International Journal of Multidisciplinary Academic Studies and Research (IJMASR)
Registered with MSME, Govt. of India: UDYAM-MH-20-0329275
Available at https://ijmasr.org Volume-1, Issue-3, March 2026, Page- 323-330.

To Cite This Article
Ms. Soniya S. Chichghate, Prof. Mayur M. Lohe, & Prof. Rutuja K. Kakpure. (2026). Experimental Research on Sugarcane Bagasse Ash as a Sustainable Supplementary Cementitious Material. International Journal of Multidisciplinary Academic Studies and Research (IJMASR), 1(3), 323–330. https://doi.org/10.5281/zenodo.19739310

Article Info
Received: 26th March 2026, Accepted: 29th March 2026, Published: 30th March 2026.

Experimental Research on Sugarcane Bagasse Ash as a Sustainable Supplementary Cementitious Material

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ABSTRACT: The increasing environmental concerns associated with cement production have led to the exploration of sustainable alternative materials in construction. Sugarcane Bagasse Ash (SCBA), an agricultural waste obtained from sugar industries, has emerged as a promising supplementary cementitious material (SCM) due to its high silica content and pozzolanic characteristics. This research investigates the utilization of SCBA as a partial replacement of cement in mortar mixes with proportions 1:4, 1:5, and 1:6. SCBA was incorporated at different replacement levels of 0%, 5%, 10%, 15%, and 20%. Experimental evaluation was carried out through compressive strength tests at curing ages of 7, 14, and 28 days. The results indicate that SCBA improves strength up to an optimum replacement level (around 5–10%) due to pozzolanic reactions, while higher percentages reduce strength due to dilution of cement content. The study also highlights improvements in sustainability by reducing CO_2 emissions, promoting waste utilization, and conserving natural resources. Thus, SCBA can be effectively used as an eco-friendly and cost-effective material in mortar for sustainable construction.

Keywords: Sugarcane Bagasse Ash, Sustainable Concrete, Supplementary Cementitious Material, Pozzolanic Reaction, Durability, Green Construction.

I. INTRODUCTION

In recent years, the construction industry has experienced rapid growth due to increasing urbanization, industrial development, and population expansion. Concrete and mortar are the most widely used construction materials because of their strength, durability, and versatility. However, the production of cement, which is the primary binding material in concrete and mortar, has become a major environmental concern. It is estimated that cement manufacturing contributes approximately 7–8% of total global carbon dioxide (CO_2) emissions. This is mainly due to the energy-intensive processes involved in clinker production and the release of CO_2 during the calcination of limestone. Therefore, there is an urgent need to reduce cement consumption and adopt sustainable construction practices. One of the most effective approaches to achieve sustainability in construction is the use of Supplementary Cementitious Materials (SCMs). These materials can partially replace cement in mortar and concrete without significantly affecting performance. SCMs are generally industrial by-products or agricultural wastes that contain reactive silica and alumina, which can participate in pozzolanic reactions. When these materials react with calcium hydroxide in the presence of water, they form additional calcium silicate hydrate (C–S–H), which improves the strength and durability of the cementitious system. Sugarcane Bagasse Ash (SCBA) is one such promising agricultural waste material that has gained attention in recent years. Sugarcane is one of the major crops grown in countries like India, Brazil, and Thailand. During the sugar manufacturing process, sugarcane bagasse (fibrous residue) is used as fuel in boilers for power generation. After combustion, a large quantity of ash is produced, known as sugarcane bagasse ash. This ash is generally disposed of in open land or landfills, leading to serious environmental issues such as air pollution, water contamination, soil degradation, and health hazards. The improper disposal of SCBA creates multiple environmental problems.

The fine particles of ash can become airborne and cause air pollution, leading to respiratory diseases among workers and nearby residents. When dumped on land, SCBA can affect soil properties by reducing fertility and altering pH levels. In addition, leaching of chemicals from ash can contaminate groundwater and nearby water bodies. Furthermore, the continuous generation of SCBA creates pressure on landfill areas, resulting in inefficient waste management practices. Therefore, effective utilization of SCBA is necessary to minimize its environmental impact.
From a material science perspective, SCBA possesses significant potential as a supplementary cementitious material due to its high silica (SiO_2) content. The silica present in SCBA is mostly in amorphous form, which is highly reactive and contributes to pozzolanic activity. When SCBA is added to cement-based systems, it reacts with calcium hydroxide released during hydration to form additional C–S–H gel. This reaction enhances the microstructure of mortar, reduces porosity, and improves durability. Moreover, the fine particles of SCBA can fill voids between cement grains, leading to better particle packing and improved strength. The use of SCBA in mortar offers several advantages. It reduces the demand for cement, thereby lowering CO_2 emissions and conserving natural resources such as limestone. It also promotes effective waste management by utilizing agricultural waste that would otherwise be discarded. Additionally, SCBA can improve certain properties of mortar, such as compressive strength, durability, and resistance to chemical attack, when used in optimum proportions. From an economic point of view, SCBA is a low-cost material, which helps in reducing overall construction cost. Despite these benefits, the performance of SCBA in mortar depends on several factors such as particle size, burning conditions, fineness, and replacement percentage. If SCBA is used in excessive amounts, it may lead to a reduction in strength due to insufficient cement content. Therefore, it is important to determine the optimum replacement level at which maximum benefits can be achieved without compromising the mechanical properties of mortar.

In this study, an experimental investigation has been carried out to evaluate the suitability of sugarcane bagasse ash as a partial replacement of cement in mortar. Different mortar mix proportions (1:4, 1:5, and 1:6) have been considered to represent rich, medium, and lean mixes. SCBA has been used as a replacement material at different percentages (0%, 5%, 10%, 15%, and 20%) to analyze its effect on compressive strength. The specimens have been tested at curing ages of 7, 14, and 28 days to study strength development over time. The main objective of this research is to develop a sustainable and eco-friendly mortar by incorporating SCBA, while maintaining adequate strength and performance. The study also aims to promote the use of agricultural waste in construction and contribute towards the development of green building materials. By utilizing SCBA effectively, it is possible to reduce environmental pollution, conserve natural resources, and support sustainable development in the construction industry.

II. MATERIALS AND METHODOLOGY

Materials Used:
1. Ordinary Portland Cement (OPC – 43 Grade)
This is the main binding material used in mortar. It reacts with water and forms a hard paste that holds sand particles together. OPC 43 grade is commonly used in construction because it gives good strength and is easily available.
2. Fine Aggregate (Sand)
Sand is used as filler material in mortar. It provides bulk and reduces shrinkage. Clean river sand is generally used, which should be free from dust, clay, and organic impurities.
3. Water (Potable Water)
Clean drinking water is used for mixing and curing. Water helps in the hydration process of cement, which is necessary for strength development. Impure water can reduce the quality of mortar.
4. Sugarcane Bagasse Ash (SCBA)
SCBA is an agricultural waste obtained from sugar industries. It contains silica, which helps in pozzolanic reaction. In this study, SCBA is used as a partial replacement of cement to make mortar more sustainable and eco-friendly.

Preparation of SCBA:
1. Collection from Sugar Industry
SCBA is collected from nearby sugar mills where bagasse is burnt as fuel. This ash is generally available as waste material.
2. Sun Drying and Oven Drying
The collected ash is first dried in sunlight to remove moisture. After that, it is oven-dried to completely remove any remaining moisture for accurate mixing.

3. Sieving through 150 µm Sieve
The ash is passed through a 150 micron sieve to remove large particles and fibers. This makes the ash finer and improves its reactivity.
4. Storage in Airtight Containers
After preparation, SCBA is stored in airtight containers to prevent moisture absorption and contamination.

Mix Proportions:
Mortar Mix Ratios:
Three different mortar mixes are prepared:

- 1:4 (1 part cement : 4 parts sand) → Rich mix (higher strength)
- 1:5 → Medium mix
- 1:6 → Lean mix (lower strength)

SCBA Replacement Levels:
Cement is partially replaced with SCBA at:

- 0% (control mix)
- 5%
- 10%
- 15%
- 20%

This helps to study how different percentages affect strength.
Water-Cement Ratio (w/c = 0.50):
Water is added equal to 50% of cement weight. This ratio is maintained constant to ensure proper comparison between mixes.

Testing Procedure:
1. Fineness Test
This test checks how fine the cement particles are. Finer cement reacts faster and gives early strength.
2. Consistency Test
This test determines the amount of water required to make a standard cement paste. It helps in proper mix preparation.
3. Setting Time Test

- Initial setting time: Time taken for cement to start hardening
- Final setting time: Time taken to fully harden
  This test ensures proper working time for construction.

4. Soundness Test
This test checks whether cement expands after setting. Good cement should not expand much, otherwise it may cause cracks.
5. Compressive Strength Test
This is the most important test. Mortar cubes are tested after:

- 7 days
- 14 days
- 28 days

It shows how strong the mortar becomes over time and helps in finding the optimum SCBA percentage.

Figure 2.1: Experimental Setup

III. RESULTS AND DISCUSSION

The compressive strength results obtained from the experimental investigation clearly indicate the influence of Sugarcane Bagasse Ash (SCBA) on the performance of mortar at different replacement levels and mix proportions. The variation in compressive strength with respect to SCBA percentage for different curing periods (7, 14, and 28 days) is presented in Tables 3.1 to 3.3 and illustrated in Graphs 3.1 to 3.3.

For the 1:4 mortar mix, as shown in Table 3.1 and Graph 3.1, the compressive strength at 7 days remains almost unchanged at 14 MPa for 0% and 5% SCBA replacement, indicating that early strength is not significantly affected at lower replacement levels. However, a gradual decrease in strength is observed as the percentage of SCBA increases beyond 5%. At 14 days, the strength increases from 18 MPa (control mix) to 19.5 MPa at 5% replacement, showing improved performance due to the pozzolanic reaction of SCBA. Similarly, at 28 days, the maximum strength of 23 MPa is achieved at 5% replacement, which is higher than the control mix (22 MPa). This improvement is mainly due to the formation of additional calcium silicate hydrate (C–S–H) gel, which enhances bonding and densifies the microstructure. However, beyond 5% replacement, the strength gradually decreases to 21 MPa, 19 MPa, and 18 MPa for 10%, 15%, and 20% SCBA, respectively. This reduction is attributed to the dilution of cement content and increased porosity due to excessive ash.

For the 1:5 mortar mix, the results presented in Table 3.2 and Graph 3.2 show a similar trend but with comparatively lower strength values due to the leaner mix proportion. At 7 days, the compressive strength slightly decreases from 10 MPa (control mix) to 9.5 MPa at 5% SCBA, indicating a minor reduction in early strength. At 14 days, a slight improvement is observed, with strength increasing from 13 MPa to 13.5 MPa at 5% replacement. At 28 days, the strength reaches a maximum of 17 MPa at 5% SCBA, compared to 16 MPa for the control mix. This indicates that SCBA contributes to strength gain at later ages due to delayed pozzolanic activity. However, as the replacement level increases to 10%, 15%, and 20%, the compressive strength decreases gradually to 15 MPa, 14 MPa, and 12.5 MPa, respectively. This trend confirms that optimum SCBA content should be limited to lower percentages for better performance.

For the 1:6 mortar mix, as shown in Table 3.3 and Graph 3.3, the overall compressive strength values are significantly lower compared to 1:4 and 1:5 mixes due to reduced cement content. At 7 days, an interesting observation is that the strength increases from 4 MPa (control mix) to 6 MPa at 5% SCBA, indicating a beneficial filler effect and early pozzolanic activity. At 14 days, the strength increases slightly from 5.5 MPa to 6.5 MPa at 5% replacement. At 28 days, the maximum strength of 9 MPa is achieved at 5% SCBA compared to 8 MPa for the control mix. However, beyond this level, the strength decreases to 8.5 MPa, 7 MPa, and 6 MPa for 10%, 15%, and 20% replacement, respectively. This reduction is more pronounced in lean mixes because the available cement content is already low, and excessive replacement leads to insufficient binding material.

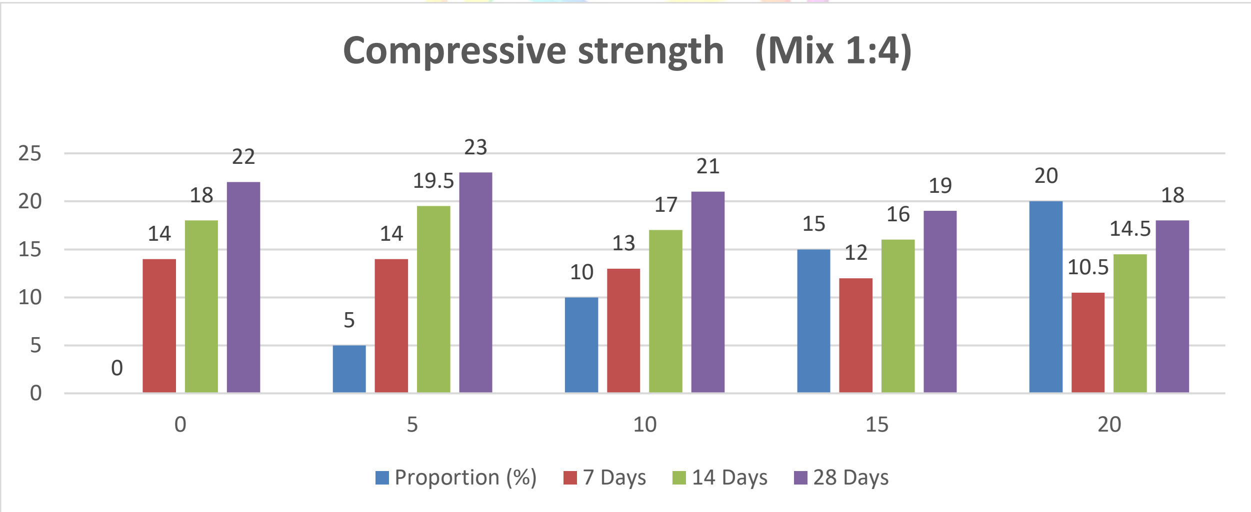
Overall, the graphical representation clearly shows that compressive strength increases up to an optimum SCBA replacement level of around 5% and then decreases with further increase in SCBA content. The improvement at lower replacement levels is due to the pozzolanic reaction and filler effect of fine SCBA particles, which enhance the microstructure and reduce voids. On the other hand, higher replacement levels result in reduced cement content, increased porosity, and lower strength. The effect is more significant in lean mixes (1:6) compared to richer mixes (1:4).

Thus, from the results and graphical analysis, it can be concluded that SCBA can be effectively used as a partial replacement of cement in mortar up to an optimum level of 5–10%, beyond which the mechanical properties start deteriorating. The findings confirm that SCBA is a suitable sustainable material for mortar applications when used in controlled proportions.

Compressive strength test (Mix 1:4):

Table 3.1: Compressive Strength of Mortar for 1:4 Mix with Different SCBA Replacement Levels (MPa)

Proportion (%)	7 Days	14 Days	28 Days
0	14	18	22
5	14	19.5	**23**
10	13	17	21
15	12	16	19
20	10.5	14.5	18

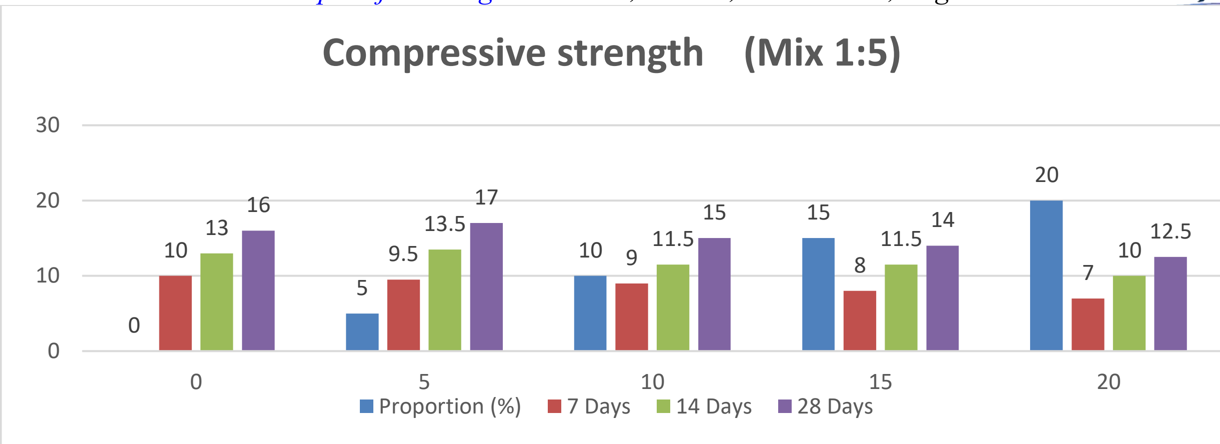


Graph 3.1: Effect of SCBA Replacement on Compressive Strength of Mortar (1:4 Mix)

Compressive strength test (Mix 1:5):

Table 3.2: Compressive Strength of Mortar for 1:5 Mix with Different SCBA Replacement Levels (MPa)

Proportion (%)	7 Days	14 Days	28 Days
0	10	13	16
5	9.5	13.5	17
10	9	11.5	15
15	8	11.5	14
20	7	10	12.5

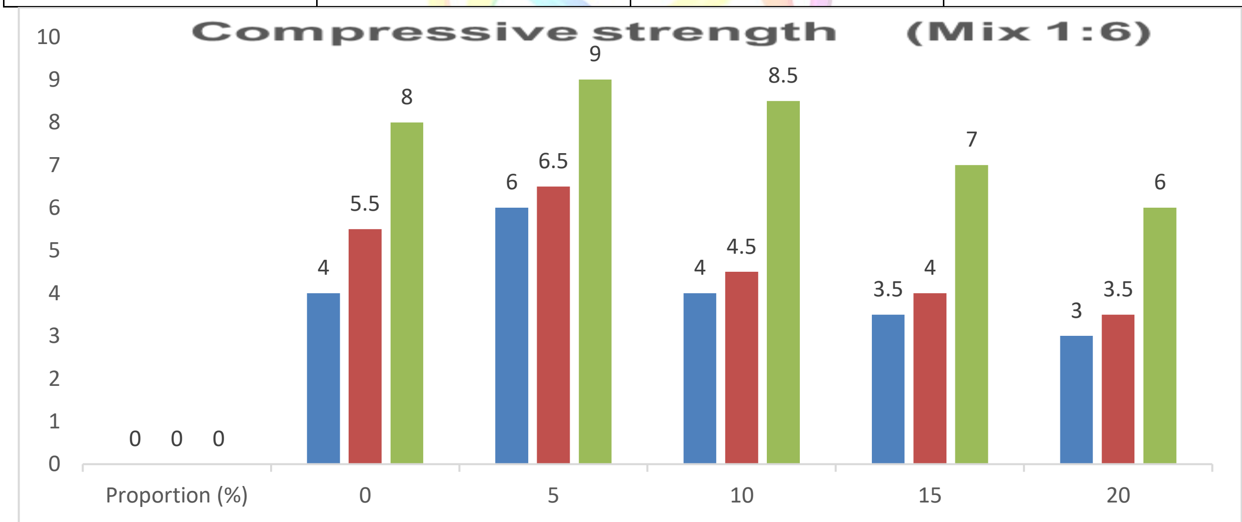


Graph 3.2: Effect of SCBA Replacement on Compressive Strength of Mortar (1:5 Mix)

Compressive strength test (Mix 1:6):

Table 3.3: Compressive Strength of Mortar for 1:6 Mix with Different SCBA Replacement Levels (MPa)

Proportion (%)	7 Days	14 Days	28 Days
0	4	5.5	8
5	6	6.5	9
10	4	4.5	8.5
15	3.5	4	7
20	**3**	**3.5**	**6**



Graph 3.3: Effect of SCBA Replacement on Compressive Strength of Mortar (1:6 Mix)

IV. CONCLUSION

The present experimental study on the use of Sugarcane Bagasse Ash (SCBA) as a partial replacement of cement in mortar clearly demonstrates its potential as a sustainable and eco-friendly supplementary cementitious material. From the results obtained, it is observed that SCBA exhibits good pozzolanic properties due to the presence of reactive silica, which contributes to the formation of additional calcium silicate hydrate (C–S–H) gel and enhances the strength of mortar at later ages. The compressive strength results indicate that partial replacement of cement with SCBA up to an optimum level of about 5% to 10% provides comparable or slightly improved strength compared to conventional mortar, especially in richer mixes such as 1:4 and 1:5. However, beyond this optimum level, particularly at higher replacement percentages like 15% and 20%, a noticeable reduction in strength is observed due to dilution of cement content and increased porosity. It is also noted that SCBA increases water demand and slightly affects workability, which may require proper mix adjustments. Overall, the study confirms that SCBA can be effectively utilized in mortar for masonry and plastering applications without compromising performance when used in controlled proportions.

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V. FUTURE SCOPE

The present study provides a strong foundation for the utilization of Sugarcane Bagasse Ash (SCBA) in mortar; however, there are several areas where further research can be carried out to enhance its application and performance. Future studies can focus on optimizing the processing techniques of SCBA, such as controlled burning, grinding, and chemical treatment, to improve its fineness and pozzolanic reactivity. Long-term durability studies should be conducted to evaluate the resistance of SCBA-based mortar against sulphate attack, chloride penetration, carbonation, and freeze–thaw conditions under different environmental exposures. There is also scope to investigate the use of SCBA in structural concrete and high-strength applications, as most studies are currently limited to mortar and low-strength mixes. Additionally, combining SCBA with other supplementary cementitious materials like fly ash, silica fume, or slag can be explored to develop hybrid eco-friendly binders with improved performance. Field-level studies and real construction trials are necessary to validate laboratory findings and assess practical feasibility on a large scale. Advanced analytical techniques such as microstructural analysis (SEM, XRD) can be used to better understand the behavior of SCBA in cementitious systems. Furthermore, development of standard guidelines and specifications for the use of SCBA in construction will help in its wider acceptance. Overall, SCBA has significant potential to be adopted as a sustainable construction material, and future research can help in improving its efficiency, durability, and large-scale implementation in the construction industry.

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