



Challenge Journal of CONCRETE RESEARCH LETTERS

Review Article

Sugarcane bagasse ash in cementitious systems: A review of fresh, mechanical, and durability properties

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ABSTRACT

Currently, research is being conducted to investigate the potential of industrial and agricultural waste as raw materials in the construction industry. Integrating such materials into concrete diminishes cement consumption and CO₂ emissions from cement manufacturing. Sugarcane bagasse is a by-product of the sugar extraction process, and a significant portion of it is used as boiler fuel for electricity generation. This process releases a considerable amount of waste sugarcane bagasse ash (SCBA), which is frequently disposed of in the environment. Incorporating this waste can be both cost-effective and ecologically advantageous, fostering sustainable development. This review critically synthesizes published studies on the physical and chemical characteristics of SCBA, fresh-state behaviour, mechanical properties, durability indicators, and CO₂ reduction potential in cementitious materials, including mortar and concrete. Particular attention is given to the effects of ash processing, fineness, silica content, burning condition, and loss on ignition on reported performance. The reviewed evidence indicates that low-to-moderate SCBA contents can enhance compressive and split tensile strength, while durability improvements are commonly reflected in reduced water absorption, lower capillary absorption and chloride penetration, and higher electrical resistivity. The literature indicates that mechanical performance is most frequently optimized at about 10-15% replacement, whereas durability benefits are often reported within a broader range of 10-30%, depending on matrix type and ash quality. The findings also show that the environmental benefit of SCBA depends on processing intensity and transport burden. Overall, SCBA emerges as a promising but process-sensitive supplementary cementitious material for sustainable concrete production.

Citation: Verma SK, Sachan AK, Shanker R (2026). Sugarcane bagasse ash in cementitious systems: A review of fresh, mechanical, and durability properties. *Challenge Journal of Concrete Research Letters*, 17(3), 387–404.

ARTICLE INFO

Article history:

Received – February 5, 2026
Revision requested – March 10, 2026
Revision received – April 12, 2026
Accepted – April 24, 2026

Keywords:

Sugarcane bagasse ash
Chemical properties
Durability
Mechanical properties
Physical properties



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1. Introduction

The key strategies for sustainable cement manufacturing include energy conservation, reduction in CO₂ emissions, and the preservation of finite natural resources. However, the production of ordinary Portland cement (OPC) is highly unsustainable due to its extensive consumption of natural resources and high carbon emissions (Fairbairn et al. 2010). The global annual concrete production exceeds 30 billion metric tons (Ozmen

and Tanriverdi 2025), with the Indian construction industry using approximately 450 million cubic metres annually (IBEF 2025). Cement reacts chemically with water and other substances to form a hardened mass that binds components together. Various additives are often introduced to enhance the properties of fresh and hardened concrete (Jittin and Bahurudeen 2022; Miller et al. 2016).

Pozzolanic materials derived from agricultural waste have gained significant attention due to their ability to

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improve the performance of blended cement concrete while mitigating environmental concerns (Agwa et al. 2022; Zeyad et al. 2016). SCBA is one such promising pozzolan, available in various regions worldwide. India alone produces over 300 million tons of sugarcane annually, generating approximately 10 million tons of SCBA as waste. The processing of sugarcane in mills results in about 0.62% residual ash and 26% bagasse per ton of sugarcane (Chindaprasirt et al. 2008; Dhengare et al. 2020; Juenger et al. 2019).

Bagasse is a fibrous residue generated after juice extraction from sugarcane and is widely used as a fuel source in the sugar industry. The ash produced from its combustion known as sugarcane bagasse ash (SCBA) has been increasingly utilized as a pozzolanic material in concrete or mortar mixtures as a partial replacement for cement and thus contribute to reducing disposal concerns. Several studies have investigated the chemical composition and pozzolanic activity of SCBA, concluding that it primarily consists of high silica content. However, unburned carbon particles in SCBA can adversely affect concrete reactivity and performance (Kumara et al. 2023; Praveenkumar et al. 2020).

Several studies on SCBA have provided useful background on its potential as a supplementary cementitious material. However, many of them remain largely descriptive or focus on isolated performance aspects without systematically linking ash processing quality to the variability observed across cementitious materials, including mortar and concrete. The present review seeks to address this gap by providing an integrated analysis of the physical and chemical characteristics of SCBA, fresh behaviour, mechanical response, durability performance, and CO₂ reduction potential within a unified framework. It further employs comparative tables and trend-based figures to identify practical optimum replacement ranges for key mechanical and durability indicators. Accordingly, this review aims to analyse the influence of SCBA on cement-based materials based on existing literature, with particular emphasis on its effects on mechanical and durability-related performance.

2. Literature Review Methodology

This review adopted a structured literature review methodology to synthesise the influence of sugarcane bagasse ash (SCBA) on cementitious materials. Relevant studies were retrieved from Scopus, Web of Science, ScienceDirect, and Google Scholar to ensure broad coverage of the peer-reviewed literature. The search was limited to articles published between 2008 and 2025, which corresponds to the main period during which SCBA has been systematically examined as a partial cement replacement material.

The search strategy was developed using combinations of SCBA-related and performance-related terms, including “sugarcane bagasse ash”, “SCBA concrete”, “SCBA mortar”, “SCBA supplementary cementitious material”, “SCBA mechanical properties”, “SCBA durability”, “SCBA workability”, “water absorption”, “capillary absorption”, “sorptivity”, “chloride penetration”, and “electrical resistivity”. These terms were combined using

Boolean operators such as AND and OR to capture studies addressing the physical and chemical characteristics of SCBA as well as its effects on fresh, mechanical, and durability properties.

The retrieved records were screened through title screening, abstract screening, and full-text eligibility assessment. Studies were included if they investigated SCBA in concrete or mortar and reported results on at least one of the following aspects, namely physical or chemical characteristics, fresh properties, mechanical performance, or durability behaviour; and provided sufficient quantitative information on mix proportion, replacement level, curing condition, and measured properties. Conference abstracts without full data, non-English publications, and studies lacking adequate methodological detail were excluded.

Approximately 120 studies were initially identified through database searching. After screening and eligibility assessment, around 65 studies were retained for detailed synthesis. To improve methodological rigour, the included studies were further appraised for reporting quality on the basis of the clarity of SCBA source and processing method, mix design details, curing regime, testing procedure, and completeness of quantitative results. Studies with sufficiently reported experimental data were prioritised for the comparative tables and trend-based figures used in this review.

This systematic approach is intended not only to summarise the available evidence, but also to provide a comparative and critical synthesis of how SCBA processing, replacement level, and matrix type jointly influence fresh, mechanical, durability, and environmental performance in cementitious systems.

3. Environmental Impact and CO₂ Reduction Potential of SCBA

Sugarcane bagasse ash (SCBA) is increasingly regarded as a low-carbon supplementary cementitious material because it can partially replace Portland cement, the production of which is highly emission intensive due to clinker burning and limestone calcination. The carbon footprint of conventional cement is generally reported to be around 0.8–0.9 kg CO₂ per kg cement, although the exact value varies with clinker factor, kiln efficiency, fuel type, electricity mix, and regional production conditions (Benhelal et al. 2013; Chen et al. 2010; Kajaste and Hurme 2016; Mohamad et al. 2022). The environmental benefit of SCBA lies in its capacity to valorise an agro-industrial residue while reducing clinker demand. However, the literature does not support a single universal carbon emission factor for sugarcane bagasse ash (SCBA). Reported carbon emission values for SCBA vary markedly with allocation assumptions and the system boundary adopted, particularly whether drying, sieving, grinding, calcination/activation, and transport are included (Fairbairn et al. 2010; Cordeiro et al. 2008, 2009; Kolawole et al. 2021; Francioso et al. 2024). Torres de Sande et al. (2023) quantified this variation, reporting 0.024 kg CO_{2e}/kg (carbon dioxide equivalent per kilogram) for untreated locally used SCBA and 0.46 kg CO_{2e}/kg for treated or activated imported SCBA, com-

pared with 0.912 kg CO_{2e}/kg for cement in the same study. Other studies have similarly adopted an SCBA emission factor of about 0.11 kg CO₂/kg (Ullah et al. 2025; Li et al. 2022; Chindaprasirt et al. 2020), confirming that although SCBA is generally far less carbon-intensive than Portland cement, its environmental benefit is strongly conditioned by processing intensity and transport burden.

Accordingly, the climate advantage of SCBA is best expressed as net CO₂ reduction. The net CO₂ reduction can be expressed as the difference between the carbon emissions avoided by replacing a given amount of cement and the carbon emissions generated from processing the equivalent amount of SCBA. The analysis was performed using the expression: Net CO₂ reduction = (cement replaced × 0.85) - (SCBA used × 0.46), assuming mass-equivalent replacement within 1 tonne of total binder, as shown in Table 1. The analysis adopted a cement emission factor of 0.85 kg CO₂/kg, which lies within the commonly reported range of 0.8–0.9 kg CO₂/kg for conventional cement production (Benhelal et al. 2013; Chen et

al. 2010; IEA 2023, as cited in Environmental Impact & CO₂ Reduction Potential of SCBA). An emission factor of 0.46 kg CO₂/kg was adopted for SCBA in the present analysis, as this value has been reported for treated or activated imported SCBA in the literature (Torres de Sande et al. 2023). Accordingly, it is taken to represent the cumulative influence of processing-related stages, including treatment or activation, on the embodied emissions of SCBA. The analysis shows a linear increase in net CO₂ savings with rising SCBA replacement levels under the adopted emission factors. At 5%, 10%, 20%, and 30% substitution, the estimated net CO₂ reductions are 19.5, 39, 78, and 117 kg CO₂/t binder, respectively. The consistently positive savings arise from the lower embodied emissions of SCBA (0.46 kg CO₂/kg) relative to cement (0.85 kg CO₂/kg). These results strengthen the environmental justification for SCBA as a supplementary cementitious material and highlight the need to evaluate net life-cycle benefits rather than relying solely on gross avoided emissions from cement replacement (Chindaprasirt et al. 2020; Li et al. 2022).

Table 1. Calculated net CO₂ reduction for different SCBA replacement levels.

SCBA replacing cement (%)	Cement avoided (kg/t binder)	Gross CO ₂ avoided from cement (kg/t binder)	CO ₂ burden of SCBA processing (kg/t binder)	Net CO ₂ reduction (kg/t binder)
5	50	42.5	23	19.5
10	100	85.0	46	39
20	200	170.0	92	78
30	300	255.0	138	117

Note: Calculations are based on 1 tonne of binder and assume one-to-one mass replacement of cement by SCBA.

4. Sugarcane Bagasse Ash Processing and Material Characteristics

Fig. 1 illustrates the process flow for sugar production and its byproducts. Bagasse, the fibrous residue after juice extraction, is burned in sugar mills, producing SCBA as waste. Fig. 2 presents images of raw sugarcane bagasse and SCBA. The SCBA has been widely investigated as a supplementary cementitious material. However, evidence from several studies indicates that performance depends not merely on its agricultural origin, but on the manner in which the ash is processed before incorporation into cementitious systems. The most influential processing variables include burning temperature, residence time, oxygen availability, grinding duration, fineness, carbon removal, and the resulting proportion of amorphous and crystalline silica (Cordeiro et al. 2011; Bahurudeen and Santhanam 2015; Embong et al. 2016; Gupta and Sachan 2019; Kolawole et al. 2021). A recurring finding across several studies is that untreated or poorly processed SCBA often contains fibrous residues, porous coarse particles, and substantial quantities of unburned carbon, all of which reduce pozzolanic reactivity and contribute to inconsistent material performance (Bahurudeen et al. 2016; Ouedraogo et al. 2022; Embong et al. 2016). Accordingly, SCBA should not be treated as a uniform material; rather, it should be understood as a process-dependent family of ashes whose engineering

value is governed by combustion history and post-treatment.

4.1. Physical characteristics of SCBA

Morphological observations generally describe irregularly shaped particles with rough and porous surfaces (as shown in Fig. 3), while Abdalla et al. (2022) and Bahurudeen and Santhanam (2015) also reported the co-existence of fine burned particles and unburned fibrous particles in raw ash. The physical characteristics of SCBA reported in several studies are summarized in Table 2. Studies indicate that the specific gravity of SCBA typically ranges from 1.65 to 2.42, while bulk density commonly varies between 410 and 610.6 kg/m³. Reported fineness values indicates substantial variation, ranging from 27.4 to 60320 m²/kg, reflecting differences in grinding and sieving procedures across studies (Abdalla et al. 2022; Bahurudeen and Santhanam 2015; Patil et al. 2021). Mello et al. (2020), Navaneetha et al. (2025) and Patil et al. (2021) reported that post-processing of SCBA resulted in higher fineness values. Treatments such as grinding, sieving, drying, or their combination was found to enhance the fineness of the ash. The high surface area can enhance filler action and pozzolanic reactivity. However, it can also increase water demand and affect fresh-state behaviour when accompanied by high porosity or carbonaceous impurities.

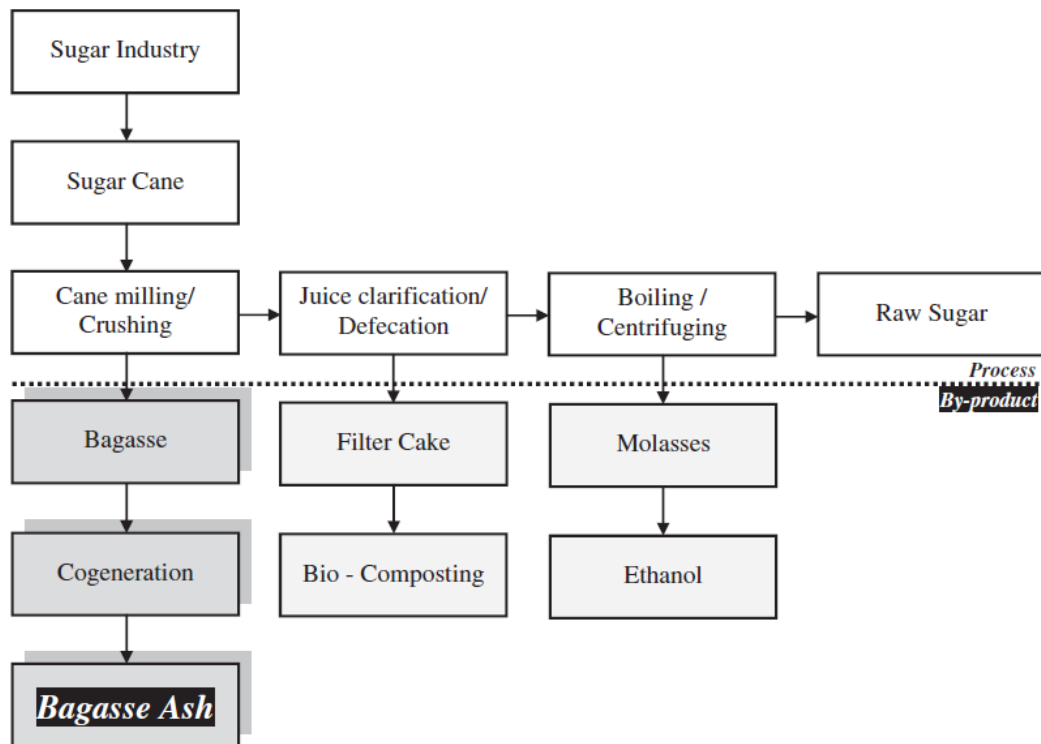


Fig. 1. Sugar production process (Sua-iam and Makul 2013).

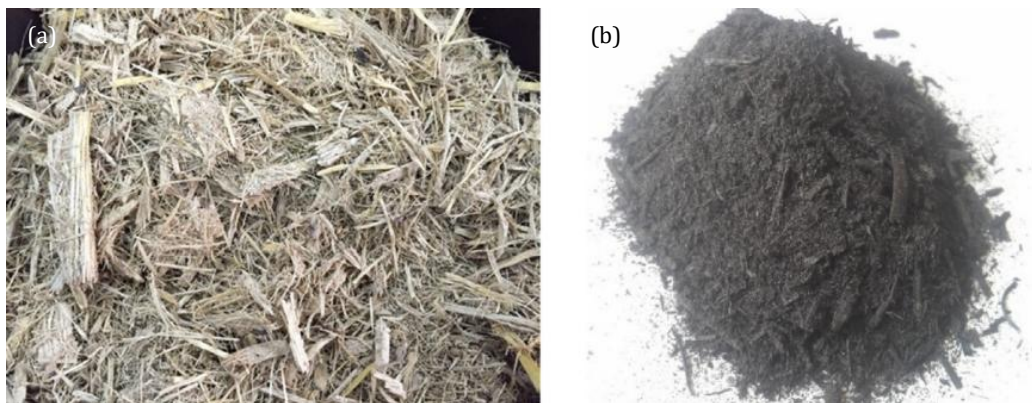


Fig. 2. a) Raw dry sugarcane; b) SCBA (Zareei et al. 2018).

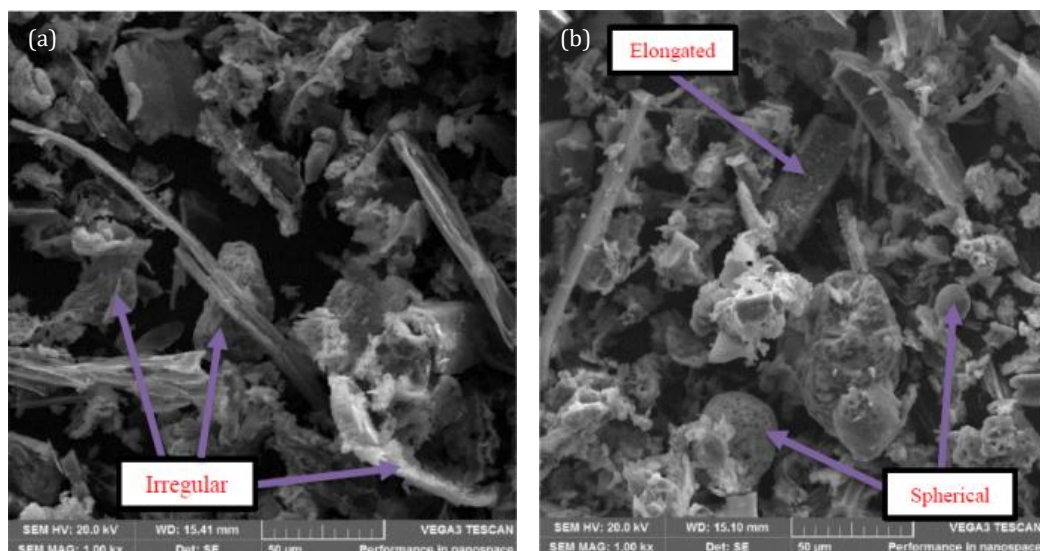


Fig. 3. SEM imaging of SCBA (a) Raw (b) Processed (Abdalla et al. 2022).

Table 2. Physical properties of SCBA reported in previous studies.

Authors	Specific gravity	Unit weight (kg/m ³)	Fineness (m ² /kg)	D ₅₀ (μm)	Sieve description and processing technique
Patil et al. (2021)	2.1	410	7832 ⁽¹⁾	–	Boiler ash (~850 °C), sieved through 90 μm
Kazmi et al. (2017)	2.12	610.6	453.2 ⁽¹⁾	–	Sieved through 300 μm and ball-milled to <45 μm
Ainomugisha et al. (2021)	1.81	474.33	–	–	Co-generation ash (~530 °C), sun-dried and sieved through 300 μm
Kumara et al. (2023)	1.65	–	225	–	Oven-dried at 110 °C for 24 h and sieved through 300 μm
Praveenkumar et al. (2020)	2.2	–	514	–	Raw bagasse burnt in open filed (110–120 °C), sieved through 300 μm and 75 μm, ball-milled (120 min), oven-dried at 600 °C for 3 h, and pulverized (1 h).
Mello et al. (2020)	2.0	–	60,320 ⁽¹⁾	–	Boiler-cleaning residue, oven-dried at 100 ± 5 °C for 24 h and rotary milled for ~3 h at 61.5 rpm
Sua-iam and Makul (2013)	2.35	–	27.4 ⁽¹⁾	107.9	Ash collected from an open dump, dried and homogenized. No sieving or grinding reported.
Andreão et al. (2020)	2.42	–	22,631	11.37	Wet-collected ash, water-washed for density separation, dried at 100 °C for 24 h, re-calcined (< 800 °C, then 600 °C for 3 h), and Attritor-milled (1–2 h)
Joseph and Murugan (2024)	1.8	594	268 ⁽¹⁾	–	Sieved through 300 μm
Le and Sheen (2023)	2.165	–	444.9 ⁽¹⁾	–	Dried at 105–110 °C for 24 h and sieved through 149 μm (# 100 sieve)
Ashok et al. (2025)	2.18	–	290	–	Finely ground (abrasion machine) and sieved through 300 μm
Navaneetha et al. (2025)	2.0	–	39,070 ⁽¹⁾	19.58	Boiler ash (550–600 °C), dried at 105 ± 5 °C, sieved through 300 μm, and ball-milled for 180 min at 33 rpm

Note: The original values from the literature were converted to m²/kg for consistency.

4.2. Chemical properties of SCBA

The chemical composition of SCBA from previous research is summarized in Table 3. Silica is the most abundant oxide in SCBA, followed by alumina and iron oxide in smaller proportions. The silica content reported in the literature varies widely from 54.45% to 87.59%, reflecting significant differences in ash origin, combustion conditions, contamination levels, and post-processing history (Embong et al. 2016; Cordeiro et al. 2009; Ouedraogo et al. 2022; Gupta et al. 2021). Controlled combustion and recalcination generally yield ashes with higher reactive amorphous silica contents, whereas field burning, mixed ash contamination, or poorly regulated furnace conditions tend to produce higher crystalline content and larger quantities of inert impurities (Frías et al. 2011; Katare and Madurwar 2017; Morales et al. 2009).

4.3. Burning temperature and retention of amorphous silica

The burning temperature is the most extensively discussed processing parameters as it governs the removal of residual organic matter and the stability of the silica phase. Several studies identify an optimum calcination range of approximately 600–700 °C, within which carbonaceous matter is adequately removed while amorphous silica is largely retained (Gupta et al. 2021; Cordeiro et al. 2009; Bahurudeen and Santhanam 2015; Maldonado-García et al. 2017). Cordeiro et al. (2009) demonstrated

that controlled calcination significantly improved the reactivity of raw bagasse ash, while subsequent studies similarly reported that thermal upgrading can enhance the pozzolanic characteristics of high-carbon ash. However, the literature does not establish a universal optimum temperature, as the effectiveness of thermal treatment is also influenced by holding time, airflow, initial ash composition, and the origin of the material, whether raw bagasse, boiler ash, or previously burned residue (Soares et al. 2014; Kolawole et al. 2021). Moreover, excessive burning or prolonged overheating may induce silica crystallisation, thereby reducing reactivity despite improving apparent cleanliness of the ash (Arif et al. 2016; Ouedraogo et al. 2022; Bahurudeen and Santhanam 2015; Cordeiro et al. 2009).

4.4. Loss on ignition and the problem of unburned carbon

Loss on ignition (LOI) is one of the most critical indicators of SCBA quality because it reflects the extent of incomplete combustion and residual carbon content. Reported LOI values from previous studies range from 1.2% to 19.39% (Table 2). The higher values highlight the extent to which some ashes remain insufficiently processed for effective cementitious use. High LOI has been consistently identified as a major barrier to SCBA utilisation because unburned carbon dilutes the reactive fraction, increases water demand, interferes with chemical admixture efficiency, and undermines the consistency of both strength and durability performance

(Bahurudeen et al. 2016; Arif et al. 2016; Ganesan et al. 2007; Gupta et al. 2021). Comparative studies on processed and unprocessed SCBA further show that sieving, washing, removal of fibrous carbonaceous residues, and recalcination can significantly improve ash quality and

pozzolanic behavior (Lyra et al. 2021; Moraes et al. 2021; Bahurudeen and Santhanam 2015). Consequently, poor performance reported in some studies should not necessarily be interpreted as an inherent limitation of SCBA itself, but rather as evidence of inadequate pre-treatment.

Table 3. SCBA chemical oxides.

Authors	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	SO ₃	LOI (%)
Jha et al. (2020)	71.11	4.85	6.8	0.5	4.04	2.25	3.89	1.50	4.56
Kazmi et al. (2017)	85.17	1.69	2.73	0.69	2.59	0.29	0.36	0.17	3.55
Kumara et al. (2023)	73.18	3.85	1.96	1.11	3.78	0.96	0.98	0.27	14.78
Praveenkumar et al. (2020)	55.49	4.92	8.29	7.96	8.74	0.93	8.34	–	5.40
Chusilp et al. (2009)	54.45	6.06	3.23	1.37	15.41	–	–	0.04	19.39
Abdalla et al. (2022)	80.00	8.92	3.19	2.37	1.48	–	2.70	–	15.08
Ainomugisha et al. (2021)	63.59	5.66	3.39	0.75	3.19	0.62	–	1.30	–
Andreão et al. (2020)	63.9	7.00	3.40	–	7.90	–	6.4	4.20	3.80
Dhengare et al. (2020)	87.59	0.51	0.67	1.65	2.59	0.17	3.64	0.03	4.80
Gupta et al. (2021)	82.68	3.01	1.69	2.86	5.58	0.43	0.47	–	3.23
Kumara et al. (2023)	73.18	3.83	1.96	1.11	3.78	0.96	0.98	0.27	14.78
Zareei et al. (2018)	64.23	9.08	5.47	2.97	8.17	0.87	1.32	–	–
Hasnain et al. (2021)	74.34	5.55	3.40	0.67	2.15	0.12	1.46	–	11.42
Wagh and Waghe (2024)	74.40	1.10	1.15	2.1	2.80	0.14	4.70	1.60	–
Ashok et al. (2025)	75.90	1.55	2.32	1.77	6.25	–	–	–	4.00
Kirthiga and Elavenil (2023)	75.98	3.71	2.37	2.05	4.86	0.38	2.60	–	7.80
Tabish et al. (2025)	74.16	3.08	1.39	2.6	2.96	1.38	2.94	2.45	–
Khan et al. (2025)	63.78	8.32	1.68	4.76	10.54	1.32	2.60	–	4.21
Shaban et al. (2024)	81.30	2.50	1.60	2.3	4.10	0.40	3.30	1.00	2.50
Amjad et al. (2025)	62.44	6.74	5.77	2.97	6.16	3.15	6.87	0.72	–
Subedi et al. (2023)	76.90	7.50	3.00	1.30	4.30	0.70	4.30	0.20	1.20
Navaneetha et al. (2025)	71.11	5.26	7.72	–	11.92	–	–	3.66	3.00

4.5. Grinding, fineness, and surface-controlled reactivity

Grinding duration and resultant fineness are also fundamental to SCBA performance because its reactivity is strongly governed by surface area and particle refinement. Cordeiro et al. (2008) established that SCBA can contribute both as a pozzolanic material and as micro-filler, although these functions become more pronounced only when the ash is ground to a sufficiently fine state. Later studies confirmed that enhanced fineness increases surface area, improves packing density, promotes portlandite consumption, and facilitates the formation of secondary calcium silicate hydrate (C-S-H) (Bahurudeen and Santhanam 2015; Moraes et al. 2021; Jagadesh et al. 2020). Although finer SCBA may enhance later-age strength and durability, it may also increase fresh-state water demand when porosity and residual carbon content remain high (Klathae et al. 2020; Abdalla et al. 2022; Sakib et al. 2023; Ainomugisha et al. 2025; Yaseen 2024). In many cases, performance is governed

not merely by the replacement percentage, but by the extent to which grinding converts a porous, carbon-rich ash into a reactive ultrafine material. Accordingly, fineness and carbon content should be interpreted in conjunction rather than as independent variables (Jagadesh et al. 2015; Embong et al. 2016).

5. Workability Behaviour of SCBA in Cement-Based Materials

Several studies have reported that the incorporation of sugarcane bagasse ash (SCBA) generally reduces slump, workability, and flowability as the replacement level increases (Fig. 4). However, the magnitude of this reduction varies with ash source, fineness, particle morphology, and overall mix design. Abdalla et al. (2022) reported a progressive decline in slump with increasing SCBA dosage and attributed this response to the rough texture, flaky shape, and porous surface of SCBA particles, which increase internal friction and water demand.

Ainomugisha et al. (2021) similarly observed substantial slump loss at higher SCBA contents, explaining that the ash's high surface area, low specific gravity, angularity, porous structure, and residual unburnt carbon reduce the amount of free water available for lubrication. Zareei et al. (2018) linked lower fluidity to the irregular and fibrous morphology of SCBA particles, whereas Wagh and Waghe (2024) found in self-compacting concrete that higher bagasse ash contents reduced slump flow and increased both T_{500} time and V-funnel time, indicating a more viscous and less mobile fresh mix.

At the same time, the literature indicates that the adverse effect of SCBA on fresh properties can be moderated through appropriate ash processing and admixture optimization. Tabish et al. (2025) maintained the required slump range in SCBA-blended concrete through the use of a polycarboxylate-based superplasticizer, indicating the effectiveness of PCE-based admixtures in dispersing fine SCBA particles without increasing water content. Shaban et al. (2024) also employed a high-range water-reducing admixture in ultra-high-performance

concrete mixes, reinforcing the view that modern polycarboxylate systems are particularly important when SCBA is used at low water-binder ratios. In SCC mixtures, Wagh and Waghe (2024) used both a superplasticizer and a viscosity-modifying admixture to preserve self-compactability. Amjad et al. (2025) similarly suggested that milling or refining bagasse ash improves fresh behaviour by enhancing particle packing and reducing the detrimental rheological influence of coarse, porous particles. Interestingly, Kumara et al. (2023) reported a slight improvement in slump at lower SCBA replacement levels, indicating that fresh-state performance is not governed by replacement percentage alone, but also by ash quality, fineness, and carbon content. Overall, the evidence suggests that SCBA typically reduces workability because of its high surface area and porous particle structure, yet this limitation can be substantially mitigated through controlled replacement levels, ash refinement, ternary blending, and, most consistently, the use of polycarboxylate-based superplasticizers.

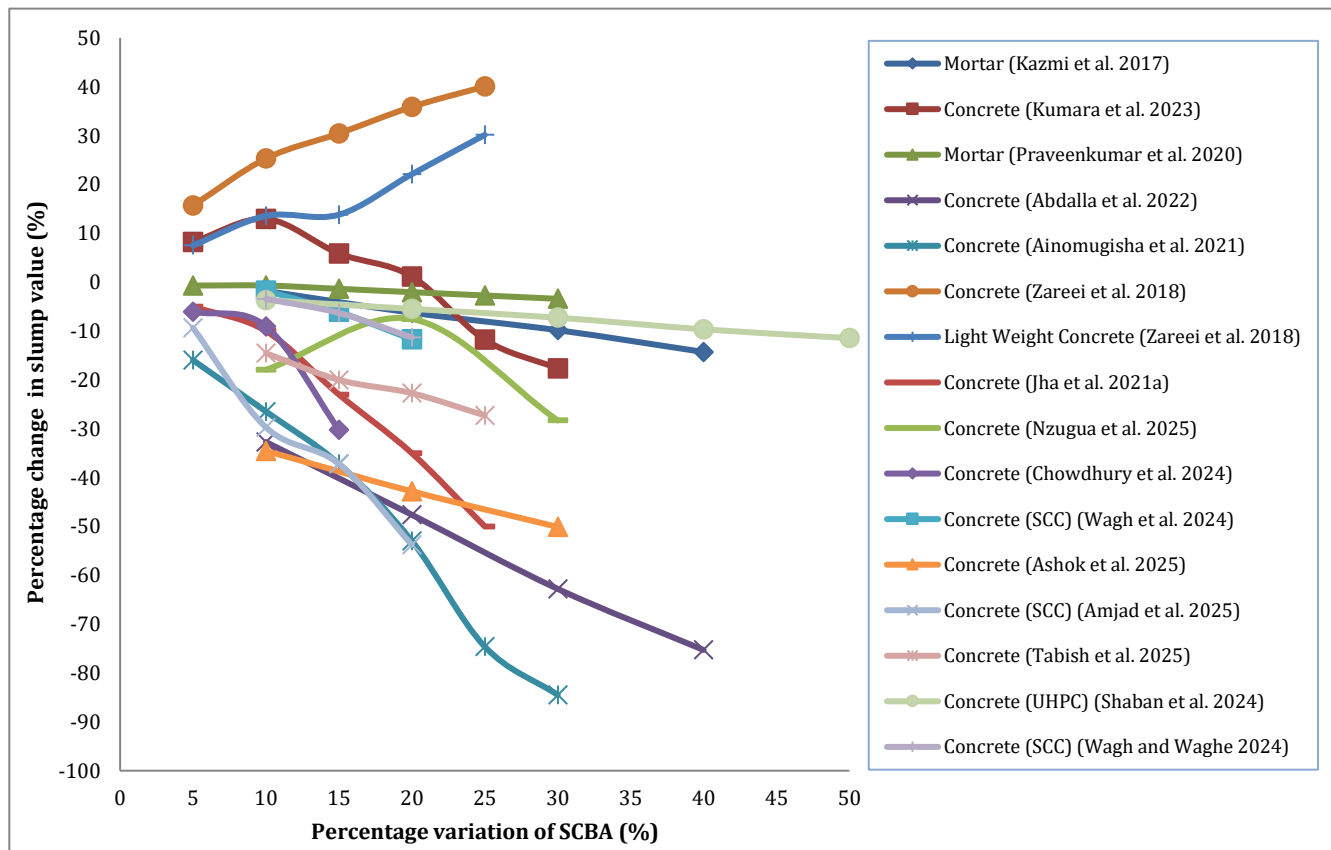


Fig. 4. Effect of SCBA on workability of cement-based materials.

6. Mechanical Properties

The mechanical properties of SCBA blended cementitious materials have been widely examined to determine the suitability of SCBA as a supplementary cementitious material in concrete and mortar. In the existing literature, mechanical performance is most commonly evaluated through strength development, as this provides a direct indication of the structural applicability of the material. The effect of SCBA on mechanical be-

haviour is influenced by several factors, including the replacement level, ash characteristics, fineness, burning conditions, curing regime, matrix type, and water-binder ratio. At low to moderate replacement levels, SCBA generally contributes to improved mechanical performance through filler action and pozzolanic reactivity, both of which promote a denser and more refined cementitious matrix (Ganesan et al. 2007; Khan et al. 2021; Kiran and Kishore 2017; Ramesh et al. 2017). Table 4 presents a comparative synthesis of quantitative

data from selected studies on SCBA blended cementitious materials. The table compiles key experimental variables, including cement type, matrix type, replacement levels, optimum replacement percentage, curing period, water–binder ratio, and percentage enhancement in 28-day strength. To ensure comparability, only

the optimum replacement level reported in each study and the corresponding improvement over the control mixture is presented. This format facilitates cross-study comparison and supports the identification of general trends in the mechanical behaviour of SCBA based systems.

Table 4. Optimum replacement of SCBA in cementitious materials and associated improvements in mechanical properties (%).

Reference	Cement type	Cementitious matrix	Replacement levels (% by weight)	Optimum replacement (%)	Curing period (days)	Water-Binder ratio	Enhancement in 28-day strength (%)	
							Compressive strength	Split tensile strength
Kumara et al. (2023)	OPC 53	Concrete	5, 10, 15, 20, 25, 30	15	7, 14, 28, 90	0.45	6.43	8.75
Praveenkumar et al. (2020)	OPC 53	Mortar	5, 10, 15, 20, 25, 30	5	3, 7, 28	0.5	3.99	–
Jha et al. (2021d)	OPC 43	Concrete	5, 10, 15, 20, 25	10	7, 28	0.45	2.14	–
Abdalla et al. (2022)	CEM I/42.5N	Concrete	10, 20, 30, 40	10	3, 7, 14, 28, 56	–	5.63	10.54
Gupta et al. (2021)	OPC 43	Mortar	5, 10, 15, 20, 25	10	3, 7, 28	–	9.21	–
Dhengare et al. (2020)	OPC 53	Concrete	5, 10, 15, 20, 25, 30	20	7, 28, 56, 90	–	7.66	–
Gupta et al. (2023a)	OPC 43	Concrete (SCC)	5, 10, 15, 20, 25	15	7, 28, 56, 90	0.4	19.57	55.73
Bheel et al. (2022)	Portland cement	Concrete	5, 10, 15, 20	10	28	0.5	9.70	8.77
Mittal and Varekar (2026)	Portland cement	Concrete	5, 10, 15, 20	5	3, 7, 28	0.5	10.29	2.76
Krishna et al. (2024)	OPC 53	Concrete	5, 10, 15, 20, 25	10	28	0.48	27.18	–
Sakib et al. (2023)	OPC	Mortar	5, 10, 15, 20, 25, 30	15	7, 14, 28, 56	0.56	10.10	–
Ullah et al. (2025)	OPC Type I	Concrete	5, 10, 15	10	14, 28, 56	0.4	19.20	22.82
Yaseen (2024)	OPC	Mortar	5, 10, 15, 20, 25, 30	5	7, 28	0.54	12.85	–
Sankeeth et al. (2025)	OPC	Concrete	5, 10, 15, 20	10	7, 28, 90	0.58	18.46	23.35
Kumar and Kumar (2023)	OPC 53	Concrete	5, 10, 15	10	7, 14, 28	0.58	21.02	–
Hasan et al. (2014)	OPC	Concrete	10, 15, 20	10	3, 7, 28	0.5	3.49	–
Jha et al. (2021a)	OPC 43	Concrete	5, 10, 15, 20, 25	10	7, 28, 90, 180	0.49	2.14	8.87
Srinivasan and Sathiya (2010)	OPC	Concrete	5, 10, 15, 20, 25	5	7, 28	–	37.40	30.67
Lourdu and Ali (2023)	OPC	Concrete	2.5, 5, 7.5, 10, 12.5, 15, 20	10	3, 7, 28	0.45	19.67	18.18
Tabish et al. (2025)	OPC43	Concrete	10, 15, 20, 25	15	7, 28, 90, 180, 365	0.48	11.42	11.15
Wagh et al. (2024)	OPC 43	Concrete (SCC)	10, 15, 20	10	7, 14, 28, 56	0.34	3.96	5.12
Chowdhury et al. (2024)	CEM I/42.5N	Concrete	5, 10, 15	5	1, 3, 7, 28	0.55	12.04	7.74

6.1. Compressive strength

The compressive strength behaviour of SCBA-blended mortar and concrete reported in the reviewed studies exhibits a broadly consistent, although not entirely uniform trend. Low-to-moderate replacement lev-

els generally preserve or enhance later-age strength, whereas higher replacement levels tend to reduce strength when the dilution of cement surpasses the pozzolanic contribution of SCBA. In mortar systems, strength enhancement is most frequently reported at about 10–15% replacement. Praveenkumar et al. (2020)

reported that the incorporation of bagasse ash improved mortar strength up to 15% replacement, which was attributed to its large surface area, enhanced pozzolanic reactivity, and filler action. Likewise, Sakib et al. (2023) found that 5–15% ground bagasse ash produced higher 56-day compressive strength than the control, with 15% replacement showing the best overall mechanical and durability performance. Yaseen (2024) similarly observed that 7-day strength decreased with increasing SCBA content because of early cement dilution and slow reaction kinetics, whereas 28-day strength increased at 5–15 wt% replacement, with the greatest increase recorded at 5 wt%. Concrete studies show the same broad pattern. Jha et al. (2021a) reported that compressive strength increased at 10% SCBA replacement and declined beyond that level, while Bheel et al. (2022) also identified 10% bagasse ash as the optimum replacement level for improving 28-day compressive strength. Moreover, Abdalla et al. (2022) concluded that bagasse ash can enhance long-term strength when used at low dosages, especially around 10%, although higher replacement levels generally produce strength reductions because of clinker dilution.

Evidence from several studies indicates that compressive strength development in SCBA-based systems is governed by the interaction of physical densification and pozzolanic reactivity. Several studies explicitly relate strength enhancement to the reaction of SCBA-derived silica and alumina with calcium hydroxide released during cement hydration. Abdalla et al. (2022) reported that these reactions produce secondary calcium silicate hydrate (C–S–H), calcium aluminate hydrate (C–A–H), and calcium aluminosilicate hydrate (C–A–S–H) phases, which contribute to strength development and microstructural refinement. In the same way, Yaseen (2024) explained that SCBA acts both as a micro-filler, which improves particle packing, and as a later-age pozzolana that forms secondary hydration products. Sakib et al. (2023) further noted that ground bagasse ash provides nucleation sites for hydration products, reduces porosity, and improves interfacial bonding. This interpretation is consistent with the microstructural observations reported by Praveenkumar et al. (2020), who attributed the increase in compressive strength at moderate replacement levels to the combined effects of fine particle filling and activated pozzolanic reaction. Likewise, Gupta et al. (2023b) identified SCBA as a pozzolanic material with good binder potential, although the benefit was confined to modest replacement levels. Overall, the literature indicates that SCBA improves compressive strength only when its filler effect and pozzolanic reactivity are sufficient to offset clinker dilution. Once the replacement level becomes excessive, however, reduced calcium availability, slower hydration, higher porosity, and weaker binder formation become dominant, resulting in strength loss (Bheel et al. 2022; Jha et al. 2021b; Kumara et al. 2023; Gupta et al. 2022; Ainomugisha et al. 2021; Kumar and Kumar 2023).

As shown in Table 4, the optimum replacement level of cement with SCBA for improving mechanical properties varies considerably across studies, reflecting the strong influence of ash processing, fineness, silica reactivity, loss on ignition, curing conditions, and mix com-

position. Although this variability prevents the identification of a universal optimum dosage, the compiled results still reveal a consistent performance range. Because compressive strength is the most widely reported mechanical property, its trends are further illustrated in Figs. 5 and 6. Fig. 5 compares the optimum SCBA contents reported in the literature and their corresponding percentage gains in compressive strength, while Fig. 6 shows the trend of average compressive strength across different replacement levels. Taken together, Table 4, Figs. 5 and 6 indicate that the most favourable mechanical performance is generally achieved at 10–15% SCBA replacement. This range likely reflects a balance between the pozzolanic contribution of reactive silica, which promotes additional C–S–H formation and matrix densification, and the dilution effect associated with higher cement replacement. However, the reported improvements are not universal, and performance declines beyond this range are common when ash quality or processing is inadequate. Thus, SCBA should be regarded as a processing-sensitive supplementary cementitious material, and 10–15% should be interpreted as a practical optimum range rather than a fixed dosage.

6.2. Split tensile strength

SCBA influences split tensile strength in a manner closely aligned with compressive strength, with improvements generally occurring only at low-to-moderate replacement levels. Across conventional and self-compacting concrete, most studies report that tensile strength rises up to an optimum SCBA content and then declines at higher dosages. Lourdu and Ali (2023) identified 10% SCBA as optimal, increasing split tensile strength from 3.3 MPa to 3.9 MPa, while Gupta et al. (2023a) reported improvement up to 15% SCBA in SCC before a reduction at higher contents. Kumara et al. (2023) similarly observed an increase from 2.97 MPa in the control mix to 3.23 MPa at 15% SCBA, followed by progressive decline beyond this level. Comparable trends were reported by Bheel et al. (2022), Chowdhury et al. (2024) and Ullah et al. (2025), indicating that the most consistent enhancement in tensile performance occurs within the 5–15% replacement range, although the precise optimum depends on ash fineness, curing age, concrete type, and mix design (Sankeeth et al. 2025).

The improvement in split tensile strength arises from the same mechanisms that govern compressive strength development, namely pozzolanic reactivity, filler action, and matrix densification. Gupta et al. (2023a) explained that silica-rich SCBA reacts with calcium hydroxide released during cement hydration to form additional C–S–H, thereby strengthening and densifying the matrix. Ullah et al. (2025) similarly linked higher tensile strength to secondary C–S–H formation, improved particle interlocking, and a denser internal structure, especially at later curing ages. Bheel et al. (2022) and Kumara et al. (2023) further emphasized that reactive silica refines the cementitious matrix and improves resistance to crack initiation and propagation. However, beyond the optimum dosage, the same adverse effects observed for compressive strength – cement dilution, reduced lime availability, unreacted ash particles, and higher poros-

ity—begin to dominate, leading to lower tensile performance (Bayapureddy et al. 2020; Srinivasan and Sathiya

2010; Abdalla et al. 2022; Ullah et al. 2025; Chowdhury et al. 2024; Kumara et al. 2023).

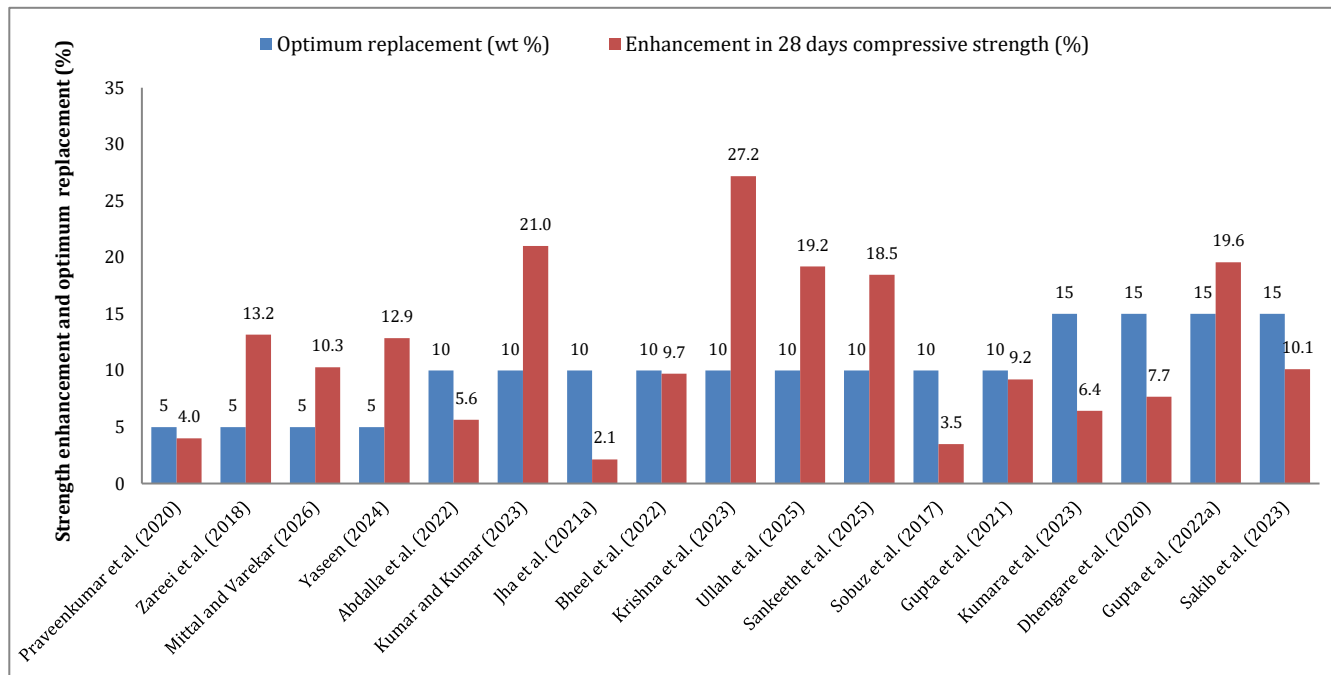


Fig. 5. Comparative representation of optimum SCBA content and corresponding percentage increase in compressive strength of cement-based materials.

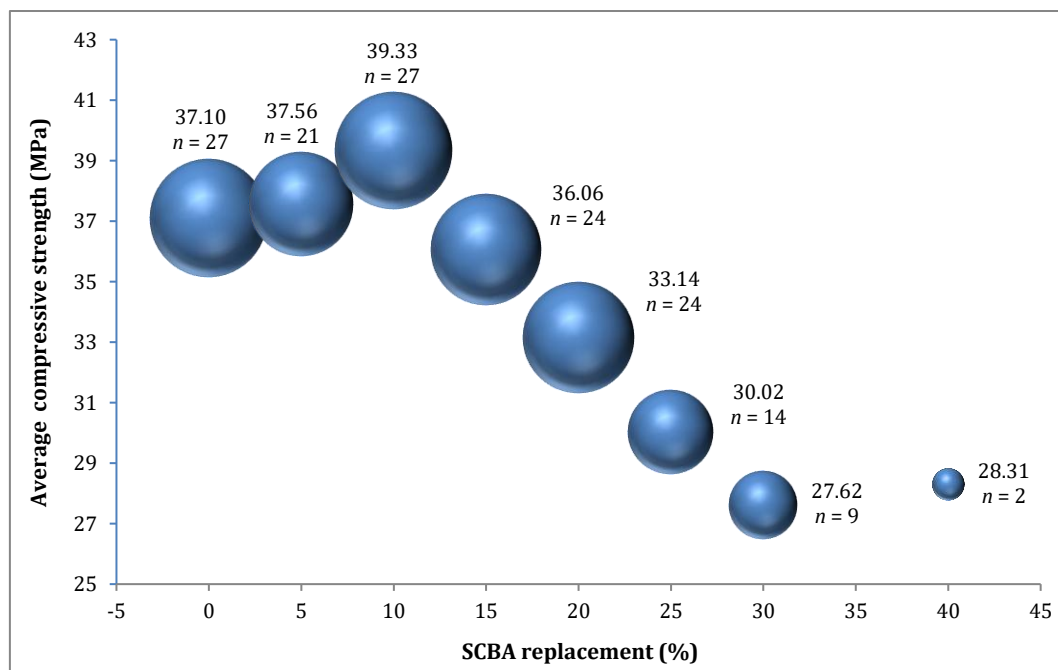


Fig. 6. Trend analysis average compressive strength value from various studies.

Similar to compressive strength, the results in Table 4 show that the optimum SCBA replacement level for improving split tensile strength generally lies within the 10–15% range, although some variation exists across studies. For comparison, the tensile strength data are presented in Figs. 7 and 8. Fig. 7 shows the reported optimum SCBA contents and the corresponding percentage increase in 28-day split tensile strength, while Fig. 8 presents the trend in average split tensile strength across

different replacement levels. Taken together, Table 4, Figs. 7 and 8 indicate that split tensile strength follows a trend broadly similar to that of compressive strength, with improvement at intermediate replacement levels and decline at higher dosages. Thus, the available evidence suggests that 10–15% SCBA is the most practical range for enhancing both compressive and split tensile strength, although the exact optimum remains study-specific.

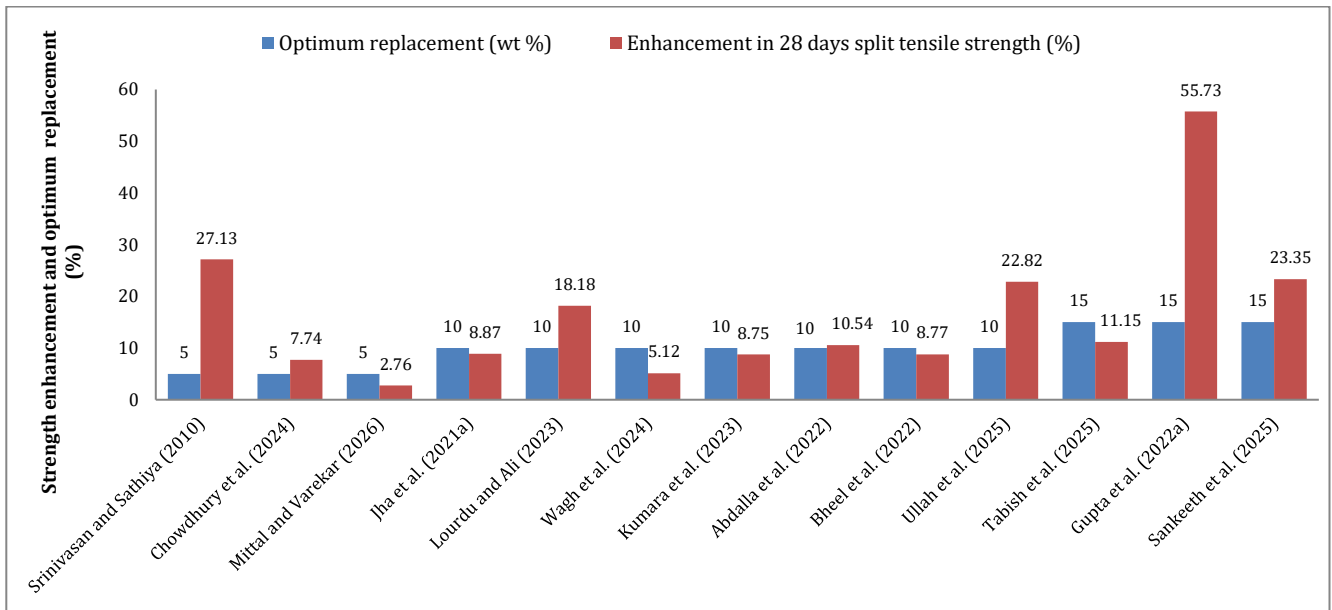


Fig. 7. Comparative representation of optimum SCBA content and corresponding percentage increase in split tensile of cement-based materials.

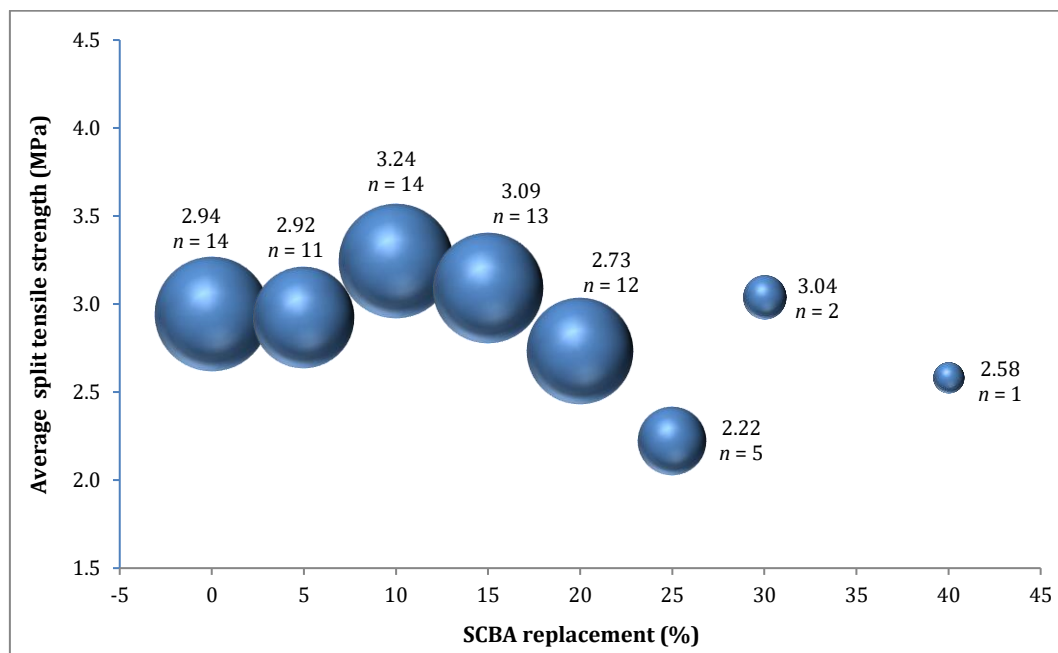


Fig. 8. Trend analysis average split tensile strength value from various studies.

7. Durability Performance

Sugarcane bagasse ash (SCBA) has been widely reported to improve the durability performance of cementitious materials when used at appropriate replacement levels, primarily through matrix densification and pore refinement, which reduce the ingress of water and aggressive ions. The literature indicates that durability has mainly been evaluated through transport-related parameters such as water absorption, capillary absorption, chloride penetration resistance, and electrical resistivity, with most studies showing improved performance at low to moderate SCBA contents. However, the extent of improvement varies with the physico-chemical characteristics of SCBA, particularly fineness, amorphous silica

content, calcination condition, and loss on ignition, as well as with the type of cementitious matrix and replacement level adopted (Ainomugisha et al. 2021; Zareei et al. 2018; Gupta et al. 2023b; Sakib et al. 2023; Yaseen 2024; Sankeeth et al. 2025). Therefore, in this section, the effect of SCBA on the durability of cement-based materials is evaluated through the key parameters most consistently reported in the uploaded studies, namely water absorption, capillary absorption, chloride resistance, and electrical resistivity.

Table 5 summarizes the studies on the durability performance of SCBA-blended cementitious materials, presenting the investigated replacement levels, the optimum SCBA content, and the corresponding changes in water absorption, capillary absorption, chloride pene-

tration, and electrical resistivity. The optimum replacement level generally ranges from 10% to 30%, although it varies with the durability parameter, matrix type, and ash characteristics. In several studies, the same optimum content applies to multiple durability indicators, whereas in others it differs across properties. Comparison of Table 4 and Table 5 further shows that the optimum SCBA content for durability does not always coincide with that for mechanical properties. Overall, low to

moderate SCBA replacement commonly reduces water absorption, capillary absorption, and chloride penetration while increasing electrical resistivity, indicating improved resistance to fluid and ion transport. The variability among studies nevertheless suggests that durability performance is influenced not only by replacement level, but also by SCBA fineness, processing condition, chemical composition, and the nature of the cementitious system.

Table 5. Optimum content of SCBA in cementitious materials for durability studies.

Reference	Replacement levels (% by weight)	Optimum replacement (%)	Decrease percentage (%)			Increase percentage (%) in electrical resistivity
			Water absorption	Capillary absorption	Chloride penetration	
Jittin and Bahurudeen (2022)	10,20,30	30	–	14.71	80.40	–
Joshaghani and Moeini (2018)	10,15,20,25	25	4.32	14.00	44.53	159.29
Praveenkumar et al. (2020)	5,10,15,20,25,30	30	–	86.26	–	–
Ainomugisha et al. (2021)	5,10,15,20,25,30	30	93.34	–	–	–
Arenas-Piedrahita et al. (2016)	10, 20	20	–	–	67.03	234.51
Cupim et al. (2025)	5,10,15,20	20	16.97	–	–	–
Allende et al. (2024)	10,20,30	30	–	–	23.01	–
Gupta et al. (2023b)	5,10,15,20,25	15	52.45	15.6	–	–
Sankeeth et al. (2025)	5,10,15,20	20	26.27	–	56.36	–
Yaseen (2024)	5,10,15,20,25,30	30	94.35	–	–	–
Jiménez-Quero et al. (2019)	10, 20	10	–	–	–	75.00
Reddy and Kumar (2026)	5,10,15,20	10	34.06	–	–	–
Nassar et al. (2022)	5,10,15	15	–	–	–	92.23
Le and Sheen (2023)	5,10,15,20	20	19.19	–	–	19.26

7.1. Water absorption

Water absorption is a key durability indicator in SCBA-based cementitious materials because it reflects pore structure, and resistance to water ingress. Fig. 9 depicts the variation of water absorption with different proportion of SCBA. The reviewed studies show that SCBA can reduce water absorption at low-to-moderate replacement levels when its filler effect and pozzolanic reactivity promote matrix densification and additional C-S-H formation. Abdalla et al. (2022) reported a reduction in water absorption from 1.21% in the control mix to 1.03% at 40% SCBA, attributing this improvement to the fine-particle filling effect of SCBA. Likewise, Joshaghani and Moeini (2017) found lower water absorption and capillary uptake in SCBA mortars than in the control, while Joshaghani and Moeini (2018) observed similar reductions in a binary SCBA-RHA (Rice Husk Ash) system due to filler action, pozzolanic activity, and secondary C-S-H formation. Comparable improvements were also reported in blended systems containing SCBA with metakaolin and polypropylene fibres (Althaqafi et al. 2024) and in self-curing concrete

incorporating copper slag and polyethylene glycol-400, particularly at 15-20% SCBA replacement (Reddy and Kumar 2026).

However, the literature also indicates that the effect of SCBA is highly dependent on ash quality, dosage, and curing conditions. Zareei et al. (2018) reported that higher SCBA contents increased water demand and water absorption because of the irregular and porous nature of the ash, with the most favourable response occurring at around 5% replacement. Similar trends were observed by Ainomugisha et al. (2021), who found increasing water absorption with higher contents of raw co-generation SCBA, and by Yaseen (2024), who reported a marked nonlinear increase at elevated replacement levels. Sankeeth et al. (2025) further confirms this threshold-dependent behaviour, showing an 8.5% reduction in water absorption at 5% SCBA but a 28% increase at 20%, although extended curing partially mitigated this adverse effect. Overall, the findings suggest that finely processed and optimally dosed SCBA can refine the pore structure and reduce water absorption, whereas excessive or poorly processed ash may increase absorption by introducing greater internal porosity.

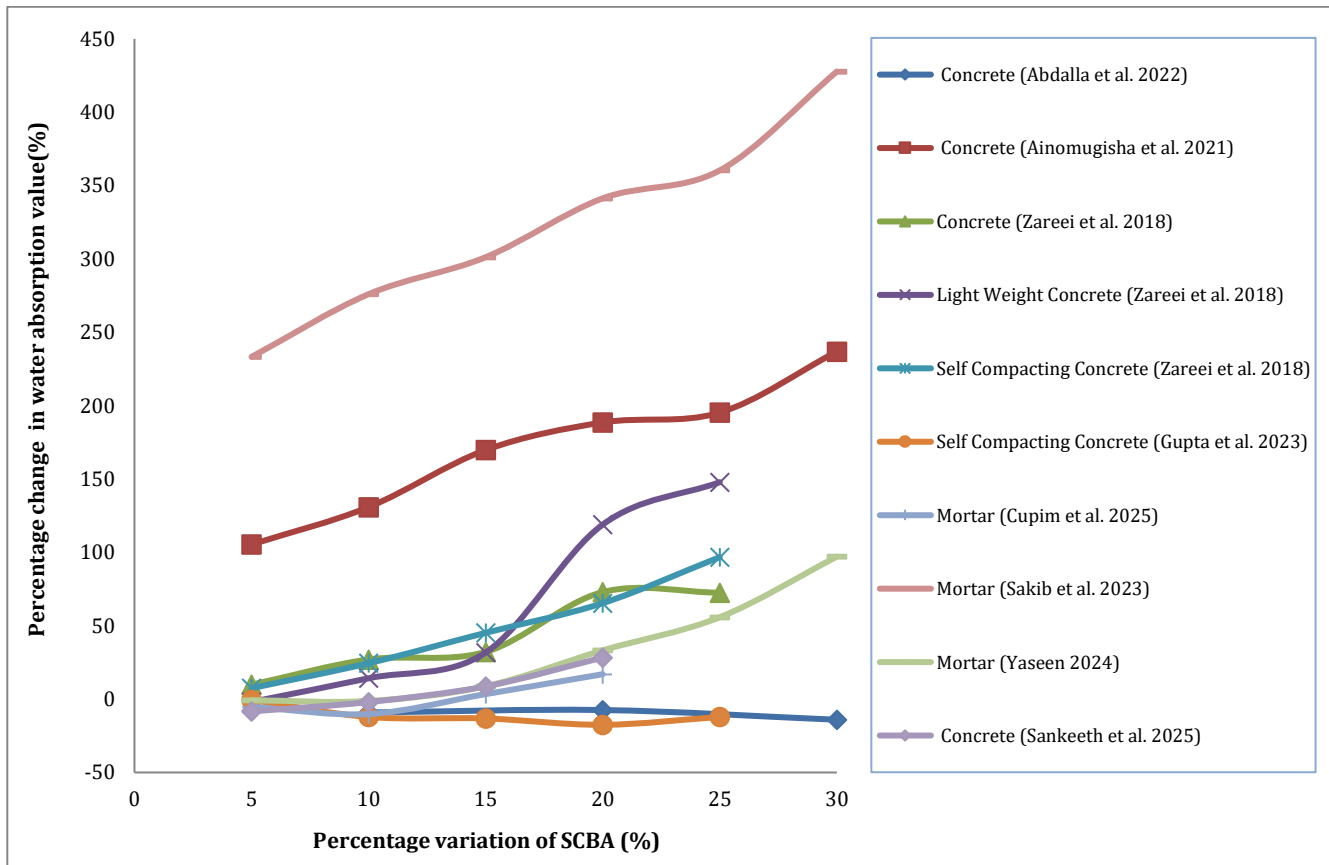


Fig. 9. Effect of SCBA on water absorption of cement-based materials.

7.2. Capillary absorption

Capillary absorption, commonly expressed as sorptivity, is a key transport property used to evaluate the rate at which unsaturated concrete absorbs water through capillary action and, therefore, serves as an important indicator of durability rather than merely a physical descriptor. In SCBA-blended concrete, lower capillary absorption is generally attributed to the filler effect and pozzolanic reaction of fine ash particles, which improve packing density, consume calcium hydroxide, and generate secondary C-S-H, thereby refining the pore structure and reducing transport continuity. This overall mechanism is widely supported in the literature, and several studies have reported improved sorptivity performance at moderate replacement levels when the ash is adequately processed and sufficiently reactive (Bahurudeen and Santhanam 2015; Ganesan et al. 2007; Gupta et al. 2023b).

However, the evidence does not justify a universal conclusion that SCBA always improves capillary performance, because the outcome remains highly dependent on ash quality, fineness, loss on ignition, replacement dosage, curing conditions, and testing protocol. While several studies have observed reduced capillary absorption and improved matrix densification at moderate replacement levels (Bahurudeen and Santhanam 2015; Praveenkumar et al. 2020; Andrade Neto et al. 2021; Memon et al. 2022; Gupta et al. 2023b), others have reported increased sorptivity or noted that improvements in sorptivity may coexist with greater carbonation susceptibility, especially at higher replacement levels or

with insufficiently processed ash (Ainomugisha et al. 2021; Quedou et al. 2021). A critical study of the literature suggests that the central issue is not whether SCBA reduces capillary absorption, but the particular processing and dosage conditions under which such reduction can be achieved consistently.

7.3. Chloride penetration and chloride resistivity

The studies indicate that sugarcane bagasse ash (SCBA) generally enhances resistance to chloride ingress and increases chloride resistivity, although the magnitude of improvement depends on curing age, ash quality, and replacement level. In mortar systems containing untreated or minimally processed SCBA, rapid chloride permeability decreased, with optimum performance commonly observed at about 10–20% replacement (Arenas-Piedrahita et al. 2016; Jiménez-Quero et al. 2019; Cordeiro et al. 2011; Minnu et al. 2021). Similarly, Jha et al. (2021c) reported reduced chloride permeability up to an optimum combination of 10% bagasse ash and 40% stone dust, beyond which performance declined. These findings suggest that chloride durability in SCBA-blended systems is governed by the interplay of filler effect, pozzolanic reactivity, and cement dilution rather than by replacement level alone.

The literature further shows that chloride-related durability becomes more pronounced at later ages and is enhanced in ternary binder systems. Joshaghani and Moeini (2017) observed that SCBA mixtures exhibited lower resistivity than the control at early ages because of slow pozzolanic activity, but showed markedly higher

resistivity and improved chloride resistance at 28 and 90 days; the SCBA–nanosilica system performed best. Comparable trends were reported for SCBA–rice husk ash mixtures, where ternary systems outperformed binary blends because of greater microstructural densification and hydration gel formation (Joshaghani and Moeini 2018; Jittin and Bahurudeen 2022). Kirthiga et al. (2025) likewise found that combining bagasse ash with silica fume significantly reduced charge passed in chloride tests, while also noting that RCPT results reflect not only permeability but also pore-solution chemistry and electrical conductivity. Overall, the evidence from several studies indicates that chloride penetration and chloride resistivity should be interpreted through an integrated microstructural and electrochemical framework, with later-age testing and synergistic SCM combinations providing the most reliable basis for assessing durability.

7.4. Electrical resistivity

Electrical resistivity is a key durability indicator in SCBA-blended mortars and concrete because it reflects resistance to ionic transport and reinforcement corrosion. The literature generally indicates that SCBA increases resistivity when it behaves as a reactive supplementary cementitious material, refining pore structure through filler effects and secondary pozzolanic reactions. However, this improvement is not universal and depends on ash processing, replacement level, and curing age. Early studies established that the hydration and pozzolanic performance of bagasse ash are governed by ash quality and silica reactivity (Singh et al. 2000; Ganesan et al. 2007). Later investigations similarly reported that SCBA can enhance resistivity and durability, particularly at moderate replacement levels. Jiménez-Quero et al. (2019) observed higher resistivity and delayed cracking under accelerated corrosion, while Nassar et al. (2022) found improved later-age resistivity, with 10 wt% replacement giving the most favorable balance of strength and durability. Le and Sheen (2023) further showed that this benefit is highly dosage and processing sensitive, with optimum performance generally occurring at about 5–10% replacement.

The literature also emphasizes that resistivity development in SCBA systems is strongly time-dependent. Joshaghani and Moeini (2017) showed that SCBA mortars may perform below the control at early ages because pozzolanic reactions are slower, yet surpass the control at 28 and especially 90 days as pore connectivity decreases. Samaila et al. (2014) likewise demonstrated that electrical resistivity is sensitive to both hydration progress and porosity evolution, making it useful for monitoring microstructural development as well as durability performance. Nassar et al. (2022) attributed higher later-age resistivity to matrix densification and reduced ionic mobility, whereas recent review evidence attributes variability across studies to differences in ash treatment, particle size, residual carbon, and thermal history (Abdalla et al. 2022). Thus, a critical reading suggests that SCBA should not be treated as uniformly increasing electrical resistivity; rather, its beneficial effect is conditional on processing quality, dosage, and test age.

8. Conclusions

Various studies have been conducted to understand the impact of SCBA in concrete and mortar properties considering various aspects. Considering the prior studies, the key findings of the present study can be summarised as follows:

SCBA shows clear potential to reduce the embodied carbon of cementitious materials through partial cement replacement. However, its environmental benefit is conditional on processing intensity and transport burden. The performance of sugarcane bagasse ash (SCBA) as a supplementary cementitious material in mortar and concrete is not governed solely by its replacement level, but is strongly influenced by its physical and chemical characteristics. The reviewed literature indicates that parameters such as silica content, fineness, particle morphology, burning conditions, and loss on ignition play a crucial role in determining the pozzolanic reactivity and overall engineering suitability of SCBA. In this regard, SCBA should not be regarded as a uniform agricultural by-product; rather, it should be understood as a process-sensitive material whose performance is highly dependent on combustion history and post-treatment quality. Consequently, the wide variation reported in previous studies appears to arise primarily from differences in ash processing and mixture design, rather than from any inconsistency in the intrinsic potential of SCBA itself.

With respect to fresh properties, the reviewed studies generally show that SCBA incorporation reduces slump, workability, and flowability as the replacement level increases. This behaviour is mainly associated with the porous texture, irregular particle shape, high surface area, and residual carbon content of the ash, all of which increase water demand and internal friction. At the same time, the review also indicates that this adverse effect can be moderated through adequate ash processing and the use of suitable admixtures, particularly polycarboxylate-based superplasticizers. Thus, reduced workability should be interpreted as a condition-dependent response rather than an inherent limitation of SCBA use.

For mechanical performance, the reviewed studies show that SCBA can improve both compressive and split tensile strength at low-to-moderate replacement levels, whereas excessive replacement generally leads to strength loss once cement dilution exceeds the benefits of filler action and pozzolanic reactivity. Although the broader beneficial range extends from approximately 5% to 20%, the comparative analysis of the reviewed data indicates that 10% is the most frequently reported global optimum, while 10–15% represents the most consistent practical performance window for strength enhancement. This range appears to provide the best balance between matrix densification, secondary hydration, and clinker dilution. However, the exact optimum remains study-specific and is influenced by ash quality, fineness, curing conditions, and matrix type.

The durability evidence similarly shows that SCBA can improve the long-term performance of cementitious systems when used at appropriate replacement levels. In general, SCBA incorporation reduces water

absorption, capillary absorption, and chloride penetration, while increasing electrical resistivity, thereby enhancing resistance to fluid and ion transport in both mortar and concrete. However, the optimum replacement range for durability does not always coincide with that for strength. The reviewed studies indicate that durability benefits are generally achieved within a wider range of 10–30%, depending on the specific durability indicator, ash characteristics, and binder system considered. This suggests that while lower to moderate SCBA contents are more favourable for mechanical optimisation, somewhat higher replacement levels may be beneficial for transport-related durability performance when a sufficiently reactive and finely processed ash is used.

Notwithstanding the growing number of studies on the utilisation of sugarcane bagasse ash (SCBA) in cementitious materials, the existing literature still reveals substantial gaps. First, the absence of standardized processing and characterization protocols continues to limit meaningful comparison across studies. Second, much of the existing literature remains focused on laboratory-scale and short-term behaviour, while long-term durability under aggressive service conditions is still under-explored. Third, field-scale validation, economic feasibility, and life-cycle assessment require greater attention to support industrial adoption. Future research should therefore prioritise standardized SCBA production criteria, long-term exposure-based durability studies, multi-scale performance evaluation, and hybrid or ternary binder systems involving SCBA with other supplementary cementitious materials. Overall, the evidence suggests that SCBA has strong potential for sustainable cementitious applications, but its successful future industrial adoption will depend on consistent ash quality, performance-based mix optimisation, and clear demonstration of both technical reliability and economic viability.

Acknowledgements

None declared.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

AI Assistance

No AI-based tools were used in the preparation of this manuscript.

Author Contributions

All authors made substantial contributions to the conception and design of the study, acquisition of data, analysis and interpretation of data; drafted or critically revised the manuscript for important intellectual content; and approved the final version to be published.

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