ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun185

Improving Concrete Characteristics using Sugarcane Bagasse Ash as a Partial Replacement for Fine Aggregate

(Innovative Use of Agro-Waste in Concrete)

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Publication Date: 2025/07/14

Abstract: Concrete is the backbone of modern construction, but producing it takes a serious toll on the environment, largely due to the massive consumption of natural resources. This study takes a closer look at an alternative that could help ease that burden: sugarcane bagasse ash (SBA). A byproduct of the sugar industry, SBA is rich in silica and has pozzolanic properties, making it a promising candidate to partially replace fine aggregate in concrete. In this research, SBA was used to replace sand in concrete at varying levels — 5%, 10%, 15%, and 20% — to see how it affects the mix's workability, strength, and long-term durability. The results were encouraging. At certain replacement levels, not only did the concrete maintain its structural integrity, but it also showed improved strength and resilience. Beyond the technical benefits, using SBA also helps address waste management issues and supports more sustainable building practices. By turning agricultural waste into a valuable construction material, this approach aligns with the goals of a circular economy — reducing environmental impact while creating cost-effective, eco-friendly concrete. Simply put, with the right balance, SBA has the potential to make concrete greener without sacrificing performance.

Keywords: *Sugarcane Bagasse Ash, Fine Aggregate Replacement, Sustainable Concrete, Compressive Strength.*

How to Cite: Manish Kumar; Tanisha Chauhan; Suyash; Anshu Kumar; Vibhuti Srivastava (2025). Improving Concrete Characteristics Using Sugarcane Bagasse Ash as a Partial Replacement for Fine Aggregate. *International Journal of Innovative Science and Research Technology*, (RISEM–2025), 160-166. https://doi.org/10.38124/ijisrt/25jun185

I. INTRODUCTION

Sugarcane Bagasse Ash (SCBA) is a byproduct of the sugarcane industry, generated during the processing of sugarcane stalks. Once the juice is extracted, the leftover fibrous material—called bagasse—is often burned as a fuel source, producing ash. This ash, when properly processed, can be repurposed as a partial replacement for fine aggregates in concrete. What makes this approach especially valuable is that it not only helps improve the performance of concrete but also supports sustainable construction practices by repurposing agricultural waste.

One of the main reasons SCBA is gaining attention in the construction world is due to its pozzolanic properties. Pozzolans are materials that react chemically with calcium hydroxide in the presence of water, forming compounds—especially calcium silicate hydrate (C-S-H)—that significantly enhance the strength and durability of concrete. SCBA, being naturally rich in silica, fits this role well. When added to a concrete mix, it contributes to the formation of more C-S-H gel, which is the key binder in concrete, resulting in a stronger and more durable structure.

In addition to boosting strength, SCBA can improve the workability of fresh concrete. Its fibrous composition helps create a more cohesive mix, minimizing issues like segregation and bleeding. This is particularly useful in applications where smooth placement and finishing are critical. SCBA can also help reduce the water-to-cement ratio needed in a mix, which often leads to improved strength and long-term durability.

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Moreover, SCBA enhances the durability of concrete by reducing its permeability. The fine ash particles fill in the tiny voids within the mix, making it more resistant to water penetration and freeze-thaw cycles—two major factors that often contribute to concrete degradation over time.

- *Key Benefits of Using Sugarcane Bagasse Ash in Concrete*

Enhanced Strength: The high silica content in SCBA reacts during the hydration process, forming additional C-S-H gel. This leads to a denser, more robust concrete matrix.

- *Reduced Permeability:*

Fine SCBA particles fill gaps in the concrete mix, reducing porosity. This makes the concrete less susceptible to water damage and environmental wear.

- *Improved Workability:*

SCBA's texture contributes to a smoother, more cohesive mix, reducing the risks of segregation and bleeding during pouring and finishing.

- *Sustainability:*

Reusing agricultural waste like SCBA helps reduce reliance on natural resources while minimizing industrial waste—supporting a circular, eco-friendly construction process.

- *Reduced Permeability:*

The fine particles in sugarcane bagasse ash help fill tiny gaps within the concrete mix, resulting in a denser structure. This reduces permeability, making the concrete less prone to water infiltration and more durable against freeze-thaw cycles.

II. LITERATUREREVIEW

- *Use of Sugarcane Bagasse Ash (SCBA) in Concrete*

Several studies have investigated the potential of sugarcane bagasse ash (SCBA) as a partial replacement in concrete, particularly focusing on its effects on strength, workability, and durability.

In 2017, **Bangar Sayali S. et al**. [1] conducted research where SCBA was sieved through a 150-micron mesh, and the fraction passing through was used to replace cement partially at levels of 2%, 4%, 6%, 8%, and 10% by weight. They used Ordinary Portland Cement (53 grade) and found improvements in concrete properties with optimal replacement percentages.

Similarly, **Lathamaheswari et al.** (2017) [2] examined concrete mixes with SCBA replacing cement from 2.5% up to 12.5%. Their results showed that increasing SCBA content had minimal effect on the workability of the concrete, which is important for practical application during mixing and pouring.

In 2013, **Prashant et al.** [4] explored the use of SCBA as a partial replacement for fine aggregates (sand) rather than cement. They experimented with replacement levels of 10%, 20%, 30%, and 40% by volume and observed that the sorptivity coefficient (a measure of water absorption) increased with higher SCBA content, indicating a potential rise in water permeability.

Earlier, **Lavanya et al.** (2012) [5] studied the effect of replacing cement with SCBA in percentages ranging from 10% to 30%, combined with different water-cement ratios (0.35, 0.41, and 0.45). Conducting tests according to Indian Standard

Table 1 Test Result of Course Aggregate

Impact Value	11.17%
Flakiness Index Value	16.188%
Specific Gravity of Coarse Aggregate	2.75
Specific Gravity of Fine Aggregate	2.70
Water Absorption Value	1.07 %
Abrasion Value	27.47 %

Codes (IS 516-1959), they measured compressive strength at 7, 14, and 28 days. Their findings suggest that SCBA can enhance the strength of concrete up to 15% replacement, especially at a 0.35 water-cement ratio, confirming its potential as a pozzolanic material that partially substitutes cement.

Furthermore, **R. Srinivasan et al.** (2010) [6] examined SCBA obtained from controlled combustion and used it to replace cement at 0%, 5%, 10%, 15%, and 25%. They evaluated both fresh concrete properties—using compaction factor and slump tests—and hardened concrete properties like compressive strength, split tensile strength, flexural strength, and modulus of elasticity at 7 and 28 days. Their comprehensive testing showed beneficial effects at moderate replacement levels.

- *SiriratJanjaturaphan et. Al (2010) [7]*

They explored the pozzolanic activity of industrial sugarcane bagasse ash by analyzing its chemical makeup and comparing it with other well-known pozzolanic materials like

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun185

rice husk ash. Their findings confirmed that SCBA is a suitable material for partially replacing cement in concrete.

➢ *Recent Research (2010s–Present):*

In recent years, research on SCBA has broadened significantly. Beyond just replacing cement, studies now look at SCBA as a partial substitute for fine aggregates and examine how it influences various concrete properties, such as flexural strength, tensile strength, and durability. There is also growing interest in applying SCBA in different types of concrete, including high-performance and self-compacting varieties.

➢ *Impact on Workability:*

The very fine particles of SCBA can affect the workability of concrete, often causing a decrease in slump (the measure of how fluid the concrete is). To address this, researchers have explored methods like adding superplasticizers or tweaking the water-cement ratio to maintain ease of use without compromising performance.

➢ *Impact on Durability:*

Consistent findings show that SCBA improves concrete's durability, especially by enhancing resistance to chloride ion penetration—which can cause corrosion—and protecting against damage from freeze-thaw cycles.

➢ *Cost-Effectiveness:*

Since SCBA is an agricultural byproduct, it is typically inexpensive, offering an affordable alternative to traditional concrete materials and supporting more sustainable construction practices.

III. METHODOLOGY AND ANALYSIS

➢ *Methodology:*

This study focused on evaluating both the fresh and mechanical properties of concrete where sugarcane bagasse ash (SCBA) was used to replace fine aggregate partially. Different replacement levels of SCBA—0%, 10%, 20%, 30%, and 40%—were tested. For this purpose, a total of 60 concrete cylinders, each measuring 200 mm in height and 100 mm in diameter, were cast. The concrete mix used had a water-to-cement ratio of 0.5 and a mix proportion of 1:2:4 (cement: fine aggregate: coarse aggregate). The specimens were cured for periods of 7 and 28 days. To assess the hardened concrete properties, tests for compressive strength and splitting tensile strength were performed following ASTM standard procedures.

➢ *Material Characterization:*

The sugarcane bagasse ash was analyzed chemically using techniques such as X-ray fluorescence (XRF) to determine its elemental composition and assess its suitability as a partial fine aggregate replacement. Water: Chemical analysis (optional) to assess its purity and potential impact on hydration. Collection of raw materials

➢ *Cement:*

Cement is a construction material that acts as a binder. It hardens and sets after mixing with water, bonding other materials together to form a solid mass.

SCBA Replacement %	Compressive strength at 28 days (Mpa or N/mm^2)			
Sample	Cube1	Cube 2	Cube 3	Avg.
10%	12.88	13.33	13.11	39.10
15%	18.22	17.77	18.44	17.92
20%	16.44	16.88	15.88	16.44

Fig 1 Test Result of Compressive Strength

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➢ *Fine Aggregate:*

Fine aggregate includes small granular materials like sand, crushed stone, or gravel with particles up to 4.75 mm in size. It helps fill the spaces between larger aggregates in concrete.

➢ *Coarse Aggregate:*

Coarse aggregates are larger particles, such as gravel or crushed stone, that provide strength and durability to concrete mixes.

➢ *Bagasse Ash:*

Bagasse ash is a by-product from the sugarcane industry. It is the ash left behind after burning sugarcane bagasse—the fibrous leftover material after juice extraction from the stalks.

➢ *Mix Proportioning:*

The concrete mix for this study was designed following IS 10262 (2009). Cement was partially replaced by sugarcane bagasse ash at 10%, 15%, and 20% levels. The water-to-cement ratio was maintained at 0.5, and the resulting mix proportion was 1:1.66:2.54 (cement: fine aggregate: coarse aggregate).

Fig 2 Curring

➢ *Adjust Workability:*

Use superplasticizers or other admixtures to adjust workability if necessary, ensuring all mixes have similar slump values.

➢ *Concrete Casting and Curing*

Once the concrete mix was prepared according to the designed proportions, it was poured into molds measuring 150 mm × 150 mm × 150 mm. The concrete was placed in three layers, with each layer compacted properly to remove air pockets and ensure uniformity.

➢ *Testing of Specimens*

A strict schedule was followed to test the concrete specimens at the designated curing periods to maintain consistency and reliability in results. All tests were carried out following standard testing procedures to assess the quality and strength of the concrete.

➢ *Description of Compression Testing Machine*

The compressive strength of the concrete cubes was measured using a standard compression testing machine with a maximum load capacity of 2000 kN, suitable for testing specimens of this size.

➢ *Tests on Aggregates*

Various tests were performed on the aggregates used in the concrete mix to understand their physical properties. These tests included specific gravity, impact value, and flakiness index, which help evaluate the suitability of aggregates for concrete production.

➢ *Test on Concrete: -*

To analyze the effect of SCBA on fresh as well as hardened properties of concrete several tests have been performed and the result of these tests are given below

- Slump Value for Concrete: -

➢ *Compressive Strength Test: -*

- *The Compressive Strength Test:*

The compressive strength test is one of the most common methods used to assess the strength of concrete. It measures the maximum load a concrete specimen can withstand before failure. This value is crucial as it reflects the overall quality and durability of the concrete. Typically, the compressive strength is expressed in Newtons per square millimeter (N/mm^2) [1, 4].

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SCBA Replacement %	Average Water absorption %
10%	4.57%
15%	4.89%
20%	5.43%

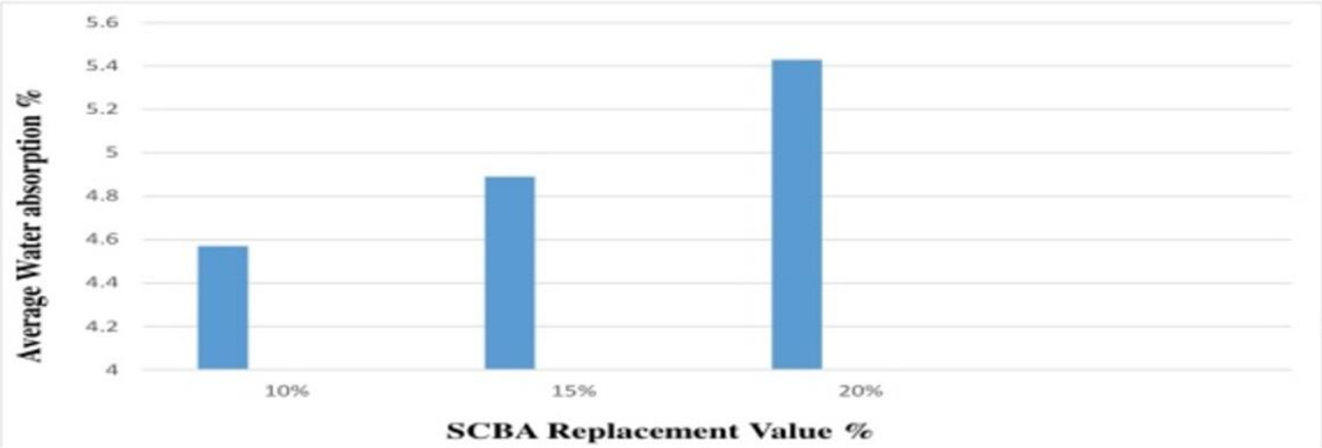

Fig 3 Test Result of Water Absorption

In experiments, compressive strength tests are usually performed at different curing ages, such as 7 days and 28 days, using a compression testing machine [6].

- *Statistical Analysis:*

To understand the impact of Sugarcane Bagasse Ash (SCBA) replacement on concrete properties, statistical tools like ANOVA or regression analysis can be used. These methods help identify whether changes in SCBA content have significant effects on strength and other characteristics [3].

- *Relationship between SCBA Content and Concrete Properties:*

By analyzing the data, researchers can establish how different percentages of SCBA influence concrete's workability, strength, and durability [2, 5].

- *Optimization:*

The goal is to find the best SCBA replacement level that balances strength, ease of handling (workability), durability, and cost-effectiveness. This optimal level ensures concrete performance is enhanced without unnecessary expense [1, 4].

- *Microstructure Analysis:*

Examining microscopic images of concrete helps reveal how SCBA affects the hydration process, the pore structure, and overall microstructure. This insight explains the improvements or changes in concrete behavior when SCBA is incorporated [7].

IV. EXPERIMENTAL RESULT

Experimental Results of Using Sugarcane Bagasse Ash (SCBA) as Partial Replacement for Fine Aggregate in Concrete

- *Compressive Strength:*

Research generally shows that incorporating SCBA as a partial replacement for fine aggregate can lead to a modest increase in compressive strength, especially at lower replacement levels—typically up to 10-15%. This improvement is mainly due to the pozzolanic reaction of SCBA, which promotes additional cement hydration, resulting in a denser and stronger concrete matrix. Compressive strength remains a vital indicator of concrete's ability to resist crushing forces [1, 4, 6].

Table 2 Test Result of Slump Value

SCBA Replacement %	Slump Value
Sample 1 (10% SCBA)	70 mm
Sample 2 (15% SCBA)	68 mm
Sample 3 (20% SCBA)	63 mm

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun185

- *Pozzolanic Activity and Particle Characteristics:*

SCBA functions as a pozzolan by reacting chemically with calcium hydroxide produced during the cement hydration process. This reaction forms additional calcium silicate hydrate (C-S-H), the key compound responsible for concrete's strength. Moreover, the fine particle size and angular shape of SCBA contribute to better particle packing and reduced voids within the concrete matrix, enhancing its overall density and resistance to load [2, 7].

- *Water Content and Workability:*

Maintaining appropriate water content is essential to achieving good workability in concrete mixes. The addition of SCBA can affect the water demand of the mix because its porous and fine particles may absorb more water. As a result, adjustments to the water content or use of admixtures like superplasticizers might be necessary to preserve the desired workability. The extent of this impact depends on factors such as the percentage of SCBA used and its physical properties, which underscores the importance of careful mix design optimization through experimental trials [3, 5].

V. KEY FINDINGS

- *Improved Compressive Strength*

Incorporating Sugarcane Bagasse Ash (SBA) into concrete mixtures has demonstrated a noticeable improvement in compressive strength, especially at moderate replacement levels (typically up to 15%). This enhancement is largely due to the pozzolanic activity of SBA, which contributes to the formation of additional binding compounds that strengthen the concrete matrix [1, 4].

- *Effect on Workability*

While SBA can improve strength, it often reduces the workability of fresh concrete. The fine particle size and absorptive nature of

SBA can lead to a stiffer mix, increasing water demand and reducing flowability. Without proper adjustments—such as modifying the water-cement ratio or using superplasticizers—this can affect ease of placement and finishing [2, 3].

- *Enhanced Durability and Reduced Permeability*

One of the significant benefits of SBA in concrete is its ability to reduce permeability. This results in increased resistance to water penetration, chloride ion attack, and freeze-thaw cycles. The improved durability is primarily due to the denser microstructure formed from the pozzolanic reaction, which fills in capillary pores and reduces pathways for moisture and chemicals [5, 6].

- *Improved Thermal Properties*

SBA also contributes to better thermal insulation properties. Its low thermal conductivity helps reduce heat transfer through the concrete, making it a valuable additive in energy-efficient construction and in structures exposed to temperature fluctuations [7].

- *Reduced Environmental Impact*

Using SBA helps address two major environmental concerns: reducing the reliance on natural sand and minimizing agricultural waste. Diverting bagasse ash from landfills and incorporating it into concrete promotes circular economy practices and reduces the carbon footprint of construction activities [1, 6].

- *Future Research Recommendations*

- *Standardization of Testing Methods:*

There is a need to develop consistent testing standards for evaluating the quality and pozzolanic activity of SBA to ensure reliable application in concrete.

- *Long-Term Performance Studies:*

More research is required to assess the long-term durability and mechanical behavior of SBA-blended concrete under diverse environmental conditions, including marine, industrial, and freeze-thaw environments.

VI. CONCLUSION

The incorporation of Sugarcane Bagasse Ash (SCBA) in concrete presents a promising approach to enhancing the performance of concrete while advancing sustainable construction practices. SCBA has demonstrated the potential to improve the mechanical, physical, and durability characteristics of concrete, all while reducing the demand for natural fine aggregates.

- *Enhanced Durability*

SCBA functions effectively as a pozzolanic material, reacting with calcium hydroxide produced during cement hydration to form additional cementitious compounds like calcium silicate hydrate (C-S-H). This secondary hydration not only improves strength but also significantly enhances the concrete's resistance to chemical attack, abrasion, and freeze-thaw cycles—critical factors in long-term durability [1, 4, 6].

- *Cost-Effectiveness*

SCBA is often an agricultural by-product readily available at minimal or no cost, especially in sugar-producing regions. Its use can lower the overall cost of concrete production, offering both economic and environmental benefits. By replacing a portion of the cement or fine aggregates, it contributes to cost-efficient and eco-conscious construction [2, 6].

- *Future Research Directions*

Despite the promising results, further research and development are needed to fully leverage the potential of SCBA in concrete applications:

- *Optimization of Particle Size and Grinding Methods:*

The impact of different grinding techniques and particle size distributions on concrete properties (e.g., strength, workability, and setting time) should be systematically investigated to ensure consistency and performance.

- *Combination with Other Pozzolanic Materials:*

Blending SCBA with materials like fly ash, metakaolin, or silica fume may yield synergistic effects that further improve concrete properties. Future studies should focus on identifying optimal combinations and analyzing their structural and durability outcomes [3, 7].

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun185

- *Long-Term Durability in Varied Environments:*

Further investigation is required to evaluate the long-term performance of SCBA-containing concrete in aggressive environments, such as coastal or industrial zones.

- *Standardization and Quality Control:*

Developing standardized testing protocols and quality control measures for SCBA will be essential to ensure its safe and reliable use in structural concrete.

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