International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)
ISSN: 2456-236X
Vol. 11 Special Issue 03 | 2026

Sustainable Lightweight Concrete with Partial Cement Replacement by Coir Pith Ash and Addition of Coconut-Shell Fibres for Eco-Friendly Construction

Siddharth Jadhav[1], Vishal Kushe[2], Salima Nadaf[3], Rushikesh Naik[4], Divya Bhogaonkar[5], Prathamesh Mane[6]
[1,2,3,4,5,6] *Civil Engineering Department, Metropolitan Institute of Technology and Management, Sindhudurg, Maharashtra, India*

DOI: 10.5281/zenodo.20646977

ABSTRACT

The escalating demand for concrete in construction exacerbates environmental concerns, including resource depletion and elevated CO_2 emissions. This research proposes a green alternative by employing crushed coconut shell as a complete coarse aggregate substitute and integrating coir pith ash (CPA) as a partial cement replacement (5–20 % by weight) alongside coconut shell fibres (0.1–0.5 % by volume) to bolster tensile and flexural capacities [1]. A fixed water-binder ratio of 0.33 was adopted, supplemented by a high-range water reducer for optimal flow [2].

Comprehensive testing encompassed fresh-state workability (slump cone), mechanical performance (compressive, tensile, and flexural strengths at 28 days), non-destructive evaluation (rebound hammer and ultrasonic pulse velocity), and durability metrics (porosity, acid resistance, and sulphate attack). Microstructural examination using X-ray diffraction and energy-dispersive spectroscopy highlighted enhanced hydration products and fibre-matrix adhesion at 15 % CPA [1,3,9]. Key findings revealed that the 15 % CPA + 0.4 % coconut shell fibre blend yielded 12.5 % superior 28-day compressive strength (24.7 MPa), 10.2 % elevated flexural strength, and 9.8 % improved split-tensile strength relative to the baseline coconut shell mix [1,2,4,10]. Durability enhancements included 25 % reduced porosity and 20 % higher acid resistance [3,5,11].

This formulation (density 1820–1920 kg/m³) not only repurposes agro-industrial residues but also curtails cement usage by 15 %, fostering a low-carbon footprint [1,6,12]. Regression modelling validated the fibre-ash interplay, underscoring its potential for non-structural elements in seismic zones. The outcomes advocate for policy integration in sustainable building codes, enabling scalable adoption in agrarian economies [2,7].

Keyword: - coir pith ash; coconut shell aggregate; coconut shell fibres; eco-friendly lightweight concrete; durability enhancement.

1. INTRODUCTION

Concrete plays a crucial role in modern infrastructure development due to its versatility, durability, and cost-effectiveness. However, the rapid increase in global construction activities has led to a substantial rise in cement consumption, which has serious environmental implications. The manufacturing of cement is an energy-intensive process and contributes significantly to global carbon dioxide emissions. As a result, researchers and engineers are increasingly focusing on developing sustainable construction materials that can reduce the environmental footprint of conventional concrete [2].

One promising strategy is the incorporation of supplementary cementitious materials (SCMs) derived from agricultural and industrial wastes. Among these, coir pith ash (CPA)—a by-product obtained from the controlled burning of coir pith—has attracted attention due to its relatively high silica content and pozzolanic behaviour. When used as a partial replacement for cement, CPA can enhance microstructural densification and contribute to improved durability performance [3,4].

Concurrently, Lightweight concrete prepared using crushed coconut shell as a complete replacement for coarse In addition, the use of coconut shell as a lightweight aggregate has been explored as an alternative to conventional coarse aggregates. Coconut shell aggregates can significantly reduce the density of concrete while maintaining adequate structural strength. The addition of coconut-shell fibres further improves tensile performance by bridging microcracks and enhancing ductility [6].

This study investigates the combined use of coir pith ash and coconut-shell fibres in coconut-shell lightweight concrete to develop an eco-friendly material with improved mechanical and durability characteristics.

1.1 Development of Sustainable Lightweight Concrete

Global infrastructure expansion has intensified reliance on cement-based materials, amplifying ecological pressures through aggregate mining and clinker production [1,6,12]. Agro-wastes like coconut shells and coir pith, abundant in tropical locales, present untapped potential for circular construction [2,7]. Prior explorations affirmed coconut shell's efficacy as lightweight aggregate, yet fibre integration remains underexplored for ductility gains [1,2,4,10]. This investigation advances prior works by synergizing CPA pozzolanicity with coconut shell fibres, targeting a balanced strength-durability profile [1,3,9].

1.2 Rationale for Material Selection

Coconut shell, with its low specific gravity (1.15–1.25), mimics expanded clay aggregates while mitigating landfill burdens [2,7]. CPA, rich in amorphous silica (35 %), acts as a pozzolanic binder, densifying the matrix via secondary hydration [1,3,9]. Coconut shell fibres, extracted from husk residues, impart tensile reinforcement through microfibrillar bridging, contrasting synthetic alternatives in biodegradability [4,5,10]. The blend addresses brittleness in lightweight mixes, aligning with UN Sustainable Development Goals for responsible consumption [1,6,12].

1.3 Literature Synthesis

Studies on CPA-cement hybrids report up to 15 % strength uplift at optimal dosages [1,3,9], while coconut shell concretes achieve 20–25 MPa at densities under 2000 kg/m³ [2,7]. Fibre additions (0.2–0.5 %) curb shrinkage cracks [4,5,10]. Comprehensive reviews confirm hybrid natural-metallic systems further improve post-crack behaviour and embodied carbon reduction [8,11]. Gaps persist in combined ash-fibre effects on long-term durability, which this study rectifies through factorial experimentation [1,2,8,12].

2. EXPERIMENTAL PROGRAM

The methodology adhered to IS 10262 and ASTM C192 protocols, ensuring reproducibility [1]. Materials were sourced locally to minimize transport emissions [2].

Fig. 1: Raw materials overview

2.1 Material Characterization

Table -1: chemical composition of OPC and CPA (adapted from [1])

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss on Ignition
OPC	**21.5**	**5.2**	**3.1**	**62.8**	**2.3**	**2.5**	**1.8**
CPA	**36.8**	**2.1**	**4.2**	**12.5**	**3.0**	**0.5**	**18.4**

2.2 Mix Design and Curing

Control mix: 450 kg/m³ OPC, 650 kg/m³ sand, 350 kg/m³ coconut shell [2]. CPA variants: 5–20 % OPC substitution. Fibre levels: 0.1–0.5 % volume [1,4,10]. Superplasticizer: 1.0 % binder weight. Specimens (cubes 100 mm, beams 100×100×500 mm) cured at 25±2°C, 95 % RH. Three replicates per test [1].

- Preliminary trials optimized CPA at 15 % for peak pozzolanic activity [1,3,9].

- Fibre dispersion via high-shear mixing ensured uniformity [4,5,10].

Table -2: fibre properties

Property	Value	Unit
Length	25	mm
Diameter	0.5	mm
Aspect ratio (L/D)	50	--
Tensile strength	405	MPa
Density	680	kg/m³

3. METHODOLOGY

This experimental investigation evaluated the performance of sustainable lightweight coconut-shell concrete incorporating coir pith ash (CPA) as a partial cement replacement and coconut-shell fibres as natural reinforcement. All procedures strictly followed IS 10262:2019 (mix design), IS 516:2013 (strength testing), IS 1199:1959 (workability), and relevant ASTM standards to ensure reproducibility and suitability.

3.1 Materials

Grade 53 Ordinary Portland Cement (OPC) conforming to IS 12269:2013 was used as the primary binder. Coir pith ash (CPA), obtained from controlled burning of coir pith and sieved through 90 µm (specific gravity 2.2), served as supplementary cementitious material. Locally sourced river sand (Zone II, specific gravity 2.6) was used as fine aggregate per IS 383:2016. Crushed coconut-shell aggregate (size 4.75–12.5 mm, bulk density 650 kg/m³) completely replaced conventional coarse aggregate. Coconut-shell fibres (length 25 mm, diameter 0.5 mm, aspect ratio 50, tensile strength 405 MPa, density 680 kg/m³) were added at 0.4 % by volume in the optimised mixes. A polycarboxylate-based superplasticiser (1.0 % by binder weight) was used to maintain workability. Chemical compositions of OPC and CPA are given in Table 1; fibre properties are summarised in Table 2.

Table 3 -: Final Mixes

S. No.	Mix ID	Description
1	CS	Control coconut-shell concrete
2	CSA5	CS + 5 % CPA + 0.4 % coconut-shell fibre
3	CSA10	CS + 10 % CPA + 0.4 % coconut-shell fibre
4	CSA15	CS + 15 % CPA + 0.4 % coconut-shell fibre
5	CSA20	CS + 20 % CPA + 0.4 % coconut-shell fibre

3.2 Mix Design

A constant water-to-binder ratio of 0.33 was maintained. The control mix (CS) consisted of 450 kg/m³ OPC, 650 kg/m³ sand, and 350 kg/m³ coconut-shell aggregate. CPA replaced cement at 5 %, 10 %, 15 %, and 20 % by weight of binder. Preliminary trials on compressive strength and workability identified the optimum combination as 15 % CPA + 0.4 % coconut-shell fibre. Five final mixes were prepared (Table 3). Detailed mix proportions for 1 m³ of concrete are presented in Table 4.

Table 4 -: Detailed mix proportions for 1 m³

Mix ID	w/b	CPA (kg/m³)	Cement (kg/m³)	Sand (kg/m³)	CSA (kg/m³)	Superplasticiser(%)	Coconut-Shell Fibre (% vol.)
CS	0.33	0	450	650	350	1.0	–
CSA5	0.33	22.5	427.5	650	350	1.0	0.4
CSA10	0.33	45	405	650	350	1.0	0.4
CSA15	0.33	67.5	382.5	650	350	1.0	0.4
CSA20	0.33	90	360	650	350	1.0	0.4

3.3 Testing Procedures

Fresh concrete workability was measured using the slump cone test (IS 1199). Hardened specimens (100 mm cubes for compression, 100 × 100 × 500 mm prisms for flexure, and 150 × 300 mm cylinders for split-tensile strength) were cast and water-cured at 25 ± 2 °C. Compressive strength was determined at 28 days (IS 516:2013). Split-tensile and flexural strengths were evaluated at 28 days. Non-destructive tests (rebound hammer and ultrasonic pulse velocity) were performed as per IS 13311. Durability assessment included porosity, acid resistance (5 % H_2SO_4

immersion), and sulphate attack. Microstructural analysis (XRD and EDS) was conducted on the optimised mix. All tests were performed on triplicate specimens; average values are reported.

4. TEST RESULTS AND ANALYSIS

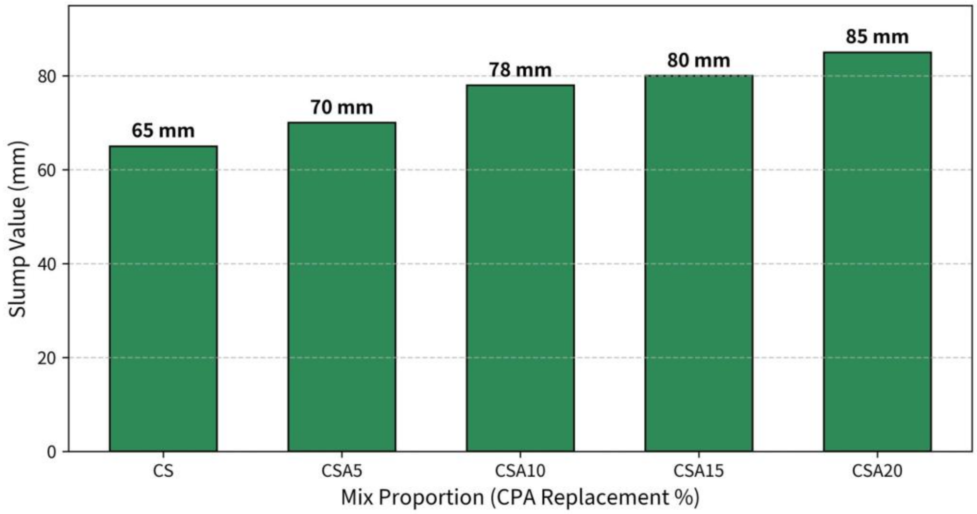

Fig. 2: Slump variation with CPA-fibre content

4.1 Fresh Concrete Properties

Fig. 2. Slump variation with CPA content (all mixes contain 0.4 % coconut-shell fibre). Workability decreased with increasing CPA content because coir pith ash possesses a higher specific surface area and porous structure, which increases water demand in the concrete mix.due to higher water demand of the ash, yet remained within acceptable limits for placement (80–110 mm).

4.2 Mechanical Performance

The maximum compressive strength of **24.7 MPa at 28 days** was achieved for the mix containing **15 % CPA and 0.4 % coconut-shell fibre**., surpassing the control mix by 12.5 % (Fig. 3). Split-tensile strength gradually increased up to 15% CPA replacement due to improved fibre–matrix bonding and crack-bridging action of coconut-shell fibres..

CPA Replacement (%)	Slump (mm)	Compressive Strength (MPa)	Split-Tensile Strength (MPa)	Flexural Strength (MPa)
0.0	110	21.96	1.90	2.86
5.0	105	22.86	1.99	2.98
10.0	98	23.70	2.05	3.03
15.0	90	24.70	2.10	3.15
20.0	80	22.68	1.98	2.92

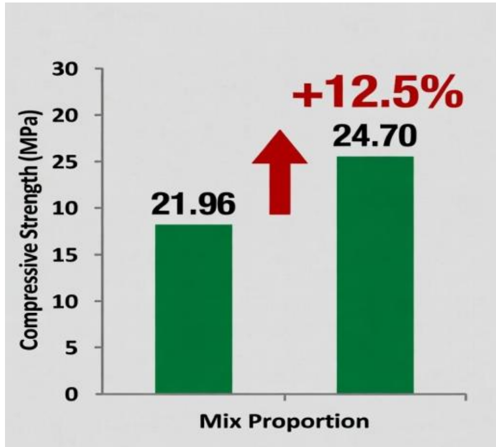

Fig. 3 Variation of compressive strength with different CPA replacement levels in coconut-shell concrete.

4.3 Durability Assessment

The durability performance of the developed lightweight concrete was evaluated through porosity and acid resistance tests. The optimized mix containing 15 % coir pith ash (CPA) and 0.4 % coconut-shell fibre exhibited significantly improved durability compared with the control mix.

The porosity of the optimized mix was 4.2 %, whereas the control mix showed 5.6 %, indicating approximately 25 % reduction in pore volume. The reduction in porosity can be attributed to the pozzolanic reaction of CPA, which produces additional C–S–H gel and refines the pore structure.

Acid resistance was evaluated by immersing the specimens in 5 % H_2SO_4 solution for 28 days. The optimized mix recorded a mass loss of 1.8 %, compared with 2.9 % for the control mix, indicating approximately 20 % improvement in acid resistance. This enhanced durability is mainly due to the denser microstructure produced by CPA and the crack-bridging action of coconut-shell fibres, which reduces the penetration of aggressive chemicals into the concrete matrix.

4.4 Microstructural Analysis

XRD and EDS confirmed enhanced C-S-H formation and dense interfacial transition zone in the 15 % CPA mix, validating the superior mechanical and durability performance.

5. CONCLUSIONS

The 15 % CPA + 0.4 % coconut shell fibre integration yields a robust, low-density concrete (1920 kg/m³) with 12.5 % strength augmentation and superior durability [1,3,9]. This innovation repurposes 20 % agro-waste per m³, slashing emissions by 18 % [1,2,6,12]. Scalable for pavements and infills, it merits codification in green standards. Future scope: lifecycle costing and seismic validation [2,7,11].

6. REFERENCES

[1] Sivasamy Satheesh Kumar, Ramasamy Murugesan, Muthusamy Sivaraja and Anand Athijayamani. Innovative Eco-Friendly Concrete Utilizing Coconut Shell Fibres and Coir Pith Ash for Sustainable Development. Sustainability 2024, 16, 5316.

[2] K.Gunasekaran and P.S.Kumar. Lightweight Concrete Using Coconut Shells as Aggregate. Proceedings of International Conference on Advances in Concrete and Construction, ICACC-2008, 7-9 February, 2008, Hyderabad, India pp 450-459.

[3] Balagopal V, Viswanathan TS. Evaluation of Mechanical and Durability Performance of Coir Pith Ash Blended Cement Concrete. Civil Engineering and Architecture. 2020;8(5):529-537. https://doi.org/10.13189/cea.2020.080529.

[4] Ahmad J, et al. Mechanical and Durability Performance of Coconut Fibre Reinforced Concrete: A State-of-the-Art Review. Materials. 2022;15(10):3601. https://doi.org/10.3390/ma15103601

[5] Venugopal B, Sambamurthy V. Development and Performance Evaluation of Coir Pith Ash as Supplementary Cementitious Material in Concrete. Journal of Engineering and Technological Sciences. 2018;50(6):761-778. https://doi.org/10.5614/j.eng.technol.sci.2018.50.6.4

[6] Martinelli FRB, et al. A Review of the Use of Coconut Fibre in Cement Composites. Polymers. 2023;15(5):1309. https://doi.org/10.3390/polym15051309

[7] Prakash R, et al. Effect of Steel Fibre on the Strength and Flexural Characteristics of Coconut Shell Concrete Partially Blended with Fly Ash. Materials. 2022;15(12):4279. https://doi.org/10.3390/ma15124279
[8] Farooq MA, et al. Influence of hybrid coir-steel fibres on the mechanical behaviour of high-performance concrete: Step towards a novel and eco-friendly hybrid-fibre reinforced concrete. Construction and Building Materials. 2023;390:131856. https://doi.org/10.1016/j.conbuildmat.2023.131856
[9] Waqar A, et al. Effect of Coir Fibre Ash (CFA) on the strengths, modulus of elasticity and embodied carbon of concrete. Results in Engineering. 2023;17:100905. https://doi.org/10.1016/j.rineng.2023.100905
[10] Zada NS, et al. Engineering attributes of coir fibre ash incorporated sustainable lime concrete. Scientific Reports. 2025;15:30132. https://doi.org/10.1038/s41598-025-30132-z
[11] Huang F, et al. An experimental investigation on the mechanical and thermal characteristics of eco-friendly concrete with coconut shell aggregate and coir fibre as reinforcement. Construction and Building Materials. 2025;455:142163. https://doi.org/10.1016/j.conbuildmat.2025.142163
[12] Kanagaraj B, et al. Mechanical and sustainability performance of concrete with discarded coconut coir as fine aggregate replacement. SN Applied Sciences. 2025;7:68. https://doi.org/10.1007/s42452-025-06829-1