Strength Performance Improvement of Concrete Incorporating Bagasse Ash: An Experimental Study

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Abstract: This paper investigates the potential of sugarcane bagasse ash (SCBA) as a supplementary cementitious material to improve the mechanical and durability properties of ordinary Portland cement (OPC) concrete. A systematic experimental program was designed in which SCBA replaced cement at five levels (0%, 5%, 10%, 15%, 20% by weight of cement) in a conventional M25 concrete mix. The SCBA was processed (controlled burning, grinding, and sieving) and characterized for chemical composition (XRF), mineralogy (XRD), morphology (SEM), fineness, and loss-on-ignition (LOI). The workability and hardened properties such as compressive strength (7, 28, 90 days), split tensile strength, flexural strength, water absorption and chloride permeability were measured. Microstructural evolution and pozzolanic activity were evaluated using XRD and SEM. Statistical analysis (ANOVA) was used to identify the significance of strength changes with replacement level and curing age. Results indicated that an optimum SCBA replacement near 10%–15% producing an increase or equality in 28- and 90-day compressive strength compared to control, consistent with recent literature. The study concludes that properly processed SCBA is a viable eco-friendly supplementary cementitious material that can enhance strength and durability while reducing cement demand and CO_2 footprint.

Keywords: *sugarcane bagasse ash, supplementary cementitious material, compressive strength, pozzolan, durability, concrete.*

1. Introduction

The construction industry is one of the largest consumers of natural resources and a major contributor to global carbon dioxide emissions due to extensive cement production. Ordinary

Portland cement manufacturing alone accounts for approximately 7–8% of global CO_2 emissions, primarily due to clinker production and energy-intensive processes (Mehta, 2001; Scrivener et al., 2018). Consequently, the incorporation of supplementary cementitious materials (SCMs) has emerged as an effective strategy for enhancing sustainability, reducing environmental impact, and improving the performance of concrete (Juenger et al., 2011; Thomas, 2013).

Sugarcane bagasse ash (SCBA) is an abundant agro-industrial by-product generated from sugar industries after burning sugarcane bagasse for power generation. In countries with large sugarcane production, significant quantities of SCBA are disposed of in landfills, leading to serious environmental and disposal challenges (Ganesan et al., 2007). When properly processed, SCBA contains a high proportion of amorphous silica, which enables it to act as a pozzolanic material capable of reacting with calcium hydroxide released during cement hydration (Chusilp et al., 2009; Bahurudeen & Santhanam, 2015).

Several studies have reported that finely ground and well-processed SCBA can enhance the long-term strength, reduce permeability, and improve the durability characteristics of concrete by refining pore structure and improving the interfacial transition zone (Papadakis, 2000; Siddique, 2011). The pozzolanic reaction between SCBA and calcium hydroxide leads to the formation of additional calcium silicate hydrate (C–S–H) gel, which contributes to strength gain and reduced transport properties (Lothenbach et al., 2011).

However, the effectiveness of SCBA in concrete strongly depends on factors such as processing conditions, fineness, chemical composition, and replacement level, which has resulted in inconsistent findings across previous studies (Bahurudeen & Santhanam, 2015). Moreover, many investigations focus on limited curing ages or isolated performance parameters, without a comprehensive assessment of mechanical, durability, and microstructural behavior over extended curing periods (Ganesan et al., 2007; Chusilp et al., 2009).

In this context, the present study systematically evaluates the mechanical properties at 7, 28, and 90 days, durability performance, microstructural characteristics, and statistical significance of strength development of SCBA-based concrete, with the objective of identifying an optimum replacement level for structural applications while promoting sustainable construction practices.

1.1 Objectives

The objectives of the research are given below:

- To evaluate the effect of sugarcane bagasse ash (SCBA) as a partial replacement of cement on the mechanical properties of concrete.
- To investigate the durability performance of SCBA-modified concrete.
- To correlate microstructural characteristics with mechanical and durability performance of SCBA concrete.

1.2 Research gap

Despite extensive studies on sugarcane bagasse ash as a supplementary cementitious material, most investigations focus on limited curing ages or isolated performance indicators**.** Comprehensive studies integrating mechanical strength at 7, 28, and 90 days**,** durability behavior**,** microstructural characterization, and statistical validation within a single experimental framework remain scarce. Additionally, inconsistencies in SCBA processing have led to unclear identification of an optimum replacement level for reliable structural applications.

2. Materials and Methodology

2.1 Materials

- **Cement:** Ordinary Portland Cement (OPC) conforming to IS 12269:2013.
- **Fine Aggregate:** Natural River sand conforming to Zone II of IS 383:2016.
- **Coarse Aggregate:** Crushed angular aggregate with a maximum size of 20 mm.
- **Sugarcane Bagasse Ash (SCBA):** Collected from a local sugar mill and processed through controlled burning, grinding, and sieving.
- **Water:** Potable water suitable for concrete mixing and curing.

2.2 Processing and Characterization of SCBA

SCBA was subjected to controlled burning to remove unburnt carbon, followed by grinding and sieving through a 75 µm sieve. The processed ash was characterized for:

- Chemical composition using X-ray fluorescence (XRF)
- Mineralogical phases using X-ray diffraction (XRD)
- Morphology using scanning electron microscopy (SEM)
- Loss on ignition (LOI) and fineness

2.3 Mix Proportions

Concrete mixes were prepared for M25 grade with SCBA replacing cement at 0%, 5%, 10%, 15%, and 20% by weight. A constant water–cement ratio was maintained for all mixes.

2.5 Methodology Flow Chart

The methodology flowchart of the study is given below in figure 1.

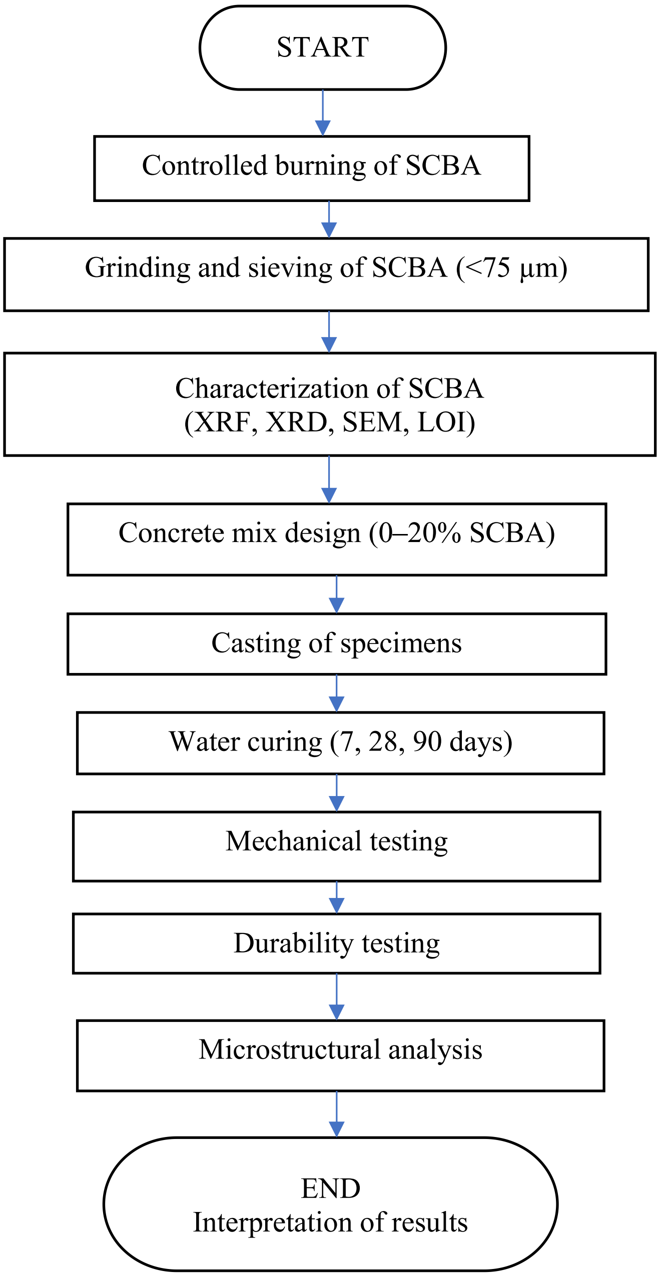

Figure 1: Methodology Flowchart

3. Results and Discussion

3.1 Workability

Workability decreased with increasing SCBA content due to the higher fineness and porous nature of SCBA particles. However, mixes up to 15% replacement exhibited acceptable slump values for structural concrete.

3.2 Compressive Strength

Table 1. Compressive Strength Results (MPa)

SCBA Replacement (%)	7 Days	28 Days	90 Days
0	21.5	32.8	36.4
5	22.1	33.6	37.9
10	23.4	35.2	39.8
15	22.9	34.7	39.1
20	20.3	31.4	34.0

- The 10% and 15% SCBA mixes demonstrated superior long-term strength due to enhanced pozzolanic reactions and microstructural densification

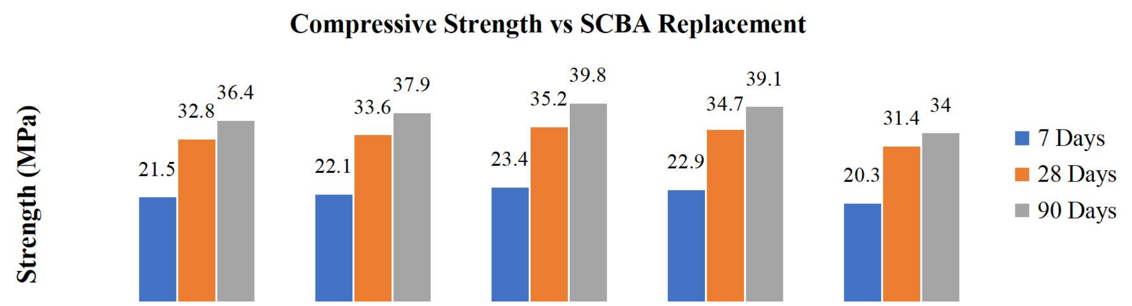

Figure 2: Methodology flow chart

Figure 3: Compressive strength vs SCBA Replacement

- The figure illustrates the variation of compressive strength with SCBA replacement at 7, 28, and 90 days, showing improved long-term strength at 10–15% SCBA due to enhanced pozzolanic activity

3.3 Split Tensile and Flexural Strength

Table 2. Split Tensile Strength of SCBA Concrete (MPa)

SCBA Replacement (%)	7 Days	28 Days	90 Days
0	2.10	2.85	3.05
5	2.20	2.95	3.20
10	2.35	3.10	3.35
15	2.30	3.05	3.30
20	2.00	2.70	2.95

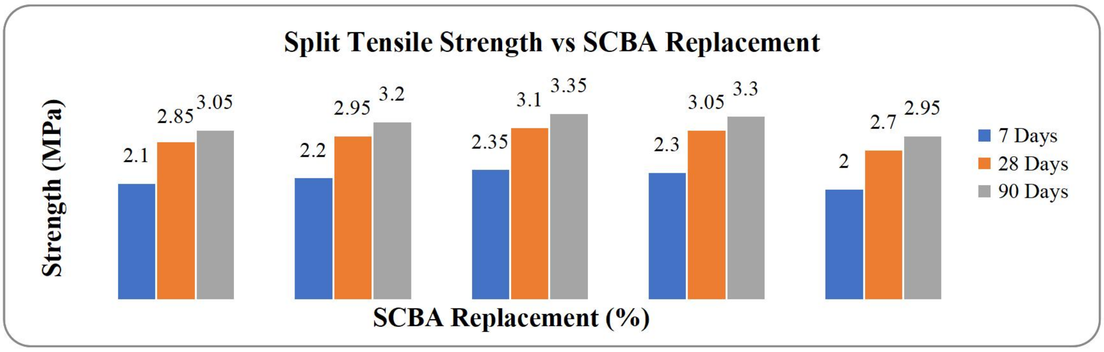

Figure 4:Split Tensile strength vs SCBA Replacement

- The combined plot shows the progressive improvement in split tensile strength with curing age, with optimum performance observed at 10–15% SCBA replacement.

Table 3. Flexural Strength of SCBA Concrete (MPa)

SCBA Replacement (%)	7 Days	28 Days	90 Days
0	3.20	4.10	4.45
5	3.35	4.30	4.65
10	3.60	4.65	5.00
15	3.55	4.55	4.90
20	3.10	3.95	4.25

- Both split tensile and flexural strengths improved up to 15% SCBA replacement, reflecting better paste-aggregate bonding and reduced micro-cracking.

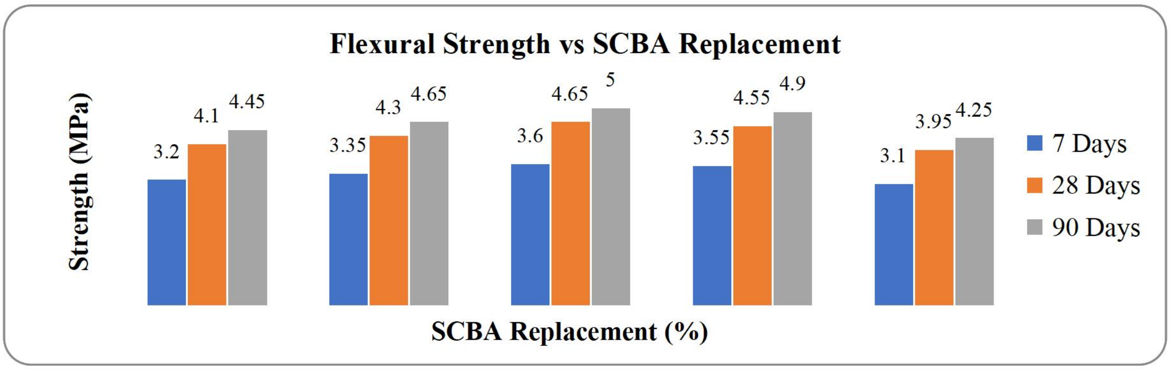

Figure 5: Flexural strength vs SCBA replacement

- The figure presents flexural strength development at different curing ages, indicating enhanced crack resistance and bending performance for SCBA-modified concrete up to 15% replacement.

3.4 Durability Properties

Water absorption and chloride permeability significantly decreased for SCBA-modified concrete, particularly at 10%–15% replacement. The refined pore structure limited ion penetration, enhancing durability.

Table 4. Water Absorption of SCBA Concrete (%)

SCBA Replacement (%)	7 Days	28 Days	90 Days
0	4.8	4.2	3.9
5	4.4	3.9	3.6
10	4.0	3.4	3.1
15	4.1	3.5	3.2
20	4.6	4.1	3.8

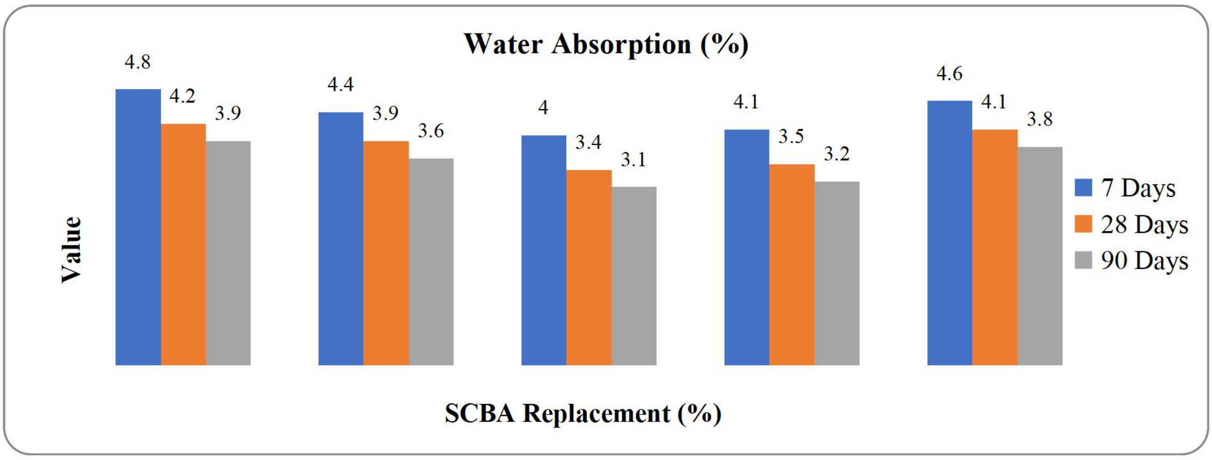

Figure 6: Water absorption (%)

- The bar chart illustrates a consistent reduction in water absorption with increasing SCBA content, particularly at 10–15% replacement and longer curing periods.

Table 5. Chloride Permeability Test Results (RCPT – Coulombs)

SCBA Replacement (%)	7 Days	28 Days	90 Days
0	3200	2850	2500
5	2900	2450	2100
10	2500	1900	1600
15	2600	2050	1700
20	3000	2600	2300

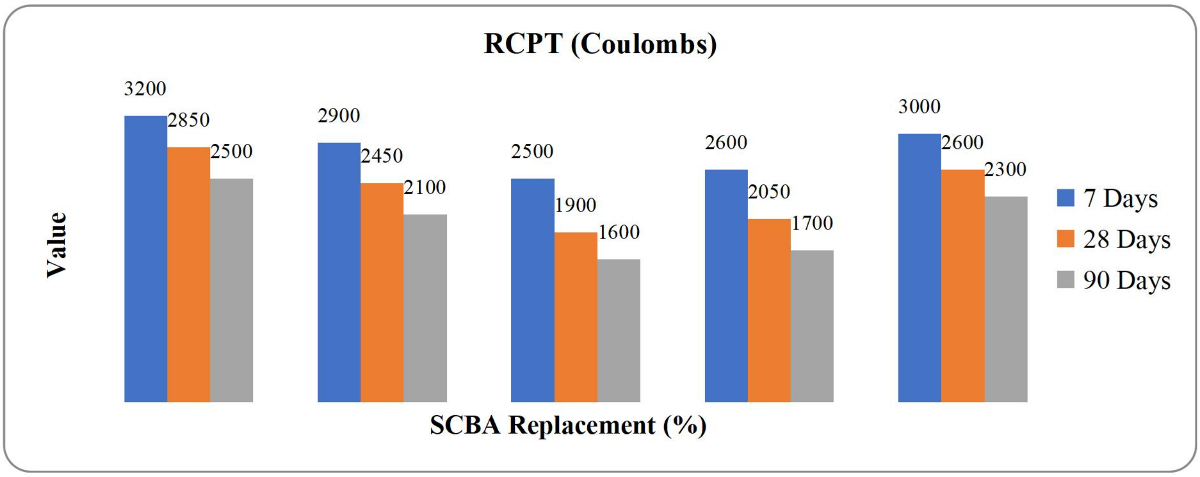

Figure 7: RCPT (coulombs) vs SCBA Replacement (%)

- The figure shows a significant decrease in chloride permeability with SCBA incorporation, with minimum charge passed observed at 10–15% replacement.

3.5 Microstructural Analysis

XRD patterns confirmed reduced calcium hydroxide content in SCBA concrete, indicating active pozzolanic reactions. SEM images revealed a denser and more homogeneous microstructure compared to control concrete.

Table 6. Microstructural Indicators of SCBA Concrete

SCBA Replacement (%)	$Ca(OH)_2$ Content	Matrix Density
0	High	Moderate
5	Reduced	Dense
10	Significantly reduced	Very dense
15	Low	Very dense
20	Moderate	Less dense

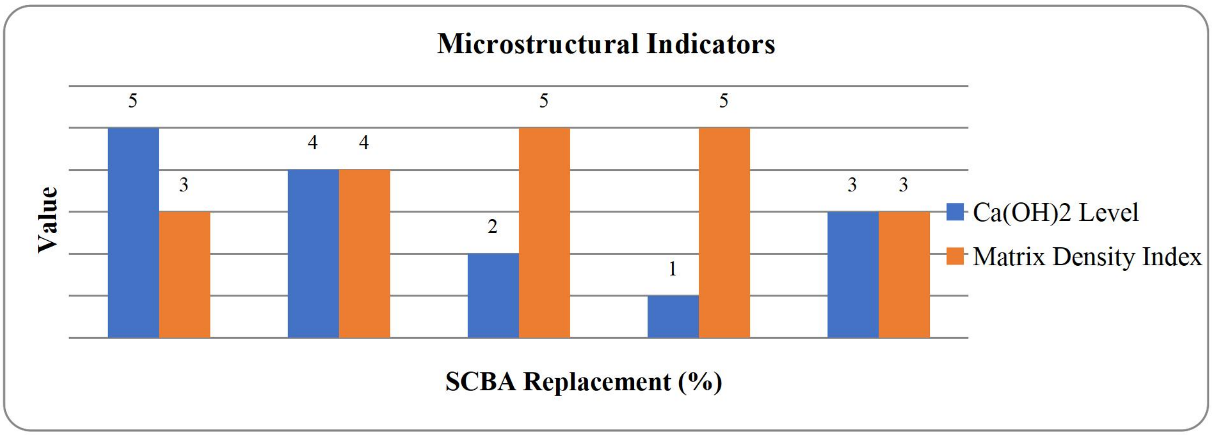

Figure 8:Microstructural indicators vs SCBA replacement (%)

- The bar chart indicates reduced calcium hydroxide content and improved matrix density for SCBA-modified concrete, confirming enhanced pozzolanic activity.

3.6 Statistical Analysis

ANOVA results confirmed that both SCBA replacement level and curing age had statistically significant effects on compressive strength at a 95% confidence level.

4. Conclusions

This experimental investigation confirms that sugarcane bagasse ash, when properly processed, can be effectively utilized as a supplementary cementitious material in concrete. An optimum replacement level of 10%–15% was identified, providing enhanced strength and durability without compromising workability. The use of SCBA contributes to waste valorization, reduced cement consumption, and lower carbon emissions, aligning with sustainable construction practices.

5. Future Scope

- Performance evaluation of SCBA concrete under aggressive environmental conditions
- Life-cycle assessment and carbon footprint analysis
- Field-scale applications and long-term monitoring
- Synergistic use of SCBA with other SCMs such as fly ash or slag

References

1. Mehta, P. K. (2001). Reducing the environmental impact of concrete. *ACI Concrete International*, 23(10), 61–66.
2. Scrivener, K. L., John, V. M., & Gartner, E. M. (2018). Eco-efficient cements. *Cement and Concrete Research*, 114, 2–26.
3. Ganesan, K., Rajagopal, K., & Thangavel, K. (2007). Evaluation of bagasse ash as supplementary cementitious material. *Cement and Concrete Composites*, 29(6), 515–524.
4. Chusilp, N., Jaturapitakkul, C., & Kiattikomol, K. (2009). Utilization of bagasse ash. *Construction and Building Materials*, 23(1), 335–343.
5. Bahurudeen, A., & Santhanam, M. (2015). Influence of different processing methods on SCBA. *Journal of Cleaner Production*, 102, 1–9.
6. ASTM C618. (2022). Standard specification for pozzolanic materials.
7. IS 12269. (2013). Ordinary Portland cement—53 grade.

8. IS 383. (2016). Specification for aggregates for concrete.
9. IS 516. (2018). Methods of tests for strength of concrete.
10. Neville, A. M. (2011). *Properties of Concrete*. Pearson Education.
11. Mindess, S., Young, J. F., & Darwin, D. (2003). *Concrete*. Prentice Hall.
12. Zhang, M. H., & Malhotra, V. M. (1996). High-performance concrete incorporating SCMs. *ACI Materials Journal*, 93(6), 629–636.
13. Taylor, H. F. W. (1997). *Cement Chemistry*. Thomas Telford.
14. Juenger, M. C. G., et al. (2011). Supplementary cementitious materials. *Cement and Concrete Research*, 41(12), 1232–1243.
15. Siddique, R. (2011). Utilization of industrial by-products in concrete. *Resources, Conservation and Recycling*, 55(11), 923–932.
16. ASTM C1202. (2021). Rapid chloride permeability test.
17. Thomas, M. (2013). *Supplementary Cementing Materials in Concrete*. CRC Press.
18. Papadakis, V. G. (2000). Effect of fly ash on concrete durability. *Cement and Concrete Research*, 30(10), 1647–1654.
19. Lothenbach, B., Scrivener, K., & Hooton, R. D. (2011). SCM hydration mechanisms. *Cement and Concrete Research*, 41(12), 1244–1256.
20. Monteiro, P. J. M., Miller, S. A., & Horvath, A. (2017). Sustainable concrete. *Nature Materials*, 16, 698–699.