



# Exploring the Potential of Rice Husk, Sugarcane Bagasse, and Cow Dung Ashes as Eco-Activators in Geopolymer Concrete

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**Abstract.** This study explores the development and evaluation of geopolymer concrete produced using agro-waste ashes—specifically rice husk ash (RHA), sugarcane bagasse ash (SBA), and cow dung ash (CDA)—as sustainable binder alternatives. Various mix combinations were designed by varying the proportions of the three ashes while keeping the alkaline activator ratio and aggregate content constant. Fresh properties were assessed through slump tests, while mechanical performance was evaluated through compressive strength, split tensile strength, and flexural strength at 7, 28, and 90 days. The results revealed that RHA-rich mixes exhibited superior workability and mechanical strength due to their high silica content and finer particle structure. Mixes containing SBA also performed well, particularly in terms of long-term strength gain. When utilized independently, cow dung ash (CDA) exhibits relatively lower reactivity; however, its performance improves markedly when combined with more reactive supplementary ashes in blended formulations. The investigation establishes that, through careful optimization of mix proportions, geopolymer concrete incorporating agro-industrial residues can attain satisfactory mechanical strength and durability characteristics. The findings advocate the integration of agricultural waste materials into construction practices as a viable approach to enhancing environmental sustainability and promoting efficient resource utilization within the built environment.

**Keywords:** Eco-friendly, agro-waste, mechanical properties, fresh properties, geopolymer concrete.

## 1. Introduction

Over the last ten years, the construction industry has undergone a significant evolution marked by the increasing integration of environmentally responsible materials [1-3]. The increasing focus on sustainable construction practices can be attributed to heightened global awareness surrounding ecological deterioration, the exhaustion of non-renewable resources, and the substantial environmental impact associated with traditional cement production methods. The production of ordinary Portland cement

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(OPC) is characterized by significant energy requirements and represents one of the primary contributors to anthropogenic carbon dioxide emissions. As a result, there has been a progressive shift within the construction sector toward alternative binding systems, with geopolymer technology gaining attention as a viable and environmentally favorable substitute [4–6].

Geopolymer concrete is produced through the alkali activation of alumino-silicate-rich materials and is recognized for its potential to significantly reduce environmental impact. In addition to its capacity to lower greenhouse gas emissions, this material exhibits superior durability and accommodates the inclusion of a wide spectrum of waste materials, particularly those originating from industrial and agricultural processes. Agricultural by-products, which are frequently underutilized or disposed of through open burning, have shown considerable promise as precursors in geopolymer synthesis due to their enrichment in reactive silicates and aluminates [7–10].

Among the most promising agricultural residues are rice husk ash (RHA), sugarcane bagasse ash (SBA), and cow dung ash (CDA), all of which are abundantly generated in regions with intensive agricultural activity. RHA is especially noted for its high silica content and pronounced pozzolanic behavior, making it a highly reactive primary binder. SBA, derived from sugar production waste, contributes beneficial mineral oxides that aid in mechanical strength development. CDA, though less commonly employed, contains a chemically active matrix suitable for partial substitution in green concrete formulations, contributing to the sustainability of the overall mix design [11–14].

This research undertakes a detailed examination of the standalone and synergistic effects of RHA, SBA, and CDA on the performance of geopolymer concrete in both fresh and cured conditions. By adjusting the mix proportions of these ashes in a series of controlled experimental trials, the study seeks to determine compositions that optimize essential performance indicators, including workability, compressive strength, flexural strength, and tensile capacity. The insights derived aim to support the advancement of environmentally responsible concrete technologies that are adaptable to a wide array of construction needs, encompassing both metropolitan development and rural infrastructure initiatives.

## 2. Materials used

This investigation was carried out using materials that were locally available considering their pozzolanic activity, and compatibility with geopolymer synthesis protocols. Each constituent was procured from nearby sources and underwent standardized pre-treatment processes to ensure uniformity and reliability in their physicochemical behavior throughout the experimental program. RHA was obtained from the controlled combustion of rice husks collected from a local rice mill. The ash was sieved through a 75-micron mesh to eliminate coarse particles and ensure a uniform particle size distribution. Rich in amorphous silica, RHA served as a primary alumino-silicate precursor for the geopolymer binder. Its fine texture and high reactivity contributed to early strength development and improved matrix densification. SBA was sourced from a sugar factory where bagasse is used as boiler fuel. After collecting, the ash was

air-dried, ground, and passed through a fine sieve to remove any unburnt carbon and oversized particles. SCBA is known to contain reactive silica and some alumina, making it suitable for inclusion in geopolymer systems. It served as a partial replacement material to study its synergy with RHA and CDA. CDA was produced by burning sun-dried cow dung cakes in open conditions. The ash was cooled, sieved, and stored in dry containers. While CDA has a variable composition depending on diet and burning conditions, it typically contains calcium, potassium, and other minerals. Its inclusion in the mix aimed to assess its viability as a secondary binder component in combination with other ashes. The alkaline solution used to activate the geopolymer reaction consisted of sodium hydroxide (NaOH) and sodium silicate ( $\text{Na}_2\text{SiO}_3$ ). Sodium hydroxide pellets were dissolved in distilled water to achieve a molarity of 12M. The sodium silicate solution was commercially obtained, having a silicate-to-sodium oxide ratio suitable for geopolymerization. The two solutions were mixed in a predefined ratio and aged for 24 hours before use to stabilize the mixture. Well-graded river sand was used as the fine aggregate. It was clean, free from silt and organic matter, and conformed to standard specifications for use in concrete. The aggregate-to-binder ratio was kept constant across all mixes to maintain uniformity in comparison. Potable tap water was used for dissolving sodium hydroxide and for cleaning purposes. Extra water was not added to the mix beyond what was essential for preparing the activator solution. Table 1 shows the physical and chemical properties of the precursor material used.

**Table 1:** Properties of precursor material.

Physical and chemical properties	RHA	SBA	CDA
Size (mm)	--	--	--
Fineness (Passing 45 $\mu\text{m}$ )	3	3.1	3.4
Specific gravity ( $\text{kg}/\text{cm}^3$ )	2.12	2.3	2.1
$\text{Al}_2\text{O}_3$ (%)	0.19	9	17
$\text{SiO}_2$ (%)	90.3	64	61
$\text{CaO}$ (%)	0.71	11	9.5
$\text{Fe}_2\text{O}_3$ (%)	0.1	0.6	3.5
$\text{MgO}$ (%)	--	4.5	--
$\text{Na}_2\text{O}$ (%)	--	1.7	--
$\text{TiO}_2$ (%)	--	0.1	--
$\text{FeO}$ (%)	--	--	--
$\text{SO}_3$ (%)	1.8	--	--
$\text{K}_2\text{O}$ (%)	--	4	--
$\text{P}_2\text{O}_5$ (%)	--	1.1	--
LOI (%)	3.12	2	--
Others (%)	3.78	2	9

### 3. Methodology

The present study aimed to evaluate the effects of varying proportions of rice husk ash (RHA), sugarcane bagasse ash (SBA), and cow dung ash (CDA) on the fresh and mechanical properties of geopolymer concrete. A methodical experimental framework

was adopted, encompassing all phases from raw material processing to mechanical performance assessment, thereby ensuring procedural uniformity and data accuracy across all test series. The alkaline activator solution was prepared by dissolving sodium hydroxide pellets in distilled water to achieve a concentration of 12 molarity, providing the necessary alkalinity for geopolymerization reactions. Separately, sodium silicate solution was used as received from a commercial supplier. The two solutions were combined in a fixed ratio by weight and stirred thoroughly. This blended activator solution was allowed to rest for 24 hours before use to reach chemical equilibrium and ensure better reactivity. Five different mix formulations were developed by varying the ratios of R, S, and C ashes. The total binder content remained constant, while the proportions of individual ashes were adjusted to investigate their effects. The mixes included 100% RHA, 100% SCBA, 100% CDA, and two blended combinations of RHA with SCBA and RHA with CDA in equal parts. The alkaline solution-to-binder ratio and aggregate proportions were kept uniform across all mixes. The mixing was carried out in a pan-type concrete mixer. First, the dry materials (ashes and fine aggregate) were thoroughly blended to achieve a homogeneous mixture. Then, the prepared alkaline activator solution was gradually added while mixing continued. The mixing was done until a uniform and workable consistency was achieved. Care was taken to ensure there were no dry pockets or clumps of unblended materials. Freshly mixed geopolymer concrete was poured into standard moulds for different mechanical tests:

- 150 mm cubes for compressive strength
- 100 mm × 100 mm × 500 mm beams for flexural strength
- 100 mm diameter × 200 mm height cylinders for split tensile strength

Each mould was filled in two layers and compacted using a table vibrator to eliminate entrapped air. The top surfaces were levelled and smoothed before setting. After casting, all specimens were covered to prevent moisture loss and kept undisturbed at room temperature for 24 hours. Once demoulded, they were stored under ambient conditions without external heat treatment to replicate practical curing scenarios. Mechanical testing was conducted at 7, 28, and 90 days. The mix design procedure of Mahapara and Gyanendra was followed in this study [15]. Table 2 shows the mix proportions of the mixers.

### 3.1. Testing Procedures

- Slump Test: Conducted immediately after mixing to assess the workability using a standard slump cone.
- Compressive Strength: Evaluated using a compression testing machine at designated curing intervals.
- Flexural Strength: Measured using a third-point loading setup on beam specimens.
- Split Tensile Strength: Determined by applying diametral load on cylindrical specimens until failure.

**Table 2:** Mix Proportions

Mix	R100S0C0	R0S100C0	R0S0C100	R50S50C0	R50S0C50
Na <sub>2</sub> SiO <sub>3</sub> / NaOH	2.0	2.0	2.0	2.0	2.0

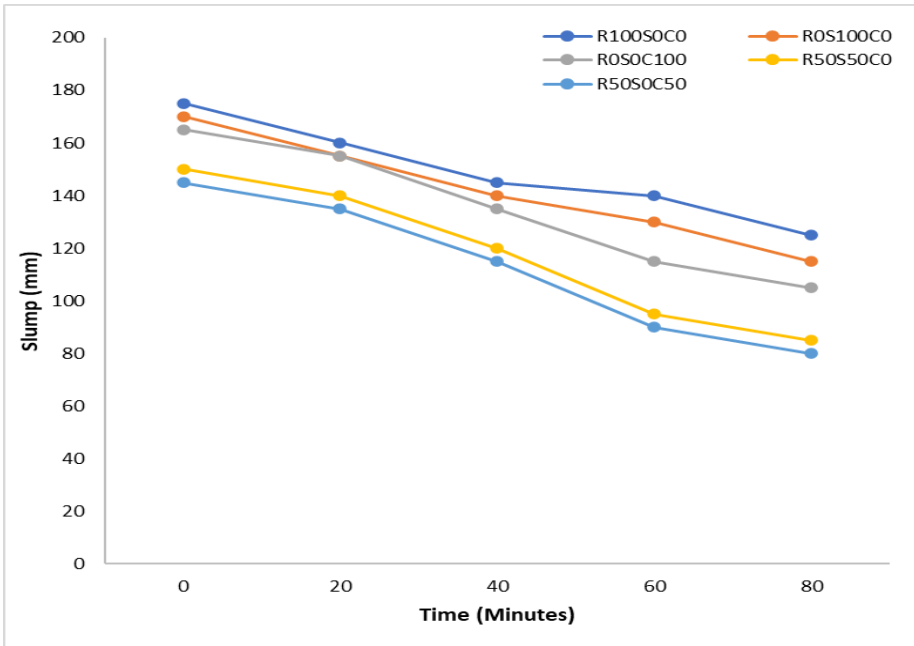
NaOH (kg/m <sup>3</sup> )	66.67	66.67	66.67	66.67	66.67
Alkaline Activator/binder content	0.4	0.4	0.4	0.4	0.4
Na <sub>2</sub> SiO <sub>3</sub> (kg/m <sup>3</sup> )	133.33	133.33	133.33	133.33	133.33
Superplasticizer (kg/m <sup>3</sup> )	5.0	5.0	5.0	5.0	5.0
Extra water (kg/m <sup>3</sup> )	40.0	40.0	40.0	40.0	40.0
NaOH (M)	12	12	12	12	12
RHA (kg/m <sup>3</sup> )	500	00	00	250	250
SBA (kg/m <sup>3</sup> )	00	500	00	250	00
CDA (kg/m <sup>3</sup> )	00	00	500	00	250
Coarse Aggregates (kg/m <sup>3</sup> )	1026	1026	1026	1026	1026
Fine Aggregates (kg/m <sup>3</sup> )	555	555	555	555	555

## 4. Results and Discussion

### 4.1. Workability

Figure 1 presents the variation in slump values over time for geopolymer concrete mixes composed of different combinations of **RHA(R)**, **SBA (S)**, and **CDA (C)**. The mixes were designated based on the percentage contribution of each ash type, where, for instance, R100S0C0 refers to a mix containing 100% RHA with no inclusion of bagasse or CDA. At the initial testing point (0 minutes), the **R100S0C0** mix exhibited the highest slump, indicating superior flowability and fresh-state consistency. This behavior can be attributed to the fine, lightweight, and highly reactive nature of RHA, which typically allows for better water retention and paste cohesion [7], [10-12], [16]. As time progressed, although the slump of this mix gradually declined, it maintained relatively better workability than the others, even at 80 minutes. Mixes containing a **combination of R and S** (e.g., R50S50C0 and R50S0C50) demonstrated a steeper reduction in slump over time. The observed trend indicates that the incorporation of sugarcane bagasse ash (SBA) or cow dung ash (CDA) influences both the water demand and the rheological behavior of the geopolymer mix. SBA, characterized by its porous morphology, tends to absorb a substantial portion of the alkaline activator solution, thereby diminishing the availability of free water and promoting early stiffening of the mixture [11], [13], [17]. Cow dung ash (CDA), with its non-uniform particle shape and coarse texture, also affected fresh mix flow. The concrete mixes without rice husk ash (RHA)—R0S100C0 and R0S0C100—had the lowest slump values throughout all testing periods. Due to its high silica content and finely graded particles, RHA promotes workability. RHA removal seems to disturb mix uniformity and fluidity owing to increased internal resistance and a lack

of reactive binder paste needed to build a homogeneous coating surrounding aggregate particles [16], [18-22].

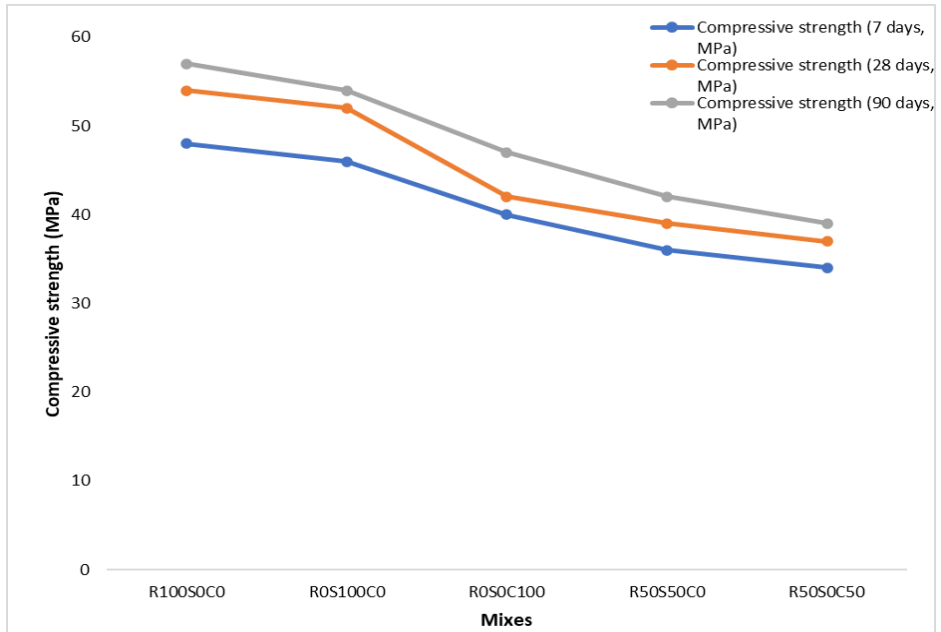


**Figure 1:** Workability of the mixes.

## 4.2. Compressive strength

Figure 2 shows the compressive strength results at 7, 28, and 90 days for geopolymer concretes with varying ratios of rice husk ash (RHA), sugarcane bagasse ash (SBA), and cow dung ash. Ash content significantly affects binder system short-term strength growth and durability. The R100S0C0 mix—all RHA—had the maximum strength throughout all curing periods. This performance is due to RHA's high silica content and finely split nature, which promotes fast geopolymerization and creates a thick, cohesive matrix [23-27]. The sustained strength increase up to 90 days indicates RHA's prolonged pozzolanic action, promoting matrix densification. SBA alone in the R0S100C0 combination produced somewhat lower compressive strength values, especially at 28 and 90 days. This shows that SBA has significant pozzolanic reactivity and may operate as a solo binder in alkali-activated systems. CDA-only R0S0C100 had the lowest strength values among the evaluated mixtures. Due to the coarse particle size and uneven chemical composition of CDA, homogeneous matrix growth and polymeric gel formation may be hindered [14, 28-30]. However, the gradual strength improvement suggests that CDA still geopolymerizes, although at a slower pace. In R50S50C0 and R50S0C50, the compressive strengths were midway between the greatest and lowest performing mixtures when the ashes were blended. These findings

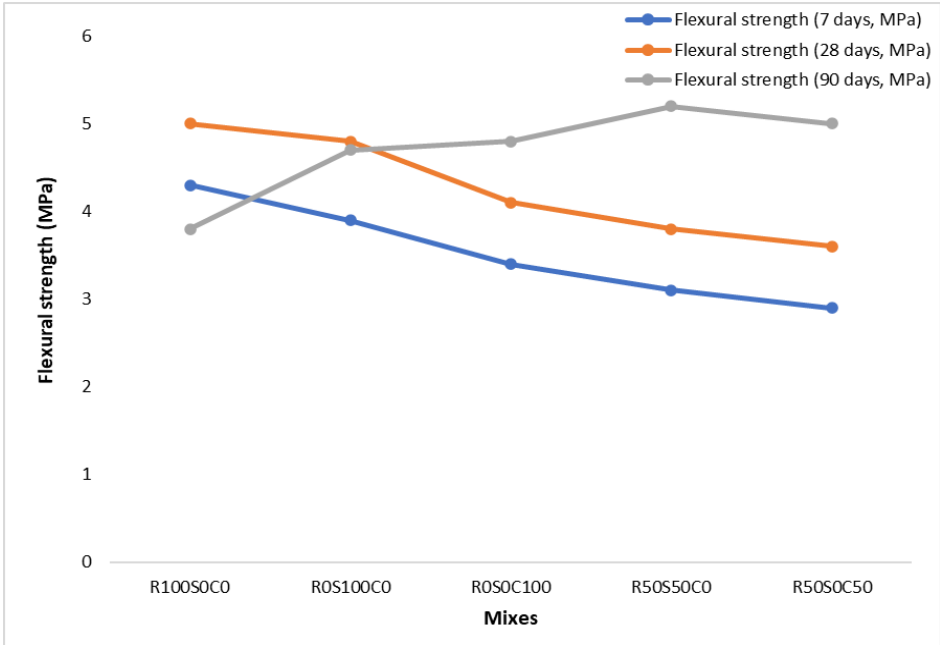
indicate synergy between ashes. Partial replacement of RHA with SBA or CDA reduces peak strength, but composite blends remain structurally strong, especially at later ages [3], [10], [31], [32]. By strategically incorporating agro-industrial by-products, geopolymer concretes may be well-balanced and ecologically friendly.



**Figure 2:** Compressive strength of the mixes.

### 4.3. Flexural strength

The results displayed in the Figure 3 reflect how different proportions of RHA, SBA, and CDA influence the flexural performance of geopolymer concrete across 7, 28, and 90 days of curing. The **R100S0C0** mix, which includes only RHA, registered the highest flexural strength at 28 days. This early-age performance is likely due to the fine particle size and high silica content of RHA, which fosters rapid geopolymeric gel formation, improving the overall binding and crack-bridging capacity [3], [7], [33], [34]. An unexpected decline in compressive strength was observed at the 90-day mark in certain mixes, which may be attributed to internal microcracking or drying shrinkage effects that counteracted the anticipated strength progression over time. Such phenomena could compromise the structural integrity of the hardened matrix, leading to a marginal reduction in mechanical performance despite ongoing geopolymeric reactions. In contrast, the **R0S100C0** mix—comprising solely sugarcane bagasse ash—demonstrated a more consistent and progressive increase in flexural strength across the entire curing period, from 7 to 90 days. This consistent improvement suggests that SBA may provide a more uniform and regulated matrix development, improving geopolymer system flexural resilience and durability [27], [35], [36].



**Figure 3:** Flexural strength of the mixes.

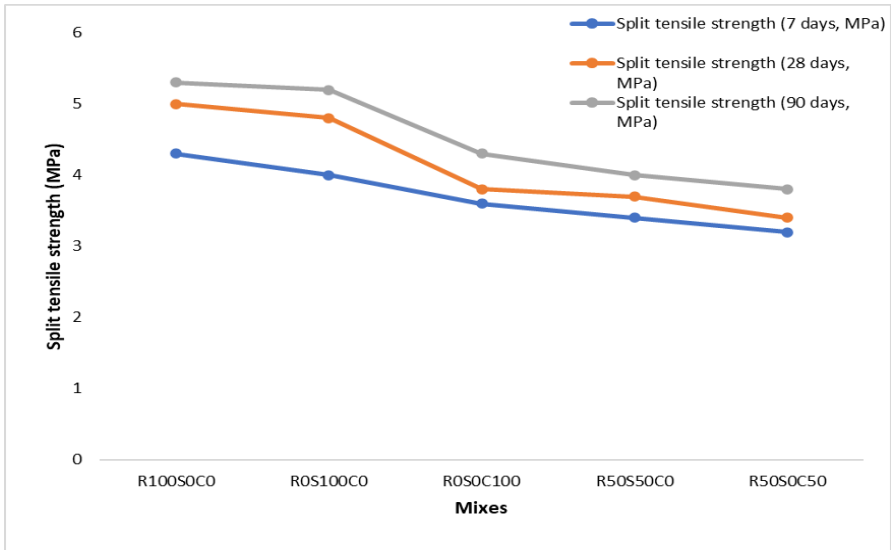
#### 4.4. Split tensile strength

The results illustrated in Figure 4 detail the evolution of split tensile strength in geopolymer concrete formulated with varying proportions of rice husk ash (RHA), sugarcane bagasse ash (SBA), and cow dung ash (CDA), assessed at 7, 28, and 90 days. These intervals were selected to capture both the initial mechanical behavior and the long-term strength development of the binder systems. Among the tested formulations, the R100S0C0 mix—composed exclusively of RHA—exhibited the highest split tensile strength across all curing durations. This enhanced performance is primarily attributed to the high silica content and fine particle size of RHA, which promote efficient geopolymer gel formation and contribute to the early development of a compact and cohesive matrix. Such a matrix is effective in resisting internal tensile stresses, thereby improving crack resistance and overall tensile capacity [20], [37], [38].

The R0S100C0 mix, in which SBA served as the sole precursor, demonstrated a moderate reduction in tensile strength when compared to the RHA-based mix. Nevertheless, it maintained commendable strength characteristics, particularly at the 90-day mark, suggesting that SBA supports continued geopolymerization and contributes to the formation of a structurally robust matrix over time.

This suggests that while bagasse ash may be slower to react, its long-term contribution to tensile strength is significant, likely due to continuous aluminosilicate gel development [11], [39], [40]. The mix labeled **R0S0C100**, which relies solely on CDA, produced the lowest split tensile strength values. This can be attributed to the irregular particle size, lower reactivity, and possibly non-uniform chemical composition of CDA. Nevertheless, the steady increase in strength over time indicates some poz-

zolanitic behaviour, albeit less efficient than RHA or SBA. For sustainable development further research could be enhanced using modern AI and ML techniques along with optimizations like Taguchi and RSM [41-45].



**Figure 4:** Split tensile strength of the mixes.

## 5. Conclusion

- The investigation into the performance of geopolymer concrete mixes formulated from agricultural ashes—namely RHA, SBA, and CDA—has revealed several key insights. The results clearly demonstrate that the type and proportion of binder significantly affect both the fresh and hardened properties of the composite material.
- Among the different blends, the mix containing 100% RHA consistently achieved the highest values in compressive, split tensile and flexural strength. This suggests that RHA, due to its fine particle structure and high silica content, contributes substantially to the formation of a dense and reactive geopolymer matrix. Its superior performance across all age intervals further affirms its role as a reliable and high-quality precursor for geopolymer production.
- The SBA-based mix also showed promising results, especially in long-term strength development. Its gradual and sustained performance indicates a slower yet effective participation in the geopolymerization process. While CDA alone demonstrated relatively lower mechanical strength, its inclusion in partial replacement ratios did not severely compromise the performance, provided the proportion was kept within an acceptable range.
- In terms of workability, mixes with higher RHA content retained slump for longer durations, whereas mixes containing greater amounts of bagasse and

CDA showed quicker loss in flow, indicating the need for water-reducing agents or improved mix design when using these ashes in high volumes.

Overall, the study confirms that geopolymer concrete prepared using combinations of agro-waste ashes can be tailored to meet structural and sustainability requirements. With proper proportioning, these materials offer a viable alternative to traditional cement-based systems, promoting both environmental conservation and resource efficiency.

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