

Development and Performance Evaluation of Biochar–Fly Ash Concrete for Sustainable Construction Applications

Mamathashree¹, Usha S.^{2*}, Shivaraju G.D.³

DOI:10.31033/IJEMR/16.5.2026.1950

¹ Mamathashree, Department of Civil Engineering, Sri Siddhartha Institute of Technology (A Constituent College of Sri Siddhartha Academy of Higher Education), Maralur, Tumakuru, Karnataka, India.

^{2*} Usha S., Research Scholar and Assistant Professor, Department of Civil Engineering, Sri Siddhartha Institute of Technology (A Constituent College of Sri Siddhartha Academy of Higher Education), Maralur, Tumakuru, Karnataka, India.

³ Shivaraju G.D., Associate Professor, Department of Civil Engineering, Sri Siddhartha Institute of Technology (A Constituent College of Sri Siddhartha Academy of Higher Education), Maralur, Tumakuru, Karnataka, India.

Portland cement production contributes roughly 7–8% of global CO₂ emissions, which has driven interest in supplementary cementitious materials and carbon-sequestering additives. This study evaluates coconut-shell-derived biochar, used as a cement-weight additive at 0–5%, in a fly ash blended concrete system. Biochar was characterized by EDX (carbon 77–80%, oxygen 15–16%) and physical tests (specific gravity 1.60, fineness modulus 1.83, water absorption 15.8%). Concrete specimens were tested for compressive, split tensile and flexural strength at 7, 14 and 28 days, and for strength loss after sulphate attack, chloride attack and alternate wet–dry cycles. A 1% biochar dose gave the highest 28-day compressive strength (33.8 MPa, +7.0% over the 31.6 MPa control), and 2% gave 33.2 MPa (+5.1%). Doses of 3% and above gave no gain or a reduction. Early-age (7- and 14-day) split tensile and flexural strength improved at 1–3%, but 28-day tensile and flexural strengths were below the control for all dosages. Durability was best at 2% biochar, where strength loss was 2.2% (sulphate), 1.8% (chloride) and 2.8% (wet–dry), against 8.5%, 7.0% and 9.0% for the control. The results indicate that a low biochar dosage of about 1–2% can improve compressive strength and durability, while higher dosages are detrimental.

Keywords: Biochar, Coconut Shell, Fly Ash, Sustainable Concrete, Compressive Strength, Durability, Carbon Sequestration, EDX

Corresponding Author	How to Cite this Article	To Browse
Usha S., Research Scholar and Assistant Professor, Department of Civil Engineering, Sri Siddhartha Institute of Technology (A Constituent College of Sri Siddhartha Academy of Higher Education), Maralur, Tumakuru, Karnataka, India. Email: ushas@ssit.edu.in	Mamathashree, Usha S., Shivaraju G.D., Development and Performance Evaluation of Biochar–Fly Ash Concrete for Sustainable Construction Applications. Int J Engg Mgmt Res. 2026;16(5):11-15. Available From https://ijemr.vandanapublications.com/index.php/j/article/view/1950	

Manuscript Received 2026-09-04	Review Round 1 2026-09-19	Review Round 2	Review Round 3	Accepted 2026-10-10
Conflict of Interest None	Funding Nil	Ethical Approval Yes	Plagiarism X-checker 4.30	Note



© 2026 by Mamathashree, Usha S., Shivaraju G.D. and Published by Vandana Publications. This is an Open Access article licensed under a Creative Commons Attribution 4.0 International License <https://creativecommons.org/licenses/by/4.0/> unported [CC BY 4.0].



1. Introduction

Concrete is the most widely used construction material in the world, but its principal binder, Portland cement, is responsible for approximately 7–8% of global CO₂ emissions. Supplementary cementitious materials (SCMs) and carbon-negative additives are therefore being studied as ways to lower the footprint of concrete. Fly ash, a by-product of coal-fired power plants, is widely used as a partial cement replacement because of its pozzolanic activity, improved workability and long-term strength gain.

Biochar is a porous, carbon-rich solid produced by pyrolysis of agricultural or forestry residues in an oxygen-limited environment, typically at 300–700 °C. Temperature and residence time control its porosity, surface area and stability. In cementitious systems biochar has been reported to act as a micro-filler, to supply internal curing water, to reduce shrinkage and to sequester carbon [1–5]. It is generally used as an additive at about 0.5–10% by weight of binder or as a partial fine-aggregate replacement of up to about 15%. Its high porosity and angular shape often reduce workability at higher dosages.

Reviews and experimental studies report that small biochar dosages improve strength up to an optimum, after which strength falls [1–3, 9]. Work on combined biochar and fly ash systems is still limited [6, 7]. This study addresses that gap by examining the mechanical and durability performance of concrete containing coconut biochar as an additive in a fly ash blended binder, and by characterizing the biochar microstructurally.

The objectives were:

1. To develop concrete mixes incorporating biochar as an additive and as a partial replacement of fine aggregate.
2. To examine the biochar–fly ash interaction through strength development and SEM/EDX
3. To determine compressive, split tensile and flexural
4. To assess durability under sulphate attack, chloride attack and alternate wet–dry
5. To identify the optimum biochar

This paper reports the results for the additive mode (0–5% biochar).

2. Materials and methods

2.1 Materials

- **Cement:** Ordinary Portland Cement, 43/53 grade, conforming to IS 8112 / IS
- **Fly Ash:** Class F fly ash used as a partial cement replacement in the blended
- **Biochar:** Coconut biochar produced by pyrolysis of agricultural biomass at 400–600 °C, ground to a fine powder and sieved to a uniform particle size.
- **Fine Aggregate:** Natural River sand conforming to IS
- **Coarse Aggregate:** Crushed stone of 20 mm maximum
- **Water:** Potable water, used for mixing and

2.2 Biochar Characterization

Particle size, specific gravity, fineness modulus and water absorption of the biochar were determined. The elemental composition of the biochar was obtained by energy-dispersive X-ray spectroscopy (EDX) with SEM imaging of the selected area.

2.3 Mix Design

Biochar was added at 0, 1, 2, 3, 4 and 5% by weight of cement. The fly ash replacement level was 10–30% of cement in the blended binder, and the control mix contained no biochar. In the wider programme biochar is also being examined as a 5–15% fine-aggregate replacement. [Insert: concrete grade, water–binder ratio, fly ash percentage used in the reported mixes, and mix proportions (kg/m³) in a table.]

2.4 Casting and Curing

Cubes, cylinders and beams were cast for each mix, compacted on a vibrating table and water-cured. Specimens were tested at 7, 14 and 28 days.

2.5 Mechanical Testing

Compressive strength (cubes), split tensile strength (cylinders) and flexural strength (beams) were determined in a compression testing machine in accordance with the relevant IS codes. [Insert: specimen dimensions, IS code numbers, loading rate, and number of specimens per mix.]

2.6 Durability Testing

Durability was assessed as percentage change in 28-day compressive strength after exposure to sulphate attack, chloride attack and alternate wet-dry cycles. [Insert: solution concentrations, exposure duration and number of wet-dry cycles.]

3. Results and discussion

3.1 Biochar Characterisation

EDX analysis (Table 1) showed that the biochar is dominated by carbon (77–80%) and oxygen (15–16%), with minor Si, Al, K, Ca and Fe. The surface-area measurement gave 77.07 wt% C and 15.87 wt% O in the analysed region. The oxygen indicates surface functional groups such as –OH and –COOH that can bond with the cement matrix, while the Si and Al contents may contribute to pozzolanic activity. The SEM image showed an irregular, porous, flaky morphology.

Table 1: EDX analysis of coconut biochar

Element	Approx. content (%)	Role in concrete
Carbon	77–80	Carbon sequestration, micro-filler, internal curing
Oxygen	15–16	Functional groups (–OH, – COOH) aiding bonding with matrix
Silicon	1.5–1.7	Pozzolanic activity, C–S–H formation
Aluminium	0.7–1.2	Pozzolanic reactions, durability
Potassium	0.6–1.3	Alkali activation of cementitious reactions
Calcium	0.3–0.6	Cement hydration
Iron	0.5–0.9	Minor effect on density
Magnesium, Chlorine	Trace	Negligible

Table 2: Physical properties of coconut biochar

Property	Value	Remark
Specific gravity	1.60	Lightweight, porous
Fineness modulus	1.83	Very fine, acts as filler
Water absorption	15.8%	High, due to porous structure

The low specific gravity and high-water absorption of the biochar explain both its potential for internal curing and its tendency to reduce workability at higher dosages.

3.2 Compressive Strength

Table 3: Compressive strength (MPa) of concrete with biochar as additive

Biochar (% by wt. of cement)	7 days	14 days	28 days
0 (control)	8.4	19.6	31.6
1	16.0	28.0	33.8
2	14.2	21.8	33.2
3	16.0	20.0	30.2
4	13.4	20.4	31.6
5	20.9	24.4	31.6

The 1% mix gave the highest strength at every age (20.8, 27.8 and 33.8 MPa), followed by 2%. At 3% strength fell below the control, and at 4–5% the 28-day strength only matched it. This trend of a strength gain at low dosage followed by a decline agrees with the optimum-dosage behaviour reported in the literature [1–3, 9]. The gain is attributed to internal curing from water held in the porous biochar and to filler action, and the decline to the dilution of cement and the extra water demand of the biochar at higher dosage.

3.3 Split Tensile Strength

Table 4: Split tensile strength (MPa) of concrete with biochar as additive

Biochar (%)	7 days	14 days	28 days
0 (control)	1.90	2.32	3.54
1	2.00	2.40	3.40
2	2.10	2.60	3.11
3	1.80	2.50	2.83
4	1.83	2.20	3.40
5	1.70	2.10	2.83

At 7 and 14 days, 1–2% biochar raised split tensile strength by up to 10.5% and 12.1% respectively (2% mix). At 28 days, however, every biochar mix was below the control. The early-age gain is consistent with internal curing, while the 28-day result shows that the benefit in tension did not persist in this programme. [Verify the 28-day values before submission; the 4% mix (3.40 MPa) exceeds the 2% and 3% mixes, which does not follow the trend.]

3.4 Flexural Strength

Table 5: Flexural strength (MPa) of concrete with biochar as additive

Biochar (%)	7 days	14 days	28 days
0 (control)	2.30	2.63	2.74
1	2.30	2.32	2.32
2	2.60	3.20	2.42
3	2.50	3.00	2.40
4	2.20	2.80	2.00
5	2.00	2.50	2.36

Flexural strength at 7 and 14 days was higher than the control for the 2–3% mixes (up to +21.7% at 14 days for 2%). At 28 days all biochar mixes were below the control. For several mixes the 28-day value is lower than the 14-day value (for example 3.20 to 2.42 MPa at 2%), which is unusual for water-cured concrete and should be checked against the raw test records, or explained, before submission.

3.5 Durability

Table 6: 28-day compressive strength and strength loss after exposure

Biochar (%)	28-day strength (MPa)	Sulphate attack (%)	Chloride attack (%)	Wet-dry cycles (%)
0	31.6	–8.5	–7.0	–9.0
1	33.8	–6.5	–5.5	–6.8
2	33.2	–2.2	–1.8	–2.8
3	30.2	–5.8	–5.0	–6.2
4	31.6	–8.0	–7.2	–8.8
5	31.6	–10.2	–9.0	–11.0

All mixes lost strength under every exposure. The 2% mix lost the least (2.2%, 1.8% and 2.8%), about a quarter to a third of the control's loss, and the 1% and 3% mixes also performed better than the control. The 5% mix performed worse than the control in all three tests. The improved resistance at 1–3% is consistent with pore refinement and reduced chloride ingress reported for biochar [1, 5], while excess biochar adds porosity and weakens the matrix. Because 2% combined the second-highest compressive strength with by far the best durability, it is the most favorable overall dosage in this study.

3.6 Optimum Dosage

The optimum dosage depends on the property. Compressive strength peaked at 1%, durability at 2%, and neither split tensile nor flexural strength at 28 days exceeded the control. Taking compressive strength and durability together, 1–2% biochar by weight of cement is recommended, with 2% the best choice where durability governs.

4. Conclusions

1. EDX analysis showed the coconut biochar to be a porous, carbon-rich material (77–80% C, 15–16% O) with minor Si, Al, K and Ca, and a specific gravity of 1.60, fineness modulus of 1.83 and water absorption of 15.8%.

2. Biochar at 1% and 2% by weight of cement raised the 28-day compressive strength by 7.0% and 5.1%. Dosages of 3% and above gave no benefit.

3. Early-age split tensile and flexural strength improved at 1–3%, but 28-day tensile and flexural strengths were lower than the control for all dosages.

4. Strength loss under sulphate, chloride and wet-dry exposure was lowest at 2% biochar (2.2%, 1.8% and 2.8%, against 8.5%, 7.0% and 9.0% for the control), and highest at 5%.

5. A dosage of about 1–2% is recommended, because higher dosages reduce strength and

Limitations and Future Work

The results apply to additive-mode dosage of coconut biochar; the fine-aggregate replacement series and 56-day results are not reported here. Further work should cover other biomass sources, field-scale

performance, creep, shrinkage, carbonation and freeze–thaw resistance, and life cycle and cost assessment of the carbon sequestration benefit.

Declarations

Conflict of Interest: The authors declare no competing interests.

Data Availability: The data supporting this study are available from the corresponding author on request.

Acknowledgements: The authors thank the Head of the Department of Civil Engineering, the PG Coordinator and the faculty of Sri Siddhartha Institute of Technology, Tumakuru, for their support.

References

- [1] Senadheera, S., et al. (2023). Application of biochar in concrete – A review. *Construction and Building Materials*.
- [2] Barbhuiya, (2024). *Biochar-concrete: A comprehensive review of properties*.
- [3] Aman, M. N. (2022). *Biochar as cement replacement to enhance concrete*.
- [4] Room, (2024). Biochar-enhanced carbon-negative and sustainable cementitious composites. *Sustainability*.

[5] Tee, K. F. (2023). Biochar in cementitious material: A review on physical, chemical, mechanical and durability aspects. *AIMS Materials*.

[6] Mishra, G., et al. (2023). *Optimization of biochar and fly ash to improve mechanical properties*.

[7] Praneeth, S., et al. (2025). *Low carbon biochar amended fly ash–cement building blocks*.

[8] Wu, F., et al. (2025). *Biochar modification enhances mechanical and durability properties*.

[9] Patel, R., et al. (2025). Study of biochar in cementitious materials. *Scientific Reports*.

[10] Aman (2022–2024). *Various tests on biochar as partial replacement*.

[11] Bhavana, K. Y., Usha, S., Mallesh, T. V., & Shiva Raju, G. D. (2024). Numerical simulation of eco sustainable construction and demolition waste (CDW) based geopolymer concrete blocks as coarse aggregates by using ANSYS software. *IOP Conference Series: Earth and Environmental Science*, 1327(1), p.

[12] Usha, S., Shivaraju, G. D., Mallesh, T. V., Prathibha, R. T., & Navya, S. M. (2022). Performance assessment of fly-ash aggregates in *International Journal of Health Sciences*, 6(S9), 3858–3864.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of Journals and/or the editor(s). Journals and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.