DEVELOPMENT AND PERFORMANCE EVALUATION OF BIOCHAR–FLY ASH CONCRETE FOR SUSTAINABLE CONSTRUCTION APPLICATIONS

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College : Sri Siddhartha Institute of Technology, Tumakuru
Branch : Department of Civil Engineering
Guide(s) : Dr. Usha S
Dr. Shivaraju G D
Student(s) : Ms. Mamathashree

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Introduction:

1. The construction industry is increasingly focusing on sustainable materials to reduce environmental impact and carbon emissions. In this context, biochar, a carbon-rich material derived from biomass, has gained attention due to its potential for carbon sequestration and its beneficial effects on concrete properties. Simultaneously, fly ash, an industrial by-product, is widely used as a supplementary cementitious material due to its pozzolanic characteristics. The combined utilization of biochar and fly ash in concrete offers a promising approach toward developing eco-friendly and high-performance construction materials.
2. Biochar possesses a porous structure and high water-retention capacity, which can enhance internal curing and promote hydration and pozzolanic reactions in concrete. However, its effectiveness depends on factors such as dosage, particle size, and method of incorporation, either as an additive or as a partial replacement for fine aggregates. Therefore, it is essential to evaluate the mechanical properties and durability performance of biochar–fly ash concrete.
3. This study aims to investigate the interaction between biochar and fly ash, assess strength and durability characteristics, and determine the optimum biochar content for sustainable concrete applications.

Objectives:

1. To develop concrete mixes incorporating biochar derived from suitable biomass sources, used both as an additive and as a partial replacement for fine aggregates.
2. To study the interaction between fly ash and biochar, with emphasis on the role of biochar’s water-retention capacity in enhancing hydration and pozzolanic reactions, evaluated through 28-day and 56-day strength development and microstructural analysis (SEM and EDX).
3. To evaluate the mechanical properties of biochar–fly ash concrete, including compressive strength, split tensile strength, and flexural strength at 28 and 56 days.

4. To assess the durability performance of biochar–fly ash concrete through water absorption, permeability, sulphate resistance, chloride penetration, and alternate wet–dry cycle tests.
5. To identify the optimum biochar dosage and mode of incorporation (additive or fine aggregate replacement) that provides enhanced mechanical and durability performance while contributing to carbon sequestration and improved environmental sustainability.

Methodology:

1. **Material Selection and Characterization**

Fly ash (Class F), Ordinary Portland Cement, natural aggregates, and biochar derived from suitable biomass sources (preferably wood or bamboo-based) are collected. Basic characterization of biochar, including particle size, pH, and water absorption, is carried out. Microstructural and elemental characterization using SEM and EDX is conducted for selected biochar samples and hardened concrete to understand material interactions.

2. **Mix Design Development**

Concrete mixes are prepared with varying biochar contents used in two modes:

→ As an additive (1–5% of binder)

→ As a partial replacement for fine aggregate (5–15%)

Fly ash replaces a portion of cement (10–30%) to develop a blended binder system. Control mixes without biochar are also prepared for comparison.

3. **Casting and Curing of Specimens**

Standard concrete cubes, cylinders, and beams are cast for all mix combinations. Specimens are cured under controlled conditions and tested at 7, 28, and 56 days to study early-age and long-term performance.

4. **Mechanical Property Evaluation**

Mechanical properties including compressive strength, split tensile strength, and flexural strength are determined at 28 and 56 days in accordance with relevant IS standards.

5. **Durability Performance Assessment**

Durability characteristics are evaluated through water absorption, sorptivity/permeability, sulphate attack resistance, chloride penetration, and alternate wet–dry cycle tests to assess long-term durability.

6. **Microstructural Evaluation and Comparative Analysis**

SEM and EDX analyses are performed on selected hardened concrete samples to study the interaction between fly ash and biochar and to understand hydration and pozzolanic reaction mechanisms. Results are compared among biochar additive concrete, biochar fine aggregate replacement concrete, and control concrete, and the optimum mix is identified based on mechanical performance, durability, and carbon sequestration potential.

Result and Conclusion:

Table 1 : EDAX Analysis of Coconut Biochar and Its Significance

Sl. No.	Element	Presence (Approx. %)	Role / Significance in Concrete
1	Carbon (C)	77 – 80%	Provides carbon sequestration, acts as micro-filler, improves internal curing and adsorption properties
2	Oxygen (O)	15 – 16%	Indicates functional groups (–OH, –COOH) which enhance bonding with cement matrix and hydration
3	Silicon (Si)	1.5 – 1.7%	Contributes to pozzolanic activity, helps in formation of C-S-H gel and strength gain
4	Aluminium (Al)	0.7 – 1.2%	Supports pozzolanic reactions and improves durability
5	Potassium (K)	0.6 – 1.3%	Alkali element aiding in activation of cementitious reactions
6	Calcium (Ca)	0.3 – 0.6%	Contributes to cement hydration and strength development
7	Iron (Fe)	0.5 – 0.9%	Minor role in improving density and stability of matrix
8	Magnesium (Mg)	Trace	Helps in minor binding reactions and matrix stability
9	Chlorine (Cl)	Trace	Present in negligible amount, no significant effect

Table 2: Physical Properties of Coconut Biochar

Sl. No.	Property	Value	Remarks
1	Specific Gravity	**1.40 – 1.60**	Indicates lightweight and porous material
2	Fineness Modulus (FM)	**1.83**	Very fine material (acts as filler)
3	Water Absorption	**20.9%**	High absorption due to porous structure

Table 3: Mechanical Properties of Concrete with Biochar as Additive (28 Days)

Sl. No.	Biochar Content (% by weight of cement)	Compressive Strength	Split Tensile Strength	Flexural Strength	**Remarks**
1	0	31.5	2.9	3.6	Control mix - Satisfactory
2	1	33.2	3.0	3.8	Improved Strength
3	2	35.0	3.2	4.0	Optimum Performance
4	3	33.8	3.1	3.8	Comparable to optimum
5	4	31.2	2.8	3.5	Slight reduction
6	5	29.5	2.6	3.2	Below target strength

Table 4: Mechanical Properties of Concrete with Biochar as Fine Aggregate Replacement (28 Days)

Sl. No.	Biochar Replacement (% by weight of Fine Aggregate)	Compressive Strength	Split Tensile Strength	Flexural Strength	**Remarks**
1	0	31.5	2.9	3.6	Control mix - Satisfactory
2	5	32.8	3.0	3.8	Slight improvement
3	10	34.2	3.2	4.0	Optimum performance
4	15	31.0	2.8	3.5	Comparable to control mix
5	20	28.8	2.6	3.2	Reduction in strength

In conclusion,

1. EDAX analysis revealed that coconut biochar is predominantly composed of **carbon (~77–80%)**, with minor amounts of oxygen, silica, and alumina, indicating its potential to enhance hydration and contribute to limited pozzolanic reactions.
2. The physical properties of coconut biochar indicate that it is a lightweight, porous, and fine material suitable as a micro-filler and internal curing agent in concrete.
3. Biochar incorporation in concrete improves mechanical properties at lower dosages due to its micro-filler effect and internal curing capability.
4. The optimum biochar content as an additive was found to be **2% by weight of cement**, while **10% replacement of fine aggregate** yielded the best performance in terms of strength and durability.
5. Biochar does not possess primary binding properties like cement; however, it enhances concrete performance as an additive by improving microstructure and bonding characteristics.
6. Beyond the optimum levels, strength decreases due to increased porosity and reduction in the effective load-carrying matrix.

References:

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Future Scope:

The future scope of this project includes:

1. Exploration of different biomass sources (agricultural waste, wood waste, etc.) for producing biochar with enhanced properties.
2. Study on large-scale application and field performance of biochar–fly ash concrete in real construction conditions.
3. Investigation of long-term durability aspects such as creep, shrinkage, carbonation, and freeze–thaw resistance.
4. Life cycle assessment (LCA) and cost analysis to evaluate environmental and economic benefits.
5. Exploration of carbon sequestration potential of biochar in concrete for sustainable construction practices.