

Green Concrete made up from bottom-ash, sugarcane bagasse fibre and recycled high density poly-ethylene

Koppireddy Veera Durga Surya Manideep¹, D. Leela Durga², Ch. Srinivas³

¹P.G. Student, ²Assistant Professor, ³Assistant Professor and Head of the Department
Department of Civil Engineering, Godavari Institute of Engineering & Technology (A),
Rajamahendravaram. Andhra Pradesh-533296

Abstract— The growing need for sustainable construction materials has led to extensive research on green concrete, which integrates industrial and agricultural waste to promote environmental sustainability and resource conservation. This study focuses on evaluating the mechanical, durability, and microstructural characteristics of concrete incorporating bottom ash (BA) as a partial cement replacement, sugarcane bagasse fiber (SCBF) as reinforcement, and high-density polyethylene (HDPE) plastic pellets as a substitute for coarse aggregate. Various mix compositions were prepared to analyze their impact on concrete performance. In this research, bottom ash was consistently used as a 20% replacement for cement, while sugarcane bagasse fiber was introduced at 0.25%, 0.50%, and 0.75% of cement weight. HDPE plastic pellets were utilized as a fixed 15% replacement for coarse aggregate. The modified concrete mixtures were assessed based on their compressive strength, split tensile strength, flexural strength. The findings demonstrated that the optimum combination was achieved with 20% bottom ash, 0.50% sugarcane bagasse fiber, and 15% HDPE replacement, yielding mechanical strength comparable to conventional concrete. However, excessive replacement levels resulted in a decline in mechanical performance due to increased porosity and weaker bonding between components.

Index Terms— Green concrete, Bottom ash, Sugarcane bagasse fiber, High-density polyethylene (HDPE) plastic pellets, Sustainable construction

I. INTRODUCTION

The integration of sustainable materials in concrete has gained significant attention in recent years due to the increasing concerns over environmental degradation, depletion of natural resources, and the high carbon footprint associated with cement production. Various researchers have explored the incorporation of recycled and industrial waste materials in concrete to enhance sustainability while maintaining or improving its mechanical properties. This chapter reviews the existing literature on the use of bottom ash, sugarcane bagasse fiber, and high-

density polyethylene (HDPE) plastic pellets in concrete, highlighting their impact on strength, durability, and environmental sustainability.

1.1 Bottom Ash as a Partial Replacement for Cement and Fine Aggregate

Bottom ash is an industrial by-product generated during the combustion of pulverized coal in thermal power plants. It is a granular material that settles at the bottom of boilers after combustion, differing from fly ash, which remains suspended in exhaust gases. The primary chemical constituents of bottom ash include silica (SiO_2), alumina (Al_2O_3), and iron oxides (Fe_2O_3), all of which contribute to its pozzolanic reactivity when used in cementitious materials (Aggarwal et al., 2010). The presence of these compounds allows bottom ash to participate in secondary hydration reactions, leading to strength enhancement over time.

One of the significant advantages of utilizing bottom ash in concrete is its potential to address environmental concerns associated with its disposal. Large quantities of bottom ash are produced globally, and improper disposal can lead to issues such as land contamination, groundwater pollution, and air quality deterioration. By incorporating bottom ash as a partial replacement for cement and fine aggregates, the demand for natural raw materials such as river sand and limestone can be significantly reduced, promoting sustainability in the construction industry.

1.2 Physical and Chemical Properties of Bottom Ash

Bottom ash consists of fine granular particles that are generally porous and irregular in shape, which significantly influences its physical and mechanical behavior when used in concrete. One of the key characteristics of bottom ash is its high surface area and rough texture, which directly affects its water absorption properties. Compared to conventional fine aggregates such as river sand, bottom ash has a higher porosity, which leads to greater water retention

within the concrete mix. As a result, this increased water absorption can alter the workability and consistency of fresh concrete, necessitating modifications in the mix design to maintain optimal performance. The particle size distribution of bottom ash is comparable to that of natural fine aggregates, making it a feasible substitute for sand in concrete production (Kumar & Kumar, 2013). Its gradation and fineness influence the packing density and interparticle arrangement within the cement matrix, which can either enhance or weaken the overall mechanical properties of hardened concrete. Proper sieving and processing of bottom ash can improve its suitability as a sand replacement, ensuring better dispersion and reduced segregation in the concrete mix.

1.3 Impact of Bottom Ash on Concrete Properties

Multiple research studies have shown that the incorporation of bottom ash in concrete formulations enhances durability while maintaining an acceptable level of mechanical performance. The effectiveness of bottom ash as a partial substitute for fine aggregates has been extensively examined, with findings indicating that moderate replacement levels can yield favorable results in terms of strength and long-term durability. According to Ling et al. (2017), replacing up to 30% of natural sand with bottom ash in concrete mixes resulted in compressive strength values comparable to those of conventional concrete. This indicates that at controlled replacement levels, bottom ash does not significantly compromise the structural integrity of concrete. However, as the replacement percentage exceeds 30%, the compressive strength tends to decline. This reduction in strength at higher replacement levels can be attributed to the increased porosity of the hardened concrete matrix, as bottom ash has a more irregular and porous structure compared to natural sand. The presence of excessive porosity negatively impacts the density and interlocking of particles, ultimately leading to a reduction in load-bearing capacity.

II. LITERATURE SURVEY

The construction industry plays a pivotal role in global economic development, yet it significantly contributes to environmental degradation. The extensive consumption of natural resources, energy-intensive manufacturing processes, and the generation of construction and demolition waste (C&DW) pose critical challenges to sustainability (Chandara et al., 2011). Among construction

materials, concrete is the most widely used, with its production relying heavily on cement, aggregates, and water. However, the production of cement alone accounts for approximately 8% of global CO₂ emissions, making it a key target for sustainability interventions (Andrew, 2017). The depletion of natural aggregates and increasing waste generation have driven researchers and industry practitioners toward sustainable alternatives that align with the principles of a circular economy (Blomsma & Brennan, 2017).

One of the primary strategies for reducing the environmental impact of concrete is incorporating recycled and industrial by-products into its mix design. The use of recycled coarse aggregate (RCA), sourced from construction and demolition waste, presents an effective means of mitigating resource depletion and reducing landfill waste (Tam et al., 2018). Studies indicate that RCA can replace natural coarse aggregate without significantly compromising the mechanical and durability properties of concrete, provided that appropriate processing and mix proportion adjustments are made (Behera et al., 2014). Additionally, substituting conventional aggregates and cement with industrial by-products such as bottom ash, sugarcane bagasse fiber, and high-density polyethylene (HDPE) plastic pellets has demonstrated significant potential in enhancing concrete sustainability while maintaining satisfactory structural performance (Younis & Pilakoutas, 2013). Bottom ash, a by-product of coal combustion in thermal power plants, has been extensively researched as a partial replacement for cement and fine aggregates in concrete. Its pozzolanic properties and particle size distribution can contribute to improved durability and long-term strength (Aggarwal et al., 2010). Studies have shown that the inclusion of bottom ash enhances the workability of concrete while reducing its environmental impact, making it a viable alternative to natural raw materials (Kumar & Kumar, 2013).

Sugarcane bagasse fiber, an agro-industrial waste product derived from sugar production, has also emerged as an effective reinforcement material for concrete. Due to its natural fibrous composition, it enhances tensile strength, impact resistance, and durability. Research suggests that incorporating bagasse fiber in concrete mixtures reduces shrinkage and cracking, leading to an overall improvement in mechanical performance (Savastano et al., 2003). Moreover, bagasse fiber contributes to the sustainability of concrete by repurposing agricultural

waste that would otherwise contribute to environmental pollution (Onuaguluchi & Banthia, 2016).

High-density polyethylene (HDPE) plastic pellets, sourced from post-consumer plastic waste, serve as an alternative aggregate in concrete. The integration of HDPE plastics reduces the consumption of natural aggregates while improving specific properties such as impact resistance and durability. Previous studies indicate that HDPE-modified concrete exhibits enhanced resistance to chemical attacks and reduced permeability, making it suitable for infrastructure applications exposed to aggressive environments (Marzouk et al., 2007). The utilization of waste plastics in concrete not only supports sustainable waste management but also enhances the lifecycle performance of concrete structures (Saikia & de Brito, 2012).

Apart from material modifications, adopting circular economy principles in concrete production is essential for achieving long-term sustainability. Closed-loop recycling, which involves reusing construction waste within the same industry, has been identified as a more sustainable approach than open-loop recycling, where materials are repurposed in different applications (Marie & Quiasrawi, 2012; Deschamps et al., 2018). However, large-scale implementation of recycled concrete faces challenges such as variability in material properties, economic feasibility, and regulatory constraints, necessitating further research and policy support (Akhtar & Sarmah, 2018).

Green concrete has emerged as a viable alternative to conventional concrete, incorporating supplementary cementitious materials such as fly ash, ground granulated blast furnace slag (GGBFS), and metakaolin to reduce its carbon footprint. High-volume fly ash concrete, for instance, has been shown to exhibit superior durability and mechanical properties compared to traditional concrete, making it a potential replacement for cement-based mixes in construction (Rashad, 2015; Suhendro, 2014). Similarly, GGBFS has been extensively researched for its role in enhancing long-term strength and reducing the environmental impact associated with cement production (Albitar et al., 2015).

IV. METHODOLOGY FOR EXPERIMENTS

The selection of materials for this research was based on their availability, sustainability, and potential to enhance the mechanical and durability properties of concrete. This study incorporates bottom ash (BA) as

a partial cement replacement, sugarcane bagasse fiber (SCBF) as reinforcement, and high-density polyethylene (HDPE) plastic pellets as a partial replacement for coarse aggregate. The physical and chemical properties of each material were analyzed to ensure their suitability for concrete production.

4.1 Cement

Ordinary Portland Cement (OPC) of 53 grade was used as the primary binding material, conforming to IS 12269:2013. Cement plays a crucial role in the hydration process, which influences the strength development and setting properties of concrete.

4.2 Bottom Ash (BA)

Bottom ash, a by-product from coal combustion in thermal power plants, was used as a 20% partial replacement for cement due to its pozzolanic characteristics. Incorporating bottom ash enhances sustainability by reducing cement consumption and utilizing industrial waste effectively.

4.3 Mix Design

The mix design was developed for M30 grade concrete as per IS 10262:2019. The proportions of cement, bottom ash, sugarcane bagasse fiber, and HDPE were varied systematically.

4.4 Mixing Procedure

1. Cement, bottom ash, and fine aggregate were dry-mixed for uniform consistency.
2. Sugarcane bagasse fibers, pretreated with NaOH, were gradually added to prevent clumping.
3. Coarse aggregate and HDPE pellets were pre-mixed separately before incorporation.
4. Water and superplasticizer were added in increments to attain desired workability.

Casting and Curing

- Fresh concrete was poured into molds, compacted, and allowed to set for 24 hours.
- Specimens were cured in water as per IS 516:1959 for 7, 28, and 90 days.

4.5 Testing Procedures

4.5.1 Mechanical Properties

- Compressive Strength: Tested per IS 516:1959 using a compression testing machine.
- Split Tensile Strength: Conducted following IS 5816:1999.
- Flexural Strength: Evaluated via three-point bending per IS 516:1959.

4.5.2 Data Analysis and Optimization

- Experimental results were statistically analyzed to determine trends and correlations.
- The optimal mix was identified based on mechanical and durability performance.

This research follows a structured methodology involving material characterization, mix design, testing. The study contributes to sustainable construction by optimizing waste material usage in concrete, reducing cement consumption, and improving mechanical and durability properties.

V. RESULTS AND DISCUSSIONS

This section presents and discusses the results obtained from various experimental tests performed on the concrete samples containing bottom ash (BA), sugarcane bagasse fiber (SCBF), and high-density polyethylene (HDPE) plastic pellets. The results focus on mechanical properties such as compressive strength, split tensile strength, and flexural strength. Additionally, microstructural analysis using Scanning Electron Microscopy (SEM) is discussed to evaluate the interfacial transition zone (ITZ) and bonding characteristics.

5.1 Compressive Strength

Compressive strength tests were conducted at 7, 28, and 90 days as per IS 516:1959. The results indicate that the inclusion of bottom ash, SCBF, and HDPE influenced the strength development of concrete. The optimum mix (20% BA, 0.50% SCBF, 15% HDPE) exhibited strength comparable to the control mix at 28 days, while excessive fiber content (0.75%) led to a decrease in compressive strength due to increased porosity and weak bonding.

Mix ID	7 Days	28 Days	90 Days
M1 (Control)	32.5	41.2	46.5
M2	30.8	39.5	45.0
M3 (Optimum)	31.2	40.8	46.2
M4	28.7	37.3	42.5

5.2 Flexural Strength

Flexural strength was tested using a three-point bending test in accordance with IS 516:1959. The addition of SCBF enhanced flexural performance, with the optimum mix showing the best results due to improved fiber bridging action.

Mix ID	7 Days	28 Days	90 Days
M1 (Control)	4.5	5.8	6.4
M2	4.2	5.5	6.1

M3 (Optimum)	4.8	6.2	6.8
M4	4.0	5.3	5.9

5.3 Split Tensile Strength

The split tensile strength test was performed according to IS 5816:1999. The inclusion of SCBF improved tensile strength due to the fiber reinforcement effect. However, at higher fiber content (0.75%), there was a marginal reduction due to poor workability and fiber clustering.

Mix ID	7 Days	28 Days	90 Days
M1 (Control)	2.8	3.9	4.5
M2	2.6	3.7	4.3
M3 (Optimum)	2.9	4.1	4.7
M4	2.4	3.5	4.0

VII. CONCLUSIONS

- 6.1 Mechanical Properties: The inclusion of BA, SCBF, and HDPE influenced the compressive, tensile, and flexural strength of concrete. The optimum mix (20% BA, 0.50% SCBF, and 15% HDPE) exhibited comparable compressive strength to conventional concrete while showing enhanced flexural and impact resistance due to the reinforcing effect of SCBF and the ductility of HDPE.
- 6.2 Workability: The use of HDPE pellets resulted in a reduction in concrete density, making it suitable for lightweight construction applications. However, increased fiber content reduced workability, necessitating the use of a superplasticizer to maintain consistency.
- 6.3 Sustainability Benefits: The study highlights the potential of utilizing industrial and agricultural waste materials in concrete production, thereby reducing cement consumption, mitigating plastic waste accumulation, and promoting circular economy principles.

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