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STRONGER, GREENER, SMARTER-CONCRETE INNOVATION WITH SUGARCANE BAGASSE ASH

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ABSTRACT

The investigation of agro-industrial by-products as additional cementitious materials has been prompted by the growing focus on sustainable building materials. Because of its high amorphous silica content and pozzolanic qualities, sugarcane bagasse ash (SCBA), a waste from the sugar industry, is especially promising. The impact of partially substituting SCBA for cement on the durability and compressive strength of concrete is examined in this study. SCBA replacement amounts of 0%, 5%, 10%, 15%, and 20% by weight of cement were used to make concrete mixtures. The findings show that at ideal replacement levels of 10–15%, compressive strength greatly increases. This is mainly because of the pozzolanic reaction, which generates more calcium silicate hydrate (C–S–H) gel and resulting in a denser and more refined microstructure. Water absorption, permeability, and resistance to chloride ion penetration were used to assess durability. Improved durability performance was demonstrated by the use of SCBA, which decreased water absorption and permeability and increased resistance to chloride intrusion. However, the diluting effect caused the strength to decrease at greater replacement levels (above 15–20%). Overall, the results show that SCBA can be used as a sustainable supplemental cementitious material, improving concrete performance and fostering environmental sustainability through efficient waste management and lower cement use.

Keywords - Sugarcane Bagasse Ash, Sustainable Concrete, Compressive Strength, Durability, Pozzolanic Activity, Chloride Resistance.

1. INTRODUCTION

The world's consumption of cement, a key component of concrete, has dramatically expanded due to the quickening rate of infrastructure construction. Cement manufacture is an energy-intensive process that involves the calcination of limestone and clays at high temperatures, releasing significant volumes of carbon dioxide (CO_2) through fuel burning and the decarbonation of calcium carbonate, despite its essential function in construction. As a result, the cement sector accounts for around 7-8% of the world's CO_2 emissions, making it one of the biggest industrial contributors to greenhouse gas emissions [1]. (Schneider, 2019). 13 As a result, creating sustainable substitutes that can lower clinker usage while preserving or improving concrete's performance qualities is becoming more and more important [2]. Large amounts of biomass waste are produced concurrently by the agro-industrial sector, especially from the processing of sugarcane. A C4 photosynthetic plant that is widely grown in tropical and subtropical areas, sugarcane (Saccharum Officinarum) is very effective at turning solar energy into biomass [3]. After the juice is extracted during the production of sugar, the fibrous residue known as bagasse is obtained. In sugar mills, this bagasse is frequently utilized as a biofuel in cogeneration facilities to generate heat. Sugarcane Bagasse Ash (SCBA), a by-product of burning bagasse, usually makes up 0.6–1.0% of the processed cane. However, SCBA is frequently dumped untreated in open dumps or landfills due to insufficient processing and a lack of defined use standards [4]. Degradation of the environment, such as particulate air pollution, altered soil alkalinity, and trace element leaching into groundwater systems, can result from such disposal techniques. From a physicochemical perspective, SCBA is distinguished by a high silica concentration, mostly in amorphous form when produced under regulated combustion circumstances. The biological intake of silicic acid (H_4SiO_4) by the sugarcane plant during growth is the source of the amorphous silica, which is deposited as phytoliths within the plant tissues. This biogenic silica is converted into a reactive state after burning, which makes SCBA a possible pozzolanic material [5]. Numerous studies have shown how different industrial and agricultural ashes can be successfully added to concrete as supplemental cementitious materials (SCMs), improving both performance and sustainability [6]. The pozzolanic and micro-filler effects of materials like fly ash, rice husk ash, silica fume, palm oil fuel ash, and ground granulated blast furnace slag have been thoroughly investigated. These effects improve compressive strength, refine pore structure, and enhance durability characteristics like resistance to permeability, sulfate attack, and chloride ingress [7]. These ashes, which are high in reactive silica and alumina, take part in subsequent hydration reactions that produce more calcium silicate hydrate (C–S–H) gel, which densifies the cement matrix. These materials' success has created a solid basis for investigating other agro-industrial wastes with comparable chemical and mineralogical characteristics [8]. Because of its high amorphous silica concentration and bio-derived nature, sugarcane bagasse ash (SCBA) shows promise in this regard. SCBA has a great deal of potential to be successfully added to concrete due to its similar pozzolanic behaviour and widespread availability, especially in areas that produce sugar [9]. This is in line with the larger research trend of using waste-derived materials for high-performance and sustainable construction.

The current study intends to methodically assess SCBA's potential as a sustainable supplemental cementitious material in light of these factors. The main goals are to examine how different SCBA replacement amounts affect concrete's compressive strength and evaluate how they affect durability traits such water absorption, permeability, and resistance to chloride ion intrusion. The goal of this project is to improve the creation of high-performance, environmentally friendly concrete for sustainable infrastructure by combining concepts from material science, environmental engineering, and biological resource exploitation.

2. MATERIALS

2.1 Cement - The main binder was Ordinary Portland Cement (OPC) of grade 43 that complied with IS: 8112/IS: 12269. According to the applicable IS regulations, the cement's standard consistency, beginning and final setting times, and specific gravity were evaluated. The hydration kinetics and strength development are controlled by its principal constituents, C3S, C2S, C3A, and C4AF. When additional materials like SCBA are added, the release of calcium hydroxide during hydration is essential for promoting further pozzolanic reactions.

2.2 Fine Aggregate - Natural river sand that met IS: 383's Zone III grading criteria was utilized as fine aggregate. Good workability and particle packing were ensured by the sand's suitable bulk density, specific gravity, and fineness modulus.Zone III sand's grading properties improve the mix's cohesion and lessen bleeding and segregation. Concrete's strength and durability could be negatively impacted by harmful particles including silt, clay, and organic contaminants, which were absent from the sand.

2.3 Coarse Aggregate - Riverbed boulders were used to create crushed angular coarse aggregates with a nominal size of 20 mm that complied with IS: 383. The rough surface roughness and angular shape improve the binding strength and mechanical interaction with the cement paste. To guarantee mechanical strength and endurance, the aggregates were examined for characteristics such specific gravity, water absorption, aggregate crushing value, and impact value. Reduced voids and better load distribution within the concrete matrix are two benefits of properly grading coarse materials.

2.4 Water - Both mixing and curing were done using potable water that met IS: 456 requirements. Because it affects hydration reactions, setting behaviour, and long-term durability, water quality is crucial. There were no dangerous levels of acids, alkalis, salts, or organic materials in the water. Cement was properly hydrated through adequate curing with clean water, which resulted in the production of the required strength and microstructure.

2.5 Admixture - To improve the concrete mix's workability, a superplasticizer based on polycarboxylate ether (PCE) was added. By using steric hindrance and electrostatic repulsion, the additive effectively disperses cement particles and lowers flocculation. This finally leads to increased strength and durability by enabling a lower water-to-cement ratio while retaining good flowability.

2.6 Sugarcane Bagasse Ash (SCBA) - Sugarcane bagasse was procured from local sugar industries and first air-dried to eliminate residual moisture. The dried biomass was then subjected to controlled combustion in a muffle furnace at temperatures of 600–700°C to ensure complete burning while preserving the amorphous nature of silica. Controlled temperature is critical, as excessive temperatures may lead to the formation of crystalline silica, reducing pozzolanic reactivity. The resultant ash was cooled under ambient conditions and sieved to remove unburnt carbon particles and fibrous residues. The ash was then finely ground using a Los Angeles abrasion machine to increase its specific surface area, enhancing its reactivity. Subsequently, it was passed through a 90-micron sieve to achieve uniform fineness comparable to cement particles.

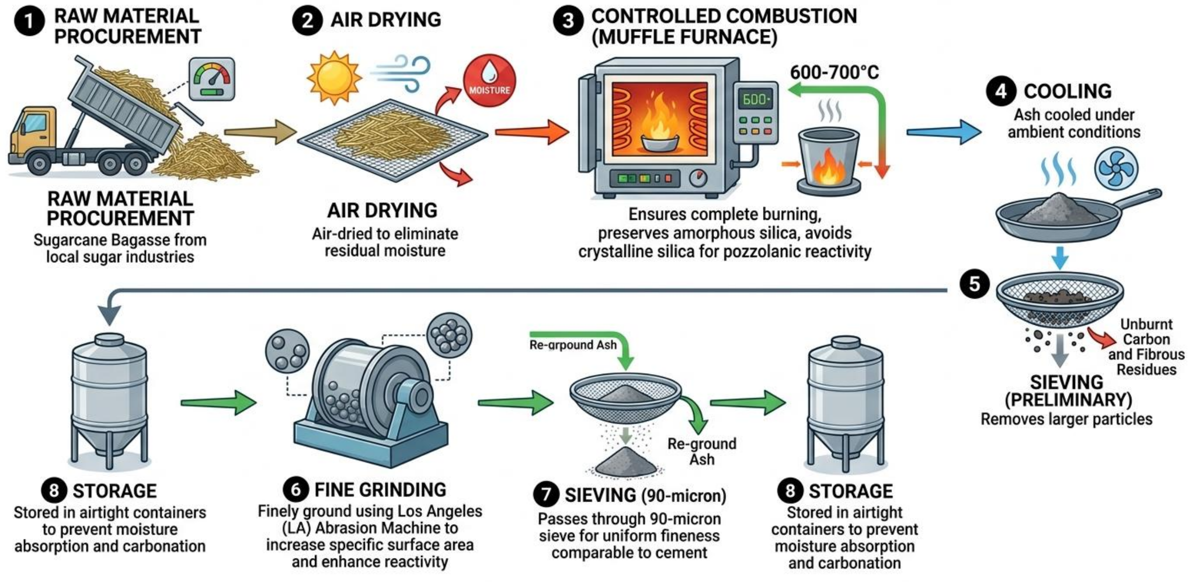

Figure 1. Manufacturing Process of Sugar Cane Bagasse Ash

3. METHOD & MIX

3.1 Method

In accordance with the mix design proportions, all dry materials—cement, fine aggregate, coarse aggregate, and SCBA—were first thoroughly mixed until a homogenous blend was achieved. After then, water was added gradually while mixing was still going on. To attain the required workability without raising the water–cement ratio, a superplasticizer based on polycarboxylate ether was added to water. Three layers of fresh concrete were put into 150 mm cube molds, and each layer was carefully crushed using a vibrating table to release trapped air. The upper surface was completed and leveled. Following a 24-hour period in the shade, the specimens were demolded and placed in water to cure.Curing was carried out for specified durations (7, 14, and 28 days) in accordance with IS: 456.

3.2 Mix Proportions

The concrete mix design was carried out in compliance with IS: 10262 (Concrete Mix Proportioning Guidelines) and IS 456 requirements following an assessment of the basic characteristics of the component materials. Sugarcane Bagasse Ash (SCBA) was added to the reference (control) mix in order to partially substitute cement at weight percentages of 5%, 10%, 15%, and 20%. To assess and compare the impact of SCBA on concrete performance, distinct batches were made, specimens were cast, and tests were carried out for each replacement level. The base mix proportion (for one cup of concrete) is listed below, and equivalent modified mixes were created by substituting SCBA for cement on a weight basis while maintaining the same amounts of other ingredients.

Table 1. Mix Proportion Table (kg/m³)

Mix ID	Cement	SCBA	Fine Aggregate	Coarse Aggregate	Water
REF	380	0	625	1235	162
SCC5	361	19	625	1235	162
SCC10	342	38	625	1235	162
SCC15	323	57	625	1235	162
SCC20	304	76	625	1235	162

The replacement was carried out on a mass basis, ensuring that the total binder content remained constant (380 kg/m³). This approach facilitates a consistent comparison of mechanical and durability properties across all mixes, enabling a clear assessment of the role of SCBA in concrete.

4. EXPERIMENTAL INVESTIGATION

4.1 Compressive Strength

In compliance with IS 516, concrete cube specimens of 150 mm by 150 mm by 150 mm were subjected to compressive strength testing. Following seven, fourteen, and twenty-eight days of curing, the specimens were surface-dried and subjected to a consistent rate of loading until failure utilizing a calibrated compression testing apparatus. Compressive strength was computed and the maximum load was noted. For every blend, the average of three specimens was taken into account. Figure 2 shows how compressive strength varies with SCBA substitution at various curing ages. The results clearly show that SCBA inclusion boosts compressive strength up to an ideal replacement level of 10–15%, after which a drop is noted. The pozzolanic reactivity of SCBA is mainly responsible for the strength improvement at lower replacement levels. The main strength-giving phase, extra calcium silicate hydrate (C–S–H) gel, is created when the amorphous silica in SCBA combines with the calcium hydroxide [$Ca(OH)_2$] released during cement hydration. The microstructural density is increased and porosity is decreased by this subsequent hydration process. Furthermore, SCBA's fine particles serve as micro-fillers, improving load transfer efficiency by strengthening the interfacial transition zone (ITZ) and refining the pore structure [10].

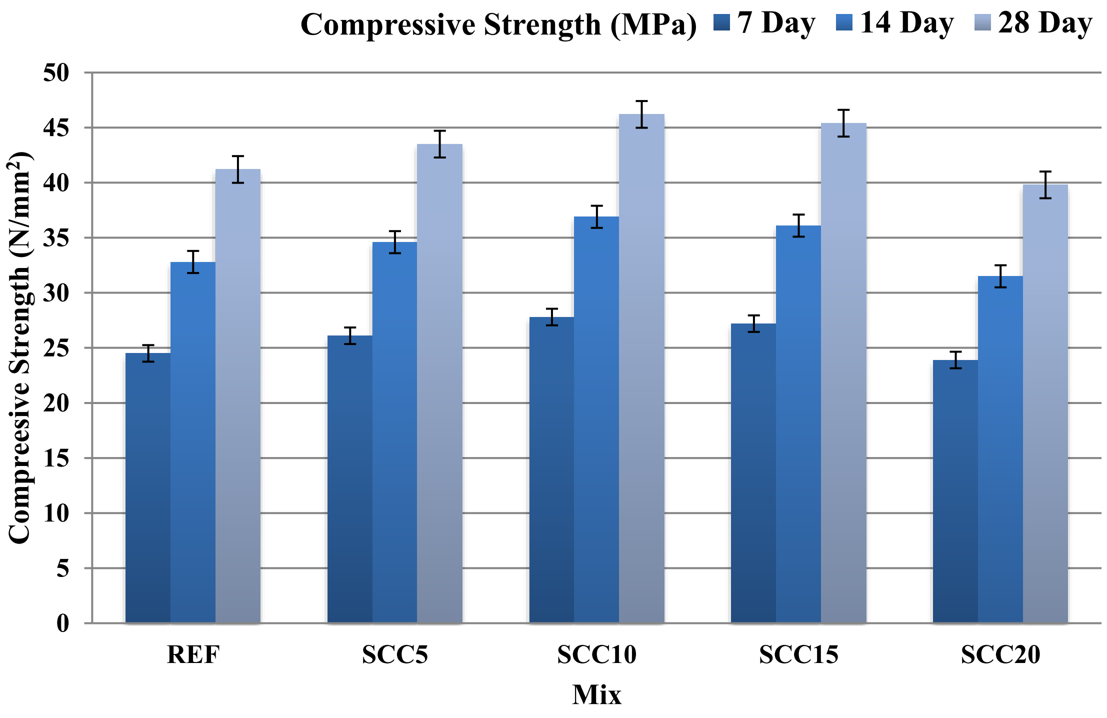

Figure 2. Compressive Strength results for tabulated mix proportions.

The dilution effect, in which the reduced cement concentration restricts the synthesis of primary hydration products, is primarily responsible for the drop in compressive strength at higher replacement levels (20%)[11]. Moreover, inadequate calcium hydroxide availability limits the pozzolanic process.

Additionally, SCBA's increased surface area and porous nature may increase water consumption, which could impact compaction and result in microstructural discontinuities [12].

4.2 Water Absorption

To assess the permeability properties and pore structure refinement of SCBA-incorporated concrete, water absorption tests were carried out. The test was conducted in compliance with ASTM C642. The concrete examples were cured for 28 days before being oven-dried at 105 ± 5°C until they reached a consistent mass. Every specimen's weight (dry weight) was noted. Following a 24-hour immersion in water, the specimens' saturated surface dry (SSD) weight was determined. The percentage increase in weight in relation to the dry weight was used to calculate water absorption. Figure 3 shows the change in water absorption following SCBA replacement.It is clear that adding SCBA reduces water absorption up to an ideal level of 10–15%, beyond which a little increase is shown at higher replacement levels. The combined effect of the pozzolanic reaction and the micro-filler action of SCBA is responsible for the decrease in water absorption at lower replacement levels. By reacting with calcium hydroxide, the amorphous silica in SCBA creates more C–S–H gel, which improves the pore structure and lowers capillary porosity [13]. Concurrently, the fine SCBA particles fill micro-voids in the cement matrix, improving packing density and decreasing pore connectivity. As a result, there is less water infiltration and permeability [14].

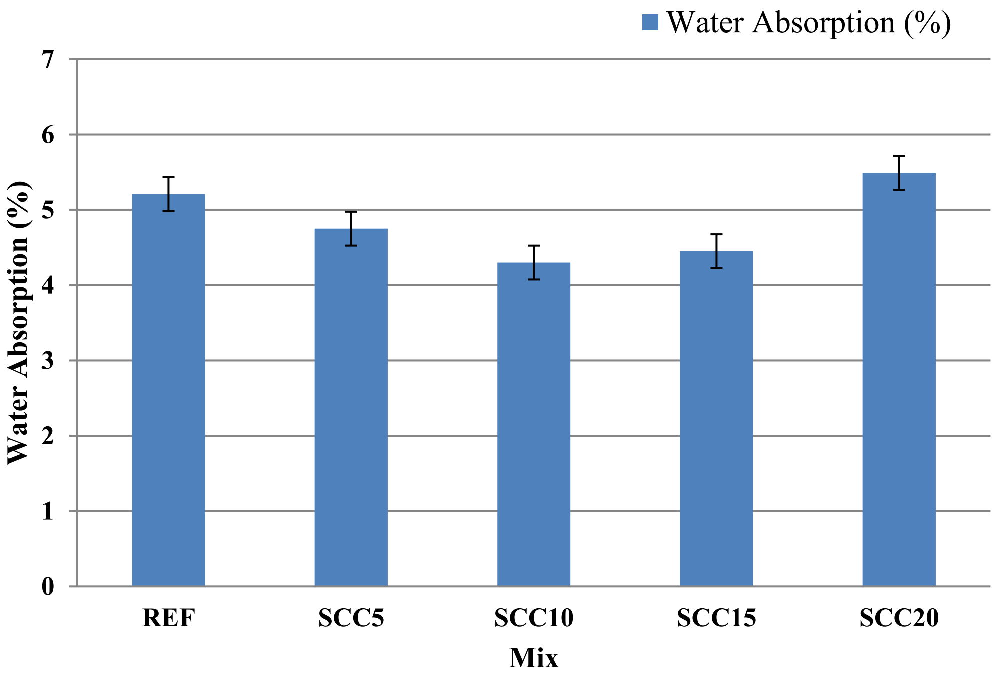

Figure 3. Water Absorption results for tabulated mix proportions.

The dilution effect and incomplete pozzolanic reaction are the main causes of the increase in water absorption at higher replacement levels (20%). The production of hydration products required for pore refining is limited by the decreased cement content [15]. Furthermore, if extra SCBA with uneven and porous morphology is not thoroughly crushed or totally reacted, it may create internal voids. Higher capillary suction and greater water absorption result from this.

4.3 Chloride Ion Penetration

According to ASTM C1202, the Rapid Chloride Penetration Test (RCPT) was used to assess concrete's resistance to chloride ion intrusion. After 28 days of hardening, cylindrical specimens (or slices made from cubes) were exposed to a 60 V potential differential across their faces for six hours. The specimen was subjected to a sodium hydroxide (NaOH) solution on one side and a sodium chloride (NaCl) solution on the other. An indirect indicator of chloride ion penetrability is the total charge passed (in coulombs) throughout the test time. Table 2 shows how the replacement of SCBA affects the penetration of chloride ions. The addition of SCBA results in a notable decrease in charge passed of up to 10–15%, suggesting enhanced resistance to chloride infiltration. Nevertheless, the charge passed rises at 20% replacement, indicating a decrease in resistance. The improvement of pore structure brought about by pozzolanic action is responsible for the enhanced performance at optimal SCBA contents. When calcium hydroxide and the amorphous silica in SCBA combine, more C-S-H gel is created, obstructing capillary holes and decreasing their connection. As a result, the microstructure becomes denser, which restricts the flow of chloride ions through the concrete matrix [16].

Table 2: Chloride Ion Penetration Results (Coulombs)

Mix ID	SCBA (%)	Charge Passed (Coulombs)	Chloride Penetrability
REF	0	3200	Moderate
SCC5	5	2680	Moderate
SCC10	10	1940	Low
SCC15	15	2160	Low
SCC20	20	2920	Moderate

Furthermore, the filler effect of finely ground SCBA decreases permeability and improves particle packing, both of which are crucial for regulating ionic transport [17]. Furthermore, the production of soluble chemicals that may ordinarily promote chloride diffusion is reduced by the decrease in calcium hydroxide level. The enhanced interfacial transition zone helps prevent hostile ions from entering. The dilution of cementitious compounds and decreased availability of hydration products are the primary causes of the increase in chloride penetration at higher replacement levels (20%). Higher conductivity may result from the delayed pozzolanic reaction and potential increase in pore capacity brought on by extra SCBA, which would raise the observed charge transmitted [18]. It's also crucial to remember that RCPT measures electrical conductivity, which can be impacted by both pore structure and pore solution chemistry.

5. CONCLUSION

1. The incorporation of Sugarcane Bagasse Ash (SCBA) as a partial replacement of cement significantly influences both mechanical and durability properties of concrete.
2. An optimum replacement level of 10–15% SCBA was identified, at which compressive strength improved due to enhanced pozzolanic activity and micro-filler effects, leading to increased formation of C–S–H gel and a denser microstructure.
3. Beyond the optimum level (≥20%), strength reduction was observed due to the dilution effect and limited availability of primary cementitious compounds.
4. Durability characteristics showed marked improvement, with reduced water absorption and lower chloride ion penetration, indicating refined pore structure and decreased permeability.
5. The improved resistance to ingress of aggressive agents highlights the suitability of SCBA-based concrete for durability-critical environments.
6. From a sustainability standpoint, SCBA utilization contributes to reduced cement consumption, thereby lowering CO_2 emissions associated with cement production.
7. The study also promotes effective waste valorization, addressing disposal issues of agro-industrial by-products and supporting circular economy principles.
8. Overall, SCBA emerges as a viable, eco-efficient supplementary cementitious material, capable of enhancing concrete performance while advancing sustainable construction practices.

6. FUTURE SCOPE

1. Investigate long-term durability under aggressive conditions such as sulphate attack, carbonation, and freeze–thaw cycles.

2. Conduct advanced microstructural analysis (SEM, XRD, TGA) to better understand hydration and pozzolanic mechanisms.
3. Study the influence of processing parameters (burning temperature, fineness, and LOI) on SCBA reactivity.
4. Explore hybrid systems combining SCBA with other SCMs or nanomaterials for high-performance concrete.
5. Evaluate the use of SCBA in specialized concretes such as self-compacting, pervious, and geopolymer concrete.
6. Perform life cycle assessment (LCA) and economic analysis to quantify environmental and cost benefits.
7. Develop standardized guidelines and codal provisions to facilitate large-scale implementation in the construction industry.

REFERENCES

[1]. Schneider, M. (2019) 'The cement industry on the way to a low-carbon future,' *Cement and Concrete Research*, 124, p. 105792. https://doi.org/10.1016/j.cemconres.2019.105792.

[2]. Turk, O. *et al.* (2024) 'Sustainable concrete production: The potential of utilizing recycled waste materials,' *Journal of Building Engineering*, 98, p. 111467. https://doi.org/10.1016/j.jobe.2024.111467

[3]. Wang, D. *et al.* (2025) 'Unlocking the potential of sugarcane: Advances in genomic innovation, biorefinery technologies, and stress resilience, and circular bioeconomy,' *Industrial Crops and Products*, 236, p. 122080. https://doi.org/10.1016/j.indcrop.2025.122080.

[4]. Langade, S., Gilke, N. and Patil, K. (2018) 'Bagasse Ash for manufacturing construction products,' *Materials Today Proceedings*, 5(9), pp. 19954–19962. https://doi.org/10.1016/j.matpr.2018.06.361.

[5].Praneetha, S. and Murugan, A.V. (2015) 'Development of Sustainable Rapid Microwave Assisted Process for Extracting Nanoporous Si from Earth Abundant Agricultural Residues and Their Carbon-based Nanohybrids for Lithium Energy Storage,' *ACS Sustainable Chemistry & Engineering*, 3(2), pp. 224–236. https://doi.org/10.1021/sc500735a.

[6]. Thomas, B.S. *et al.* (2021) 'Biomass ashes from agricultural wastes as supplementary cementitious materials or aggregate replacement in cement/geopolymer concrete: A comprehensive review,' *Journal of Building Engineering*, 40, p. 102332. https://doi.org/10.1016/j.jobe.2021.102332

[7]. Chindaprasirt, P. *et al.* (2013) 'Role of filler effect and pozzolanic reaction of biomass ashes on hydrated phase and pore size distribution of blended cement paste,' *Journal of Materials in Civil Engineering*, 26(9). https://doi.org/10.1061/(asce)mt.1943-5533.0000921.

[8].Yuan, J., Chang, J. and Bai, Y. (2025) 'Preparation of supplementary cementitious material by semi-dry carbonated ternesite and its effect on hydration and mechanical properties of Portland cement,' *Cement and Concrete Research*, 193, p. 107870. https://doi.org/10.1016/j.cemconres.2025.107870.

[9]. Bayapureddy, Y., Muniraj, K. and Gangireddy, M.M. (2023) 'Characteristic evaluation of concrete containing sugarcane bagasse ash as pozzolanic admixture,' *Research on Engineering Structures and Materials* [Preprint]. https://doi.org/10.17515/resm2023.819ma0712.

[10]. Ardhira, P.J., Shukla, S.K. and Sathyan, D. (2024) 'Synthesis of geopolymer mortar from biomass ashes and forecasting its compressive strength behaviour,' *Case Studies in Construction Materials*, 21, p. e03581. https://doi.org/10.1016/j.cscm.2024.e03581.

[11]. Ahmad, J. *et al.* (2023) 'Concrete made with partially substitution corn cob ash: A review,' *Case Studies in Construction Materials*, 18, p. e02100. https://doi.org/10.1016/j.cscm.2023.e02100.

[12]. Peng, G.-F. *et al.* (2025) 'Effect of calcined red mud on the mechanical properties and microstructure of ultra-high performance concrete,' *Construction and Building Materials*, 484, p. 141891. https://doi.org/10.1016/j.conbuildmat.2025.141891.

[13]. Srirama, D., Yadav, M.K. and Jayanthi, P.N.V. (2026) 'Potential of sugarcane bagasse ash for expansive subgrade stabilization for expanding Indian Road networks,' *Case Studies in Construction Materials*, 24, p. e06063. https://doi.org/10.1016/j.cscm.2026.e06063.

[14]. Padavala, S.S.A.B., Avudaiappan, S. and Noolu, V. (2025) 'Experimental and machine learning based analysis of pervious concrete enhanced with fly ash and silica fume,' *Next Materials*, 9, p. 101018. https://doi.org/10.1016/j.nxmate.2025.101018.

[15].Al-Shugaa, M.A. *et al.* (2024) 'Pozzolanic performance and characteristic analysis of binary blended cement incorporating ceramic polishing sludge,' *Journal of Materials Research and Technology*, 29, pp. 3711–3725. https://doi.org/10.1016/j.jmrt.2024.02.119.

[16]. Karein, S.M.M. *et al.* (2017) 'A new approach for application of silica fume in concrete: Wet granulation,' *Construction and Building Materials*,157,pp.573–581. https://doi.org/10.1016/j.conbuildmat.2017.09.132.

[17]. Abdalla, T.A. *et al.* (2024) 'Strength, durability, and microstructure properties of concrete containing bagasse ash – A review of 15 years of perspectives, progress and future insights,' *Results in Engineering*, 21,p-101764. https://doi.org/10.1016/j.rineng.2024.101764

18]. Fraj, A.B. *et al.* (2019) 'Investigating the early-age diffusion of chloride ions in hardening slag-blended mortars on the light of their hydration progress,' *Construction and Building Materials*,225,485–495. https://doi.org/10.1016/j.conbuildmat.2019.07.185