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Use Of Agro-Industrial Waste As Supplementary Cementitious Materials In Mortar: a Study On Sugarcane Bagasse Ash And Silica Fumes

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ABSTRACT

Due to the large CO2 emissions, cement production, a fundamental part of civil engineering systems, has contributed greatly to environmental degradation. The construction industry is checking additional cement materials (SCM) as sub-cement materials to reduce these effects. To improve performance and sustainability, this study examines the use of silicon fumes (SF) and sugar cane bags (SBA) as SCMS for mortar. This study aimed to reduce the strength and material costs of the mortar by using SBA and SF rather than part of the cement. To maintain a water binder ratio of 0.35, the methodology contained different mortar mixtures in different proportions of SBA (5%) and SF (10%) instead of cement. Pressure resistance, gap, and water absorption tests were performed on these mixtures after 7, 14, and 28 days. The results show that pressure resistance increased significantly over time, especially after the 28th day (when it reached 35 MPa), when SBA and SF were added. Puzzle activities of these materials resulted in a denser microstructure, improving long-term resistance and durability, but their fineness affected the process ability. Furthermore, it was found that water intake increased with cure time, promoting the required hydration reaction. This study not only provides a sustainable path to reduce the environmental impact of construction operations, but also provides methods for using waste such as SBA and SF as sustainable partial cement alternatives, which may improve the mechanical properties of mortar.

INTRODUCTION

Although cement has numerous uses in civil engineering, the process of making it has a significant negative environmental impact. Significant quantities of CO_2 are released throughout the cement timber process [1]. Although numerous experimenters are looking at backups for this material, using different accoutrements in place of cement may not be possible. One possible result is to incompletely replace it. It's a waste product that's either disposed of in a landfill or used as a toxin. This waste can be used to incompletely replace cement, opening the door for another pozzolanic [2].

To lower greenhouse gas emissions into the atmosphere, fresh cementing accoutrements are being promoted extensively as cement backups. For structural retrofitting, sugarcane bagasse ash (SBA), which is produced when agrarian waste bagasse is burned, can be used as a sustainable binder [3]. Due to its chemical makeup and the easy access to sugar club civilization in over 130 countries, including Brazil, India, China, and Thailand, sugar club bagasse ash (SCBA) has been shown in multitudinous studies to have pozzolanic eventuality. In 2017, the estimated quantity of SCBA was close to 900 million metric tons. There have been several proven benefits of using SCBA to incompletely replace cement in concrete and mortars in terms of their mechanical properties, continuity, rheology, and heat of hydration [4].

To minimize the use of cement and hence lower carbon emissions, the construction industry now uses a variety of supplemental bonding accoutrements (SCMs), including cover ash, sediment, met kaolin, and silica cloud [5]. Therefore, the material used in our exploration is silica fume and bagasse ash. Experimenters are veritably interested in geopolymers as a sustainable alternative to OPC; still, a number of these accoutrements ' characteristics limit their practical use. For illustration, in a veritably alkaline terrain, the capacity of chemical cocktails to alter the plasticity of geopolymers is limited. Thus, it's delicate to use geopolymers extensively in large-scale engineering systems [6].

Silica fume is constantly viewed as an ultrafine flyspeck in ultramodern interpretations of how it affects the rheological and hydration features of concrete, ignoring the benefits of its agglomeration tendencies [7]. A useful and sustainable alternative to cement is SCBA, a derivative of the sugar industry that can be employed to incompletely replace cement in the creation of low-carbon cementations accoutrements. SCBA has the pozzolanic eventuality to be used as a pozzolan in the manufacturing of low- carbon cement- grounded products, according to exploration [8].

In discrepancy, sloggers apply redundant water to the mortar case to make the cement mortar sufficiently workable for the ease of positioning. For colorful uses, similar to slipup list, perpendicular trouncing, and vertical trouncing, a varied type of mortar strength is needed [9]. Examinations were conducted to achieve this by altering the SCBA rate up to 30 and substituting 5 and 10 SF for cement as stable for all blend proportions. Exercising-ray luminescence (XRF), the chemical compositions of SCBA, SF, and cement were delved into. The optimal blend proportion at periods 3, 7, 14, and 28 days was determined by calculating mechanical strength characteristics. Retrogression analysis was also performed to read the mechanical strength at age 28 days [10].

Bagasse Ash Sugarcane (SCBA), the most widely grown crop worldwide, is one of these wastes. According to the foundation of profitability, 46 million tons of SCBA are produced for one year, which causes environmental problems [11].

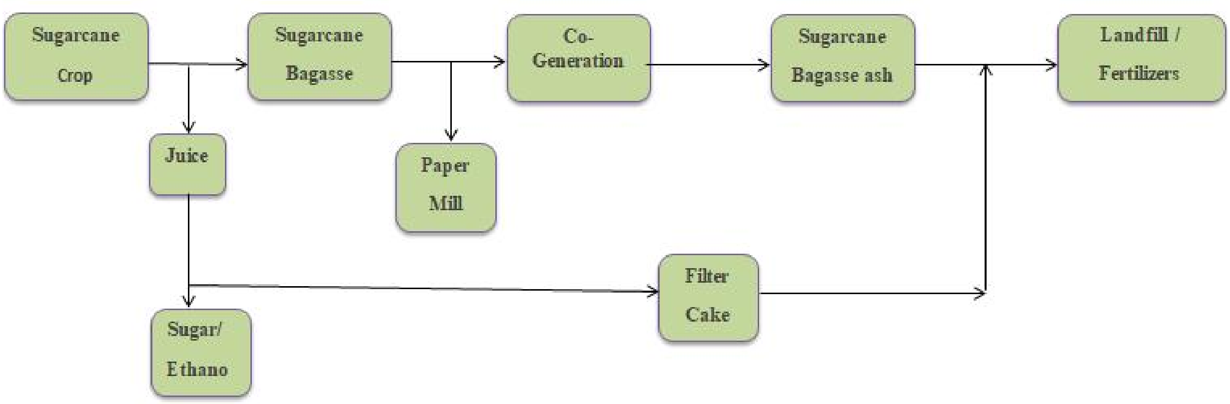


FIGURE 1: THE METHOD USED IN THE SUGAR INDUSTRY TO PRODUCE BAGASSE ASH

Year	Author	Objectives	Methods	Materials	Conclusion
2025	[3]	To assess the influence of SBA and SF regarding the mechanical characteristics and	Twelve mortar mixes varied (SBA, 0-30%) (SF, 5-10%) as cement replacements. Dry mix (cement, SBA, SF, aggregate)	Standard Portland cement (OPC), river sand, sugarcane bagasse ash	Mortars with 10% silica fume and 10% bagasse ash achieved the highest strength after

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 6 (2025)

		Resilience of the cement mortar mixtures.	was blended for 3 minutes, and then the superplasticizer and water were combined three times. Additional minutes.	(SBA), and silica fume (SF). SBA	extended curing, while both supplementary materials reduced water absorption and chloride penetration.
2024	[12]	To assess the mechanical, physical, and Microstructural characteristics of ternary and binary cementitious mortars that contain alccofine (AF) and unprocessed sugarcane bagasse ash (USBA).	Binary and ternary mortars were prepared by substituting cement with USBA, AF, or both, and their properties were tested. Compressive strength, UPV, and microstructural analysis were conducted to evaluate performance.	Concrete and raw sugarcane USBA (bagasse ash), AF (alccofine), Fine aggregate (sand) and water.	USBA increased water demand, but improved long-term power because of Pozzolanic activity, but AF improved strength and density.
2024	[13]	To look at the durability and mechanical characteristics of cement mortar	Compressive strength, flexural strength, UPV, and RCPT were conducted to	Cement, bagasse ash, fine aggregate (sand), and water.	A 15% bagasse ash dosage was identified as optimal, improving the
		To look into how the water-to-	Two mixing methods were used:	Cement, silica fume (5-15%),	Lower water-cement ratios

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 6 (2025)

2024	[14]	cement ratio affects Concentrations of silica fume on cement mortars' compressive strength.	pre-mixing cement, silica fume, and silica fume dissolution with a magnetic stirrer in water. Tests for water absorption and compressive strength were performed.	water.	increased reduced water content and compressive strength. absorbed during every stage of the cure and mixing methods.
2023	[15]	To look into how adding silica fumes affects the flames Resistivity of the mortar used for thermal insulation. To optimize the silica fume content and material ratios for constructing a high-performance fireproof insulation mortar.	Mortar mixes with varying silica fume content (0-10%) were prepared and tested for bond strength, thermal conductivity, dry density, and fire resistance. Optimal mix design was determined.	aggregate, cement, water, Fly ash, dispersible emulsion powder, Silica fume.	Silica fume addition improved the ability of the insulation to withstand fire. mortar that contains 10% silica fume showing the best results

2023	[16]	To create mortars using SCBA (sugarcane bagasse ash) As an alternative to sand for patching pavement cracks. To appraise these mortars' mechanical and physical	Mortar samples with varying SCBA content (0%, 50%, 75% sand replacement) were tested for compression, tensile strength, shrinkage, fluidity, and adhesion. Environmental impact was assessed	Cement, sugarcane bagasse ash (SCBA), sand, (possibly recycled polypropylene fibers and zeolite).	A 50% SCBA replacement for sand (M5-50%) yielded the best overall performance. Incorporating SCBA, recycled polypropylene fibers, and zeolite can considerably
2023	[17]	To investigate the effect of post-treatment burning temperatures (600°C, 700°C, 800°C) and replacement rates (5%, 10%, 15%, 20%) on the durability, mechanical strength, and microstructure of mortars combined with SBA.	SBA was sieved, burnt at 600°C, 700°C, 800°C, and used to replace cement at 5%, 10%, 15%,blended mortars Fresh and hardened properties, including porosity, mechanical strength, durability, and microstructure, were analyzed and compared to control mortar.	Portland cement, sugarcane bagasse ash (SBA), sand, water, and additives for post-treatment burning.	SBA-700 and SBA-800 at 5–10% replacement rates demonstrated the lowest porosity, highest mechanical strength, and improved durability.
		To examine studies on the application of bagasse from	SBA is used in mortar and concrete as a 5–30% cement substitute.	Cement, sugarcane bagasse ash (SBA), and	SBA's pozzolanic properties, due to high silica

2022	[2]	sugarcane Ash in concrete (SBA). To provide an overview of how the characteristics of mortar and concrete are affected when SBA is used in place of some of the cement.	Considering different amounts of water to cement (0.35 to 0.50). The characteristics of both fresh and hardened concrete were examined.	(likely other concrete constituents like aggregates and water).	content, allow for partial cement replacement. Research indicates varying effects of SBA on concrete properties depending on replacement percentage and water-cement ratio.
2024	[18]	The purpose of the study is to examine the impact of silica fume. In cement mixtures, about water-resistance qualities and strength-gaining traits.	Using steel molds, 120 mortar cubes in total were made. 50 x 50 mm in size. The water-resistance qualities were examined using two water-cement ratios (w/c) of 0.4 and 0.5. The compressive strength ratio between the saturated surface dry (SSD) and oven-dry conditions was used to compute a water-	The amounts of silica fume that were applied were 0%, 10%, 20%, and 25% as a partial substitute for cement in the mortar-making process.	According to this study, silica fume has a high pozzolanic activity and outstanding water resistance. One, the addition of silica fume results in a concrete composition that makes it

			resistant characteristic.		possible to build long-lasting concrete buildings.
2024	[19]	The purpose of this study is to thoroughly examine the addition of SF as an alternative to SCM, with an emphasis on concrete's mechanical qualities.	A large number of scientific articles were thoroughly examined and investigated between 1998 and 2023. A search for co-occurring terms and actively contributing nations was conducted across the Scopus database. It was described how the addition of SF affected both mechanical and new properties.	Silica fume (SF) was incorporated as a supplementary cementitious material (SCM), replacing cement, in concrete mixes.	This paper provides an overview of the Significant patterns as documented in the literature that are currently accessible that use SF as SCM. In addition to identifying broad trends, several research gaps have been found.
2022	[20]	To investigate the impact of swapping out a large amount of cement containing silica fume (SF) and sugarcane bagasse ash (BA)	Researchers cast and tested three ternary, three binary (cement/BA), and control mixes of concrete (BA/SF/cement). Mechanical tests	Cement, Bagasse ash (BA) from sugarcane, and SF, or silica fume, are the main. Varying	Binary concrete. Using ternary concrete and 20% BA and 7% of SF demonstrated better

		on the microstructural and mechanical characteristics of concrete.	(compressive and tensile strength) were performed on standard-cured cylindrical specimens at 7, 28, and 91 days.	components in the concrete mixes.	mechanical capabilities. Lower porosity and denser microstructures compared to other mixes, indicating their potential for high-performance sustainability.
2021	[21]	The goal is to look into Sugarcane Bagasse Ash (SCBA) as a sustainable substitute for some or all of the cement used in structural concrete.	Using SCBA as the substitute material, research is presented that summarizes SCBA production, properties, reaction mechanisms, and its impact on the features of the fresh and hardened states (power, Durability) of concrete.	SCBA as a substitute for certain cement to produce concrete.	Highlights of the research summary Impacts of SCBA on concrete's durability and strength characteristics, indicating that it may be a viable cement alternative.

Although several studies have investigated the effects of sugarcane bagasse ash (SBA) and silica fume (SF) on mortar and concrete properties, many lack a comprehensive evaluation of their combined use. There is inconsistency in replacement levels, mix proportions, and testing conditions, making comparisons across studies difficult. Most research focuses on compressive strength but often overlooks key aspects such as long-term durability, microstructural behavior, and practical challenges like workability reduction at higher SCM dosages. Furthermore, environmental and economic assessments of large-scale applications remain underexplored.

This research aims to address these gaps by examining the mechanical performance of mortar incorporating both SBA and SF under controlled conditions while considering their pozzolanic synergy and potential for sustainable application. The key objectives of this study are: (1) to increase mortar's strength by mixing silica fume and bagasse ash, and (2) to reduce construction costs by partially replacing cement with these waste-derived materials.

The research highlights that cement production has a significant negative environmental impact, releasing large quantities of CO_2. Utilizing supplemental cementing materials (SCMs) such as silica fume and sugarcane bagasse ash (SCBA) is explored as a significant approach to partially replace cement, thereby minimizing its usage and lowering carbon emissions. Ultimately, the research is significant because it presents a sustainable and effective method to utilize waste materials, improving mortar performance and promoting environmentally friendly construction practices.

Sustainable construction materials must not only meet mechanical and durability requirements but also align with broader environmental and financial sustainability goals. Akram et al. (2024) emphasized the importance of evaluating the financial viability of renewable energy and green technologies within the construction industry [22]. Similarly, this study contributes to that vision by proposing the use of low-cost, agro-industrial waste (bagasse ash and silica fume) to reduce cement dependency, offering both environmental benefits and potential cost savings.

Instead of replacing damaged structural elements, strengthening them has been determined to be a more cost-effective alternative. Fiber-reinforced polymer (FRP) wrapping with cement mortar as a binder is a contemporary method used to strengthen the weak structural part. This technology is known as FRCM. This research looks at the viability of creating a cement matrix for FRCM using SF and SBA, an agro-industrial by-product [23].

METHODOLOGY

Researchers use ordinary Portland cement (33 grade) because it is suitable for mortar (workability, strength). Researchers use bagasse ash 5% and silica fume 10% in a partial replacement of cement, and use river sand. Cement materials included PC processed SCBA (sieve size of 45 microns), and SF reduced silica smoke with a specific surface of 13,000 20,000 m2/kg. The SCBA was obtained as fresh ashes from KwaZulu-Natal in South Africa. Grade River Sand was used as a great unit [24]. Type I regular Portland cement is used and meets the requirements of EN 197-1. The SCBA used in this study was collected by Sukari Ltd. Dry the raw SCBA in the oven, sieve through a 75nm sieve, and then calculate it on a muffle stove to reduce LOI [20].

MATERIAL

BAGASSE ASH

Bagasse ash is a residue left after the crushing and extraction of juice from sugarcane. The primary binding agent in mortar, calcium silicate hydrate (C-S-H) gel, is created when this pozzolanic substance reacts with calcium hydroxide in the presence of water. At early curing ages, including 5% bagasse ash in place of traditional Portland cement (OPC), increased the mortar's compressive strength [25].

FIGURE 1: BAGASSE ASH

TABLE 1: PROPERTIES OF BAGASSE ASH

Sr. No.	Properties	Values
01	Specific gravity	1.9
02	Moisture absorption	2%

SILICA FUME

A byproduct of the silicon and ferrosilicon industries is silica fume. An extremely fine powder with a high silica content that is pozzolanic—that is, capable of reacting with calcium hydroxide in the presence of water—is the main binding agent in calcium silicate hydrate (C-S-H) gel, the mortar. To make mortar, silica fume was gradually added in concentrations of 0%, 10%, 20%, and 25%.The top of some of the cement [26].

FIGURE 3: SILICA FUME

TABLE 2: PROPERTIES OF SILICA FUME

Sr. No.	Properties	Values
1	Specific gravity	2% to 5%.
2	Moisture absorption	3.15

FINE AGGREGATE

Sand is used as filler in concrete to give the construction more strength and stability. The strength of the concrete mix is influenced by the size, shape, and grading of the sand particles. Well-graded sand produces better particle packing, which enhances aggregate particle interlocking and results in a denser concrete matrix [20].

FIGURE 2: SAND

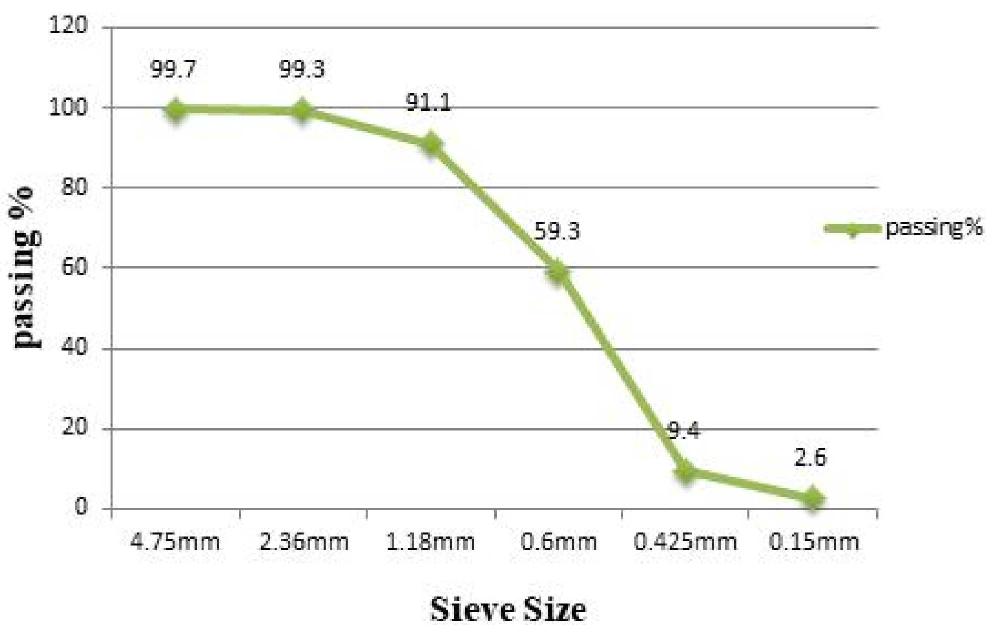
TABLE 3: PROPERTIES OF SAND

sr	Properties	River sand	Sea sand
1	Specific gravity (SSD condition)	2.36	2.49
2	Bulk density (kg/m^3)	1462	1543
3	Moisture (%)	3.40	4.50
4	Water absorption (%)	1.92	1.94

TABLE 4: SIEVE ANALYSIS

Sieve Size	Weight Retained (grams)	Cumulative weight retained (grams)	Cumulative % Retained	Cumulative % passing
4.75mm	3	0.3	0.3	99.7
2.36mm	4	0.4	0.7	99.3
1.18mm	82	8.2	8.9	91.1
0.6mm	318	31.8	40.7	59.3
0.425mm	499	49.9	90.6	9.4
0.15mm	68	6.8	97.4	2.6
Total	**1000**		**2.384**	

FINENESS MODULUS OF FINE AGGREGATE = 238.6/100=2.384



WATER

The water used for the concrete mix was ensured to be free from harmful chemicals, organic material. Water is the material used for mixing the above materials to make concrete.

TABLE 5: PROPERTIES OF WATER

Properties	Values
Specific gravity	**1.0**

METHODS

MIXING AND CURING

According to ASTM guidelines, twelve mortar mixes were created with a water-to-binder ratio of 0.35 [3]. While SF substituted cement at 5% and 10%, SBA was utilized as a partial substitute for cement at substitution levels ranging from 0% to 30%. Poured onto the tray, cement, SBA, SF, and fine materials. The aggregates were combined for three minutes. For three more minutes, the water and super plasticizers were added gradually and properly combined. Because SBA and SF have smaller particles, their combination results in a decrease in mortar flow. For each ratio, three samples were made, and the casting procedure was carried out in three layers. The samples were taken out of the molds after a day and allowed to cure in a water bath.

FIGURE 3: MIXING AND CASTING

Using bagasse ash and silica fume to partially replace cement in mortar initiates a pozzolanic reaction during curing. At **7 days**, initial strength develops mainly from cement hydration, with SCMs just starting to react, potentially leading to slightly lower early strength. By **14 days**, the pozzolanic activity increases, dignifying the mortar and contributing to noticeable strength gains. At **28 days**, the reaction is significant; silica fume enhances strength, workability, and durability due to its fineness and high silica content. Bagasse ash also contributes to strength and chemical resistance. Optimized mixes with these SCMs can achieve comparable or better long-term strength and durability than 100% cement mortar, offering benefits like reduced permeability and improved resistance to aggressive environments.

FIGURE 4: CURING TANK

TEST PROCEDURE

COMPRESSIVE STRENGTH TEST

According to IS, the CS was determined using the compressive testing machine at a rate of 1 kN/s and MPa [3]. Mortar specimens were made by substituting bagasse ash for cement (5%) and silica fume (10%), and tested after curing for 7, 14, and 28 days.

FIGURE 5: UNIVERSAL TESTING MACHINE (UTM)

SETTING TIME

Vicat Apparatus (ASTM C191): Measures the time it takes for a needle to penetrate the mortar to a specific depth. This determines the initial and final setting times.

FIGURE 6: VICAT APPARATUS

WATER ABSORPTION

Specifies a procedure for determining the water absorption of hardened mortar. Samples are dried, weighed, submerged in water, and weighed again.

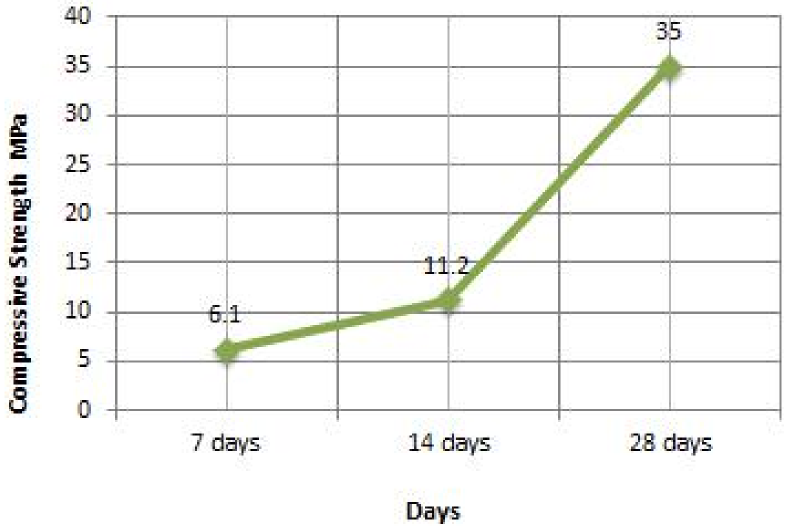
FIGURE 7: WEIGHT MACHINE

RESULTS

COMPRESSIVE STRENGTH TEST

The installation of silicon dioxide and bagasse as partial replacements of Meter cement affects how compressive strength develops over time. The mortar reached a compressive strength of 6.1 MPa after seven days of healing. This indicates the contribution of initial cement hydration. For 14 days of curing, the pressure resistance rose to 11.2 MPa, reflecting the continuous hydration process and the slow start of the silica and bagasse-based puzzle-based reaction. After 28 days, the mortar exhibited a significantly enhanced compressive strength of 35 MPa.

This substantial increase is attributed to the more complete pozzolanic reactions, where silica fume's fine particles contribute to a denser microstructure and improved strength, while bagasse ash also plays a role in long-term strength gain. These results demonstrate that the inclusion of silica fume and bagasse ash leads to a considerable improvement in compressive strength, particularly at later ages [27].



SETTING TIME (VICAT TEST)

A crucial characteristic of cement in construction is its setting time, which is the duration of the cement paste's solidification. To find this property, 400 grams of cement were used in an experiment. The findings are displayed in two tables that display the Vicat apparatus reading for varying water amounts as well as the cement paste's penetration depth at various time intervals. The penetration depth grew over time for a fixed weight of cement (400 grams): 4 mm after 10 minutes, 15 mm after 20 minutes, and 34 mm after 30 minutes. Simultaneously, tests with different water volumes using the Vicat apparatus produced different readings: 3 mm with 5 ml of water, 4 mm with 65 ml of water, and 6 mm with 7 ml of water. These metrics can be used to determine the cement's initial and final setting times.

WEIGHT OF CEMENT (400) GRAMS

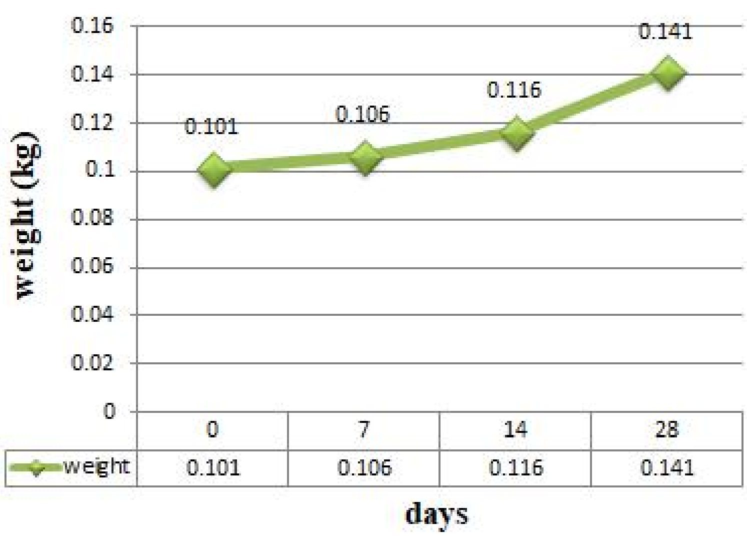
Sr. No.	Penetration (mm)	Time (min)
01	14	10
02	15	20
03	34	30

Sr. No.	Amount of water	Vicat apparatus reading
01	5ml	3mm
02	7ml	6mm
03	65ml	4mm

WATER ABSORPTION

The mass of the relatively dry sample is probably indicated by an initial weight of 0.101 kg. Generally, filling moisture is part of the curing process, especially for materials such as concrete and cement bases. This moisture is found in the pores and material structure rather than staying on the surface. For a sample to gain strength and develop its final properties, chemical reactions (such as cement hydration) must be promoted by absorbing water.

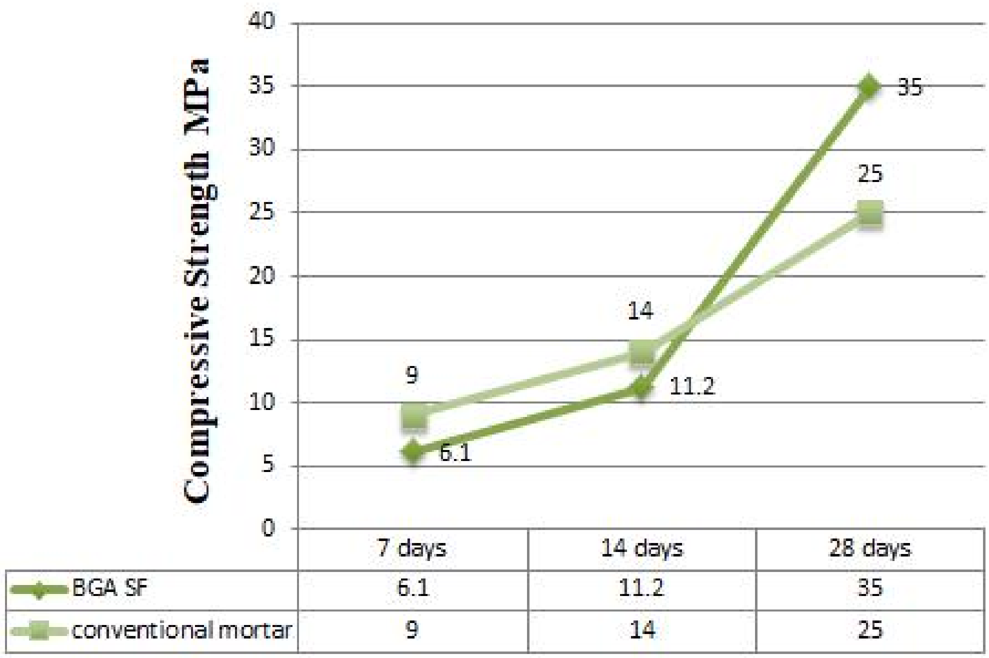
The total mass increases as the sample absorbs more water over the curing period. This will take 7-28 days. The 0.106, 0.116, and 0.140 kg of heavy climbing observed at all stages is a direct result of the additional masses that contributed to the absorbed water of the curing process.

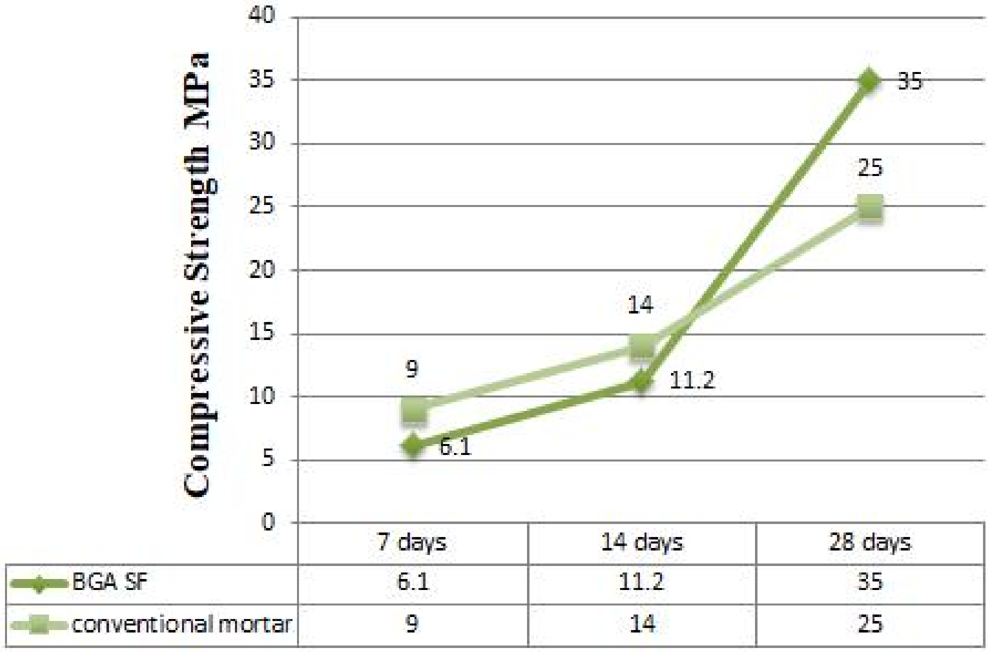


DISCUSSION

Using silica fume and bagasse ash in place of some of the cement in the mortar gradually increases pressure resistance [28]. This study showed that mortar containing these additional materials had a compressive strength of 20%, 22% after 14 days, and a significant 68% after 28 days. This increase is explained by continuous cement hydration and pozzolan reactions of bagasse ash and silica smoke. In particular, the smoke from high silicon oxide has its high silica content and fine particles, improving the strength and durability of people, especially for people's age[20].

In addition, bagasse ash improves its strength and resistance to chemicals. Optimized mixtures can be performed for the long term or more as regular cement [29]. Water absorption and settlement time tests point out that water absorption is a necessary part of the curing process for strength development, and that penetration depth increases over time during the time test measurements. The increased sample mass over 7-28 days of healing is a direct result of the absorbed water, supported by the curing process. Making use of these waste materials is offered as a workable way to enhance mortar performance and encourage green building practices [14].





After 7 and 14 days, the conventional mortar shows more strength. This is because normal Portland cement mostly contributes to early strength through its hydration process. By consuming calcium hydroxide produced during cement hydration, the pozzolanic reaction between BGA and SF to create new cementitious compounds takes longer. However, after 28 days, the mortar combining SF and BGA had a statistically higher strength than the regular mortar. This is because the pozzolanic interaction between BGA and SF gets stronger over time. The highly reactive and fine silica fume refines the pore structure and provides nucleation sites, resulting in a denser and stronger matrix [30].

BGS & SF mixture is especially stronger because it contains dragon positions and silica, especially after 28 days. These substances react with the product of cement baggage (POBLA) to produce more density and more binding gels over time than the standard OPC concrete. OPC develops strength due to hydration of the compound, producing calcium silicate hydrate (C-S-H) and calcium hydroxide, while the BGS SF mixture is advantageous from additional qualities. In this process, the slag of the silica furnace and the blast stove react with the calcium hydroxide, which is released by OPC hydration more C-H-H gels, which are the primary binding processes in concrete [31].

The continuous hydration of cement and the slower, longer-term pozzolanic reactions of these supplemental materials are the main causes of the gradual increase in strength development in cement-based materials that incorporate additional cementitious materials like bagasse ash and silica fume. When bagasse ash and silica fume were utilized in mortar to partially replace cement, the compressive strength increased significantly, peaking at 35 MPa after 28 days. Another study that looked at mortars with different amounts of silica fume (5% to 10%) and bagasse ash (5% to 30%) replacements also found that strength increased over time, with mixes containing 10% bagasse ash and 10% silica fume at 90 days [23]. However, this study found that delayed pozzolanic reactions with higher bagasse ash content caused an initial reduction in early-age strength in some mixes [32]. It also found that inadequate particle bonding caused a decrease in strength when bagasse ash replacement exceeded 10-15% [33]. The particular mix proportions and replacement levels of bagasse ash and silica fume, the type of cementations' material tested (mortar composition and possibly aggregate differences not explicitly detailed in both), and the various curing ages evaluated are some of the reasons for the variations in absolute strength values and development trends between the studies [24]. Notwithstanding these differences, both studies provide evidence that adding these extra materials improves strength and durability using pozzolanic activity [3].

Because of cement hydration and pozzolanic reactions, the strength development of cement-based materials that contain additional materials like silica fume and bagasse ash steadily increases over time. A mortar mix's in one investigation, the compressive strength rose from 6.1 MPa at 7 days to 35 MPa at 28 days. According to a different investigation, concrete that was heavily replaced with bagasse ash exhibited strengths of more than 25 MPa after 28 days. In one investigation, the compressive strength rose from 6.1 MPa at 7 days to 35 MPa at 28 days. According to a different investigation, concrete that was heavily replaced with bagasse ash exhibited strengths of more than 25 MPa after 28 days, rising to over 30 MPa by 180 days [8]. The type of mixture (concrete vs. mortar), the proportions and total amounts of cement substituted, the bagasse ash's properties (such as processing and fineness), and variations in mix designs are some of the causes of the observed differences in strengths and development rates. Including aggregate types and water content. It was observed that higher replacement levels of bagasse ash in concrete may decrease strength because of increased porosity. But in both situations, the primary cause of the increased strength with age is the creation of more cementing compounds because of the reaction between silica from additional components and calcium hydroxide, which produces a denser matrix [34].

Generally speaking, when cement-based products are mixed with sugarcane bagasse ash and silica fume, their effects on the materials' properties over time differ from those of cement-only mixes. Because the pozzolanic reaction is gradual, strength development may initially be slower. Later on, though, the additional materials help to improve durability and strength [1]. Variations in the amount and combination of bagasse ash and silica fume used as cement substitutes, as well as variations in material properties like the ash's fineness and general mix design parameters like water content, are the main causes of discrepancies in results between studies and mixes. Together, these elements affect the level of advantageous pozzolanic activity, which results in the observed differences in workability, strength gain over various curing times, and durability characteristics like electrical resistivity. The long-term advantages highlight the potential of these materials for sustainable construction practices, even though their early-age performance frequently lags behind that of traditional mixes [35].

In mortar, Compressive strength is gradually increased by substituting bagasse ash and silica fume for some of the cement, especially in later curing stages. This is explained by the pozzolanic reactions of these materials and ongoing cement hydration. This results in greater long-term strength and durability as well as a denser microstructure [26]. By decreasing permeability and enhancing resilience to challenging conditions, optimized mixes containing these supplementary cementitious materials (SCMs) can achieve strength and durability that are on par with or even better than mortar made entirely of cement. It is suggested that using these waste materials can improve mortar performance and encourage ecologically friendly building methods. The long-term benefits highlight their potential for sustainable construction, even though early-age performance may initially lag behind traditional mixes because of the pozzolanic reaction's gradual nature [36].

One drawback mentioned is that because silica fume and bagasse ash have smaller particle sizes, they may reduce mortar flow and cause workability problems. Even though mix optimization is mentioned in the study, a more thorough examination of the exact range of ideal replacement percentages for both materials across different mix designs and their impacts on various properties might be required [37].

Given the unique performance requirements of different types of concrete and mortar, to find the best silica fume to bagasse ash ratios for different applications, more research is needed. To fully understand how resistant mortar is to freeze-thaw cycles, chemical attacks, and other processes of deterioration, its long-term durability in a variety of harsh environments should be investigated [38]. It is advised to evaluate the financial and environmental viability of extensive implementation in the construction sector, taking into account factors like processing expenses, material accessibility, and overall carbon footprint reduction [39].

Further investigation into how different processing techniques affect bagasse ash's pozzolanic activity and, consequently, mortar's characteristics is advised. Adding silica fume and bagasse ash can provide more detailed information on the reaction processes and binder formation. Matrix using methods of microstructural investigation, like SEM and XRD. Finally, investigating the compatibility of silica fume and bagasse ash for other structural uses, as well as their potential application in other cementation composites, is another direction for future research.

CONCLUSION

This study effectively illustrated how adding silica fume (SF) and sugarcane bagasse ash (SBA) to mortar mixtures as partial substitutes for cement can improve performance and advance sustainability. As a result of the continuous pozzolanic reactions and the development of a denser matrix, the results show that adding these additional cementing materials to mortar considerably increases its compressive strength over time. The best mixes achieve notable strength increases by 28 days. As per previous research, mortar (1:3) compressive strength is about 25 MPA for OPC 43 grade after 28 days, but in this research, by using silica fume and bagasse ash at the ratio of 15% with the OPC of grade 43 mortar compressive strength gradually increases to 35MPa after 28 days. The technical feasibility of employing SBA and SF in mortar applications is highlighted by this increased strength in conjunction with better durability properties like decreased permeability. In addition to improving performance, using these agricultural and industrial waste materials presents a strong argument for lowering dependency on conventional cement. Nevertheless, the study also found some drawbacks, chief among them the possible decrease in mortar flow brought on by the fine particle size of SBA and SF, which may affect workability. Although mix optimization was investigated, a more thorough examination of the exact ideal replacement percentages for different mix designs is necessary.

LIMITATIONS

This research highlights the benefits of using bagasse ash and silica fume, but it also quietly brings up some issues or possible research directions. SBA and SF have smaller particles, so combining them could cause a workability problem because the mortar flow will be reduced.

Although the study mentions mix optimization, a more detailed analysis of the exact range of optimal replacement percentages for both materials across various mix designs and their effects on various properties might be required.

FUTURE RESEARCH DIRECTIONS

In future research, the integration of digital tools and artificial intelligence (AI) could play a significant role in optimizing mortar mix designs, predicting long-term performance, and reducing material waste during experimental procedures. As highlighted by Zia et al. (2024), AI applications in project management and data-driven decision-making are transforming the construction sector, allowing for enhanced efficiency, risk management, and cost control [40]. Incorporating AI-driven modeling in material studies can facilitate more accurate predictions of strength development, sustainability metrics, and lifecycle performance of eco-friendly mixes such as those containing silica fume and bagasse ash.

More research is needed to determine the ideal ratios of silica fume and bagasse ash for different applications, taking into account the unique performance needs of various kinds of concrete and mortar. Bagasse ash also contributes to the pozzolanic reaction, further enhancing the long-term strength and durability of the mortar. The combined effect of BGA and SF results in a more complete and efficient utilization of the hydration products, leading to superior strength at later ages, a maximum of 56 days, and gain doubling of strength after 91 days. The long-term durability of mortar manufactured with bagasse ash and silica fume is essential to fully understanding its resistance to chemical attack, freeze-thaw cycles, and other degradation mechanisms in a variety of harsh environments is being investigated. The adoption of sustainable materials like bagasse ash and silica fume depends on both technical performance and supportive policies. Akram et al. (2023) highlight that PPPs can provide financial and institutional backing for eco-friendly construction in Pakistan [41].

Looking at aspects like processing costs, material availability, and overall carbon footprint reduction to determine whether using bagasse ash and silica fume on a large scale in the construction industry is both environmentally and financially feasible. Investigating how Bagasse ash's pozzolanic action is affected by various processing techniques and how this affects the characteristics of mortar. Utilizing microstructural analysis (XRD and SEM) to better comprehend the mechanics of the reaction and the creation of the binder matrix with the addition of silica fume and bagasse ash. Examining the suitability of bagasse ash and silica fume for different structural applications, as well as their potential application in composites made of different cementations.

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