical performance, whereas 20%–25% replacement caused marked strength loss due to clinker dilution. Similarly, Shukla et al. [10] reported peak 28-day compressive strength gains at 10% RHA for both M30 (+6.74%) and M60 (+6.50%) concretes, while split tensile strength declined monotonically at higher RHA dosages.

Workability and curing age also govern RHA concrete behaviour. Khassaf et al. [17] observed slump reductions from 70 mm (control) to 55 mm, 45 mm, and 15 mm at 10%, 20%, and 30% RHA, respectively, attributing the loss to RHA's high specific surface area and porous particle morphology; nevertheless, 90-day compressive strength at 10%–20% RHA surpassed the control mix through prolonged pozzolanic activity. Kulkarni et al. [4] and Kartini et al. [5] corroborated that 10% RHA yields superior 28-day compressive strength in M30 mixes, and that superplasticizers are necessary at 20%–30% replacement to offset water demand. By contrast, Akeke et al. [3] noted steady reductions in split tensile and flexural strength as RHA rose from 10% to 25% in a 1:1.5:3 mix.

To counteract tensile losses, researchers have paired RHA with natural fibres. Majid Ali [8] documented the mechanical versatility and crack-bridging capacity of coconut coir fibres in structural composites, while Yalley and Kwan [19] and Nadgouda [9] showed that moderate coir additions improve split tensile toughness and post-cracking ductility, provided fibre balling is avoided. Most directly, Domke [1] investigated M20 concrete combining 2.5%–20% RHA and 1%–4% coir fibre, reporting peak 28-day compressive strength (42.4 MPa vs. 40.0 MPa control) at 12.5% RHA + 2% coir and peak split tensile strength (7.8 MPa) at 15% RHA + 3% coir. Table I synthesizes these benchmark findings alongside the present study.

TABLE I

Summary of Prior Studies on RHA and Coir Fibre Concrete

Study	Grade	RHA / Fibre	Key Finding & Optimum
Domke [1]	M20	2.5–20% RHA; 1–4% coir	12.5% RHA + 2% coir max comp. (42.4 MPa)
Ramakrishnan et al. [2]	M40	0–25% RHA only	5–10% RHA suitable; 20–25% lowers strength
Akeke et al. [3]	1:1.5:3	10–25% RHA only	10% RHA best; tensile drops above 10%
Kulkarni et al. [4]	M30	0–30% RHA only	10% RHA peak 28d comp. (42.8 vs 37.0 MPa)
Shukla et al. [10]	M30/60	0–20% RHA + SP	10% RHA +6.74% (M30), +6.50% (M60) comp.
Khassaf et al. [17]	Canal	0–30% RHA only	Slump 70→15 mm; 90d strength rises
Present Study	M20	0–20% RHA; 0–1.5% coir	10% RHA + 1.0% coir (M6) benchmark peak

III. MATERIALS AND METHODOLOGY

A. Constituent Materials and Physical Characterization

The experimental programme targets M20 grade concrete proportioned in accordance with IS 10262-1982 [20] and IS 456:2000 [22]. Ordinary Portland Cement of 43 grade conforming to IS 8112:1989 [25] serves as the primary binder, stored in moisture-free conditions prior to batching. Rice Husk Ash (<45 µm, grey, irregular, odourless, specific gravity 2.30) is used as a partial cement replacement by weight. Natural river sand sourced from Jalandhar and conforming to Grading Zone II of IS 383:1970 [21] (specific gravity 2.65) serves as fine aggregate. Crushed granite coarse aggregate is blended at 40% of 10 mm and 60% of 20 mm nominal sizes (specific gravity 2.75, water absorption 1.3%), washed and surface-dried before mixing. Potable water meeting IS 456:2000 [22] requirements is used for both mixing and curing.

Mature brown coconut coir fibres (2.5 cm length, 0.022 cm diameter, aspect ratio ≈ 110) were sourced for discrete reinforcement. Because lignocellulosic coir fibres exhibit high water absorption, fibres are pre-soaked in potable water for 2 to 3 hours prior to batching so they do not sequester mixing water or alter the effective water-cement ratio. Table II summarizes the measured physical properties of the constituent materials.

TABLE II

Physical Properties of Constituent Materials

Material	Property / Standard	Value
OPC (43 Grade)	Fineness / Sp. gravity (IS 8112)	5.28 / 3.15
OPC (43 Grade)	Initial / Final setting time	48 / 165 min
Rice Husk Ash	Particle size / Sp. gravity	<45 µm / 2.30
Fine Aggregate	Zone / Sp. gravity (IS 383)	Zone II / 2.65
Coarse Aggregate	10:20 mm / Sp. gr. / Abs.	40:60 / 2.75 / 1.3%
Coir Fibre	Length / Dia. / Aspect ratio	2.5 cm / 0.022 cm / 110

B. Specimen Preparation, Curing, and Testing Protocol

Dry cement, RHA, fine aggregate, and coarse aggregate are blended in a laboratory pan for 2 minutes until uniform colour is achieved. Approximately 50%–80% of the mixing water is added first, followed by the remaining water (and superplasticizer where specified) over 2–3 minutes of mixing. Pre-soaked, drained coir fibres are then fed gradually over 2–3 minutes while stirring to prevent fibre balling and ensure uniform dispersion. Standard 150 × 150 × 150 mm cubes and 150 mm diameter × 300 mm height cylinders are cast in oiled steel moulds, compacted on a vibrating table, demoulded after 24 hours, and water-cured for 7, 14, and 28 days.

Compressive strength (IS 516-1959 [23]) and split tensile strength (IS 5816-1999 [24]) are determined using a 1000 kN Compression Testing Machine (CTM) under gradual, shock-free loading. For durability evaluation, 28-day water-cured 150 mm cubes undergo: (1) 24-hour water absorption after oven-drying to constant mass; (2) sodium sulphate (Na_2SO_4) immersion for 28 and 56 days; and (3) dilute hydrochloric acid (HCl) immersion for 28 and 56 days, recording percentage weight loss and residual compressive strength.

IV. MATHEMATICAL FORMULATION AND MIX MATRIX

Mechanical and durability responses are quantified from ultimate failure loads and gravimetric mass measurements using standard IS expressions:

$$fc = P_max / A \quad (1)$$

$$Ts = 2\,P_max / (\pi\,D\,L) \approx 0.637\,P_max / (D\,L) \quad (2)$$

$$Wa\,(\%) = [(Ws - Wd) / Wd] \times 100 \quad (3)$$

$$\Delta W\,(\%) = [(Wi - Wt) / Wi] \times 100 \quad (4)$$

where fc is compressive strength (MPa), P_max is ultimate load (N), A is cube cross-sectional area (22,500 mm²), Ts is split tensile strength (MPa), D = 150 mm and L = 300 mm are cylinder dimensions, Wd and Ws are oven-dry and 24-hour saturated masses, and Wi and Wt are initial and post-exposure masses in sulphate or acid media.

The factorial evaluation matrix (Table III) pairs four RHA replacement levels (5%, 10%, 15%, 20% by cement weight) with three coir fibre dosages (0.5%, 1.0%, 1.5% by cement weight), benchmarked against the conventional M20 control mix (M0).

TABLE III

Factorial Mix Matrix (M0–M12) and Illustrative 28-Day Strengths

Mix	RHA (%)	Coir (%)	Comp. (MPa)	Split (MPa)
M0	0	0.0	22.50	2.35
M1	5	0.5	23.40	2.48
M2	10	0.5	24.60	2.60
M3	15	0.5	23.80	2.55
M4	20	0.5	22.00	2.38
M5	5	1.0	23.80	2.65
M6	10	1.0	25.20	2.85
M7	15	1.0	24.40	2.75
M8	20	1.0	22.80	2.50
M9	5	1.5	23.00	2.58
M10	10	1.5	24.00	2.78
M11	15	1.5	23.40	2.68
M12	20	1.5	21.50	2.45

V. RESULTS, DURABILITY ANALYSIS, AND CRITICAL EVALUATION

A. Mechanical Strength Trends (7, 14, and 28 Days)

Note on Data Provenance: As explicitly disclosed in the source M.Tech dissertation, the numerical strength and durability datasets (Tables III–IV) are simulated/illustrative benchmark values constructed to model expected pozzolanic and fibre-bridging trends prior to final laboratory verification. Across all 13 mixes, compressive and split tensile strengths increase monotonically from 7 to 14 and 28 days. At 7 days, compressive strength rises from 15.20 MPa (M0) to 16.80 MPa (M6), reaching 20.50 MPa at 14 days (vs. 18.50 MPa for M0) and peaking at 25.20 MPa at 28 days (+12.0% over M0). Similarly, split tensile strength for M6 increases from 1.98 MPa (7d) and 2.45 MPa (14d) to 2.85 MPa at 28 days (+21.3% over M0's 2.35 MPa).

Fig. 1 illustrates the characteristic parabolic response to RHA dosage and fibre content. At 5%–10% RHA, micro-filler packing and secondary C-S-H gel densify the interfacial transition zone (ITZ). Beyond 10% RHA (M3, M4, M7, M8, M11, M12), clinker dilution reduces $Ca(OH)_2$ availability and lowers compressive strength—dropping to 21.50 MPa in M12 (20% RHA, 1.5% coir). Likewise, increasing coir fibre from 0.5% to 1.0% enhances crack-bridging, whereas 1.5% fibre (M9–M12) introduces workability loss, fibre clustering, and entrapped air voids that depress both compressive and tensile capacity relative to the 1.0% fibre series.

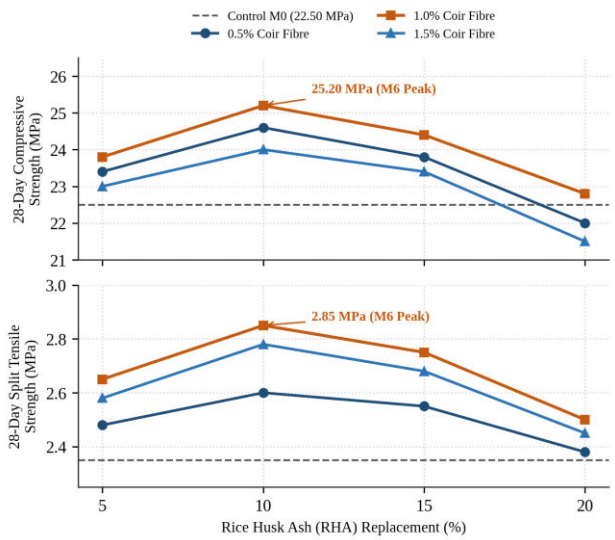

Fig. 1. Illustrative 28-day compressive and split tensile strength variation across RHA replacement and coconut coir fibre levels.

B. Durability Behaviour (Water Absorption, Sulphate, and Acid Attack)

Table IV and Fig. 2 summarize the durability benchmark dataset across five mix designations. Incorporating 10% RHA reduces 24-hour water absorption from 4.20% (Control) to 3.52% (−16.2%), reflecting capillary pore refinement from pozzolanic C-S-H formation [11], [17]. Adding 1% and 2% coconut coir fibre to the 10% RHA matrix raises water absorption slightly to 3.68% and 3.82%, respectively, which remains below the control mix but reflects the hydrophilic capillary nature of natural lignocellulosic fibres.

Under aggressive chemical exposure, weight loss increases with immersion duration from 28 to 56 days across all mixes, accompanied by declining residual strength. At 56 days in Na_2SO_4 solution, 10% RHA exhibits the lowest mass loss (2.65% vs. 3.65% for Control) and highest residual strength (31.40 vs. 27.80 MPa). Under 56-day dilute HCl exposure, 10% RHA similarly limits mass loss to 4.25% (vs. 5.60% Control) and retains 28.50 MPa (vs. 24.80 MPa Control). Adding 1% coir fibre (10% RHA + 1% coir) yields intermediate durability (2.85% sulphate loss; 4.55% acid loss), outperforming both the control mix and the 2% fibre mix.

TABLE IV

Illustrative Durability Benchmarks (Absorption, 56d Sulphate & Acid)

Mix Designation	Abs. (%)	SO_4 Loss (%)	HCl Loss (%)
Conventional Control	4.20	3.65	5.60
5% RHA	3.85	3.10	4.95
10% RHA	3.52	2.65	4.25
10% RHA + 1% Coir	3.68	2.85	4.55
10% RHA + 2% Coir	3.82	3.05	4.85

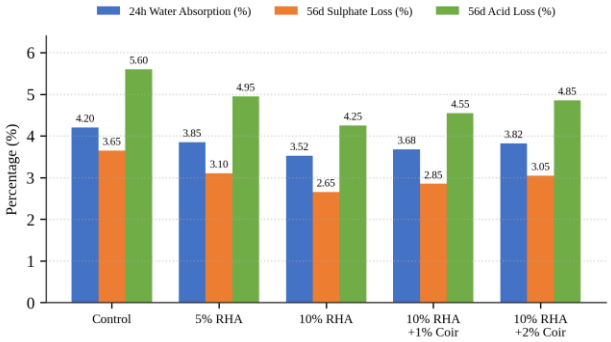

Fig. 2. Illustrative 24-hour water absorption and 56-day weight loss under sodium sulphate and dilute HCl exposure.

C. Critical Evaluation and Methodological Limitations

An independent technical audit of the source dissertation reveals four critical methodological gaps that must be resolved before field application:

1) Simulated vs. Measured Data: The strength and durability tables in Chapters 4.7 and 5 of the source report are explicitly labelled as illustrative/simulated values rather than measured CTM outputs. Reporting them transparently as parametric benchmarks avoids scientific misrepresentation and highlights the need for triplicate laboratory testing (≥3 specimens per mix and age).

2) Mix-Matrix Inconsistency: The dissertation cites 5%–25% RHA and 1%–3% fibre in Chapter 1, lists 7 mixes (M1–M7) in Section 5.2, evaluates 13 factorial mixes (M0–M12) in Sections 5.1–5.3, and switches to 5 mixes (including 2% coir) in the durability module. Harmonizing a single unified factorial matrix is essential for valid cross-property correlation.

3) Durability Baseline Discrepancy: In the durability dataset, 28-day and 56-day residual compressive strengths (27.50–33.10 MPa) exceed the 28-day unexposed M20 strength (22.50–25.20 MPa), indicating an unaligned reference grade (~M30). Future tests must pair exposed cubes with same-batch, water-cured M20 controls.

4) Missing Mix-Design, Workability, and Alkaline-Ageing Controls: Exact batch quantities (cement, RHA, aggregate, w/c ratio, and superplasticizer dosage per m^3) and fresh slump values are omitted, despite RHA and coir fibres strongly reducing workability [17]. Furthermore, untreated coir fibres can degrade in high-pH pore solutions over long service lives, warranting alkali-treatment (e.g., NaOH) and SEM/XRD microstructural validation.

VI. CONCLUSION AND FUTURE WORK

This study critically synthesizes the mechanical and durability framework for sustainable M20 concrete incorporating Rice Husk Ash and coconut coir fibre. Within the reference parametric dataset, 10% RHA combined with 1.0% pre-soaked coir fibre (M6) emerges as the optimal balance, projecting a 12.0% gain in 28-day compressive strength (25.20 MPa) and a 21.3% gain in split tensile strength (2.85 MPa) relative to conventional M20 concrete, while 10% RHA reduces water absorption and chemical mass loss under sulphate and acid attack. Conversely, exceeding 10% RHA or 1.0% fibre degrades strength due to clinker dilution, reduced workability, and void formation.

Future laboratory work will execute triplicate physical testing across a unified M0–M12 matrix, record fresh slump and exact mix-design masses per IS 10262, pair chemical immersion cubes with same-age water-cured M20 controls, and conduct SEM/XRD/EDX characterization alongside alkali-pretreated coir durability trials.

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