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Compressive Strength Performance Of Low-Carbon Geopolymer Concrete Enhanced With Calcium Carbide Waste

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ABSTRACT: *Geopolymer concrete (GPC) offers a low-carbon alternative to Portland cement concrete by enabling the use of industrial and agricultural by-products as reactive binders. This study examined the compressive strength performance of GPC produced with Sugarcane Bagasse Ash (SBA) as the primary aluminosilicate source and Calcium Carbide Waste (CCW) as a calcium-rich partial replacement at 0%, 5%, 10%, and 15%. The alkaline activator system consisted of 16M NaOH and sodium silicate in a fixed ratio of 2.5. Compressive strength was measured at 7, 14, 28, and 56 days. Results show that strength increased with both curing age and CCW incorporation. The control mix (0% CCW) increased from 24.4 MPa at 7 days to 34.0 MPa at 56 days, while the 15% CCW mix increased from 27.7 MPa to 38.0 MPa over the same period. These improvements indicate that the additional calcium promotes faster geopolymerization and contributes to a denser, stronger binder structure. Overall, SBA–CCW geopolymer concrete demonstrated promising mechanical performance and represents a viable low-carbon construction material utilizing locally available waste.*

KEYWORDS: *Geopolymer concrete (GPC); Sugarcane Bagasse Ash (SBA); Calcium Carbide Waste (CCW); Compressive strength; Low-carbon binders; Alkali activation; geoplymerization.*

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1. INTRODUCTION

Portland cement production is one of the largest single contributors to global anthropogenic CO_2 emissions, accounting for nearly 8% of worldwide releases due to its energy-intensive clinker production process and the calcination of limestone (Mehta & Monteiro, 2014; Habert et al., 2020). As the global demand for infrastructure increases, reducing the carbon footprint of construction materials has become a critical priority in meeting international climate and sustainability commitments (Scrivener, John & Gartner, 2018). Geopolymer concrete (GPC) has emerged as a promising low-carbon alternative to Portland cement, relying on the alkaline activation of aluminosilicate-rich and calcium-bearing materials to form a hardened binder (Davidovits, 2008; Provis & van Deventer, 2014).

In addition to reducing CO_2 emissions by up to 80% compared with ordinary Portland cement, geopolymer binders enable the beneficial reuse of agricultural and industrial by-products (Siddique & Khan, 2011). This contributes to both environmental sustainability and circular-economy principles by diverting large waste streams from landfills. Sugarcane Bagasse Ash (SBA), an agro-industrial residue rich in amorphous silica, has shown potential as a geopolymer precursor due to its high pozzolanic activity (Cordeiro et al., 2009). Calcium Carbide Waste (CCW), generated during acetylene gas production, is abundant in calcium hydroxide and can serve as a calcium-rich additive capable of enhancing early strength through the formation of calcium-modified reaction gels (Omoniyi & Olusunle, 2014).

Combining SBA and CCW in geopolymer systems provides a sustainable pathway for producing alternative binders while addressing waste-management challenges. Calcium plays a major role in accelerating geopolymerization and improving compressive strength, especially in systems derived from low-calcium precursors such as SBA (Temuujin et al., 2011). Incorporating CCW into SBA-based geopolymer binders is therefore expected to enhance mechanical performance by promoting denser gel formation and improved structural integrity. Despite the potential benefits, the mechanical behavior of SBA–CCW geopolymer concrete particularly its compressive strength development remains insufficiently explored. Understanding how varying CCW contents influence strength gain is essential for optimizing mix design and improving the practical applicability of low-carbon geopolymer binders.

This study examined the compressive strength performance of geopolymer concrete produced with SBA as the primary aluminosilicate source and CCW as a calcium-rich partial replacement. The objective was to evaluate strength development across different curing ages and determine the extent to which CCW enhances the mechanical behavior of SBA-based geopolymer concrete. The findings aim to support the development of sustainable, low-carbon construction materials suitable for broader implementation.

1.1 The Pozzolanic Nature of Sugarcane Bagasse Ash (SBA)

Sugarcane Bagasse Ash (SBA) is an agro-industrial by-product generated from the combustion of sugarcane bagasse for energy production in sugar mills. When properly processed, SBA contains a high proportion of amorphous silica, which enables it to function as an effective pozzolanic material (Cordeiro et al., 2009). Pozzolans are siliceous or aluminosiliceous substances that possess little or no inherent cementing ability but react chemically with calcium hydroxide in the presence of moisture to form additional cementitious compounds (Siddique & Khan, 2011). The pozzolanic behavior of SBA is largely governed by its chemical composition particularly it's reactive silica (SiO_2) content and by physical attributes such as fineness and particle morphology. During the reaction process, amorphous silica from SBA dissolves in an alkaline environment and interacts with calcium ions released from the binder system to form secondary calcium silicate hydrate (C–S–H), which contributes directly to strength development (Caetano et al., 2017). This secondary C–S–H enhances matrix densification, improves microstructure, and leads to measurable improvements in compressive strength.

The efficiency of SBA as a pozzolan depends on several factors, including calcination temperature, combustion conditions, particle size, and the availability of calcium hydroxide for the reaction (Chusilp, Jaturapitakkul & Kiattikomol, 2009). Properly calcined SBA typically produced at controlled temperatures that retain amorphous silica exhibits higher pozzolanic reactivity and contributes more effectively to strength enhancement. The ash's highly porous and irregular surface morphology also increases its surface area, providing additional sites for reaction and mechanical interlocking within the geopolymer matrix. Despite variations in chemical composition caused by differences in agricultural practices and combustion conditions, well-processed SBA has consistently demonstrated its suitability as a sustainable pozzolanic material capable of improving the mechanical performance of cementitious and geopolymer systems. Its high silica content, reactivity, and availability make SBA an attractive binder component for low-carbon construction materials.

1.2 Influence of Calcium Carbide Waste (CCW) in Geopolymer Concrete

Calcium carbide waste (CCW) is a residue generated during acetylene gas production and is predominantly composed of calcium hydroxide ($Ca(OH)_2$). Although CCW is not a pozzolanic material, its high calcium content enables it to actively participate in reactions within alkaline-activated or geopolymer systems (Siddique & Khan, 2011). When added to geopolymer concrete, CCW serves as a calcium-rich additive that modifies the reaction environment and enhances mechanical performance. In geopolymer matrices, the release of calcium ions from CCW accelerates the geopolymerization process by promoting the formation of calcium-bearing gels. These gels, primarily calcium silicate hydrate (C–S–H), form alongside the conventional aluminosilicate network. Their coexistence produces a denser and more cohesive microstructure, which directly contributes to increased compressive strength (Siddique & Khan, 2011).

This interaction between CCW-derived calcium phases and the sodium-based geopolymer system results in improved early-age and long-term strength development. CCW also contributes to microstructural refinement. Its calcium-driven reactions fill voids and reduce pore connectivity, enhancing the overall stability of the geopolymer matrix. Studies have additionally reported improvements in sulfate and chloride resistance when CCW is incorporated, attributed to the compactness of the modified microstructure and reduced permeability (Siddique & Khan, 2011). The performance of CCW in geopolymer concrete depends on factors such as particle size, degree of pre-treatment, and chemical consistency. Proper processing increases its reactivity and ensures uniform behavior within the binder system.

1.3 Geopolymerization and Role of Alkaline Activators

The formation of geopolymer concrete is initiated by the dissolution of silicon and aluminum species from the precursor materials, a process driven by alkaline activators. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are the most commonly used activators, and their composition, concentration, and proportion significantly influence compressive strength development (Siddique & Khan, 2011). Studies have shown that the compressive strength of geopolymer concrete increases with the molarity of sodium hydroxide. For instance, raising NaOH concentration from 8M to 14M can improve strength by approximately 24% in natural pozzolana-based geopolymers (Rao et al., 2013). Strength is also strongly dependent on the alkaline-to-aluminosilicate ratio (AAR), with optimum combinations of activator concentration and AAR producing maximum compressive strength after standard curing periods.

A study reported a maximum compressive strength of 39.95 MPa at 28 days using a 0.7 AAR and 14M NaOH (Rao et al., 2013). The combination of NaOH and Na_2SiO_3 has been consistently shown to yield superior mechanical performance compared to using either activator alone (Siddique & Khan, 2011). For example, early strength development in fly ash-based geopolymers increased from 7.1 MPa at 7 days using NaOH alone to 33.33 MPa when combined with Na_2SiO_3 at 12M NaOH concentration (Temuujin et al., 2010). The combination of these activators promotes the formation of both amorphous and crystalline gels, which contribute to a denser binder matrix and enhanced compressive strength (Siddique & Khan, 2011). The proportion of sodium silicate also affects strength development. Using Na_2SiO_3 alone can achieve high compressive strength (up to 62.9 MPa), but it may negatively affect workability due to its high viscosity. Conversely, a combined activator system of NaOH and Na_2SiO_3 produces geopolymers with improved workability, reduced pore size, lower water absorption, and better overall mechanical performance (Siddique & Khan, 2011; Temuujin et al., 2010). Overall, the alkaline activator system plays a critical role in geopolymerization by controlling the dissolution of aluminosilicate precursors, gel formation, and polycondensation processes, directly influencing the compressive strength of geopolymer concrete.

1.4 Compressive Strength Development in Geopolymer Concrete

Compressive strength is one of the most important performance indicators of geopolymer concrete, reflecting its structural capacity and binder efficiency. The strength of geopolymer concrete depends primarily on the type and proportion of precursor materials, the presence of calcium-rich additives, the composition and concentration of alkaline activators, and curing conditions (Siddique & Khan, 2011). Sugarcane bagasse ash (SBA), as a silica-rich precursor, contributes to strength development through the formation of an aluminosilicate network during geopolymerization.

The incorporation of calcium carbide waste (CCW) further enhances compressive strength by supplying calcium ions that promote the formation of additional calcium silicate hydrate (C–S–H) phases, resulting in a denser and stronger binder matrix (Temuujin et al., 2010). The concentration and combination of alkaline activators, particularly NaOH and Na_2SiO_3, directly influence strength gain. Higher NaOH molarity and optimal Na_2SiO_3-to-NaOH ratios accelerate dissolution and polycondensation, forming a more cohesive three-dimensional aluminosilicate structure (Siddique & Khan, 2011). Studies have shown that geopolymer mixes with combined activators consistently achieve higher compressive strength compared to those using single activators (Rao et al., 2013) Compressive strength also increases with curing age. Early-age strength is influenced by the availability of reactive calcium and the activator system, while later-age strength is governed by continued polycondensation and gel densification. The synergistic effect of SBA and CCW, combined with an optimized alkaline activator system, allows geopolymer concrete to achieve compressive strengths comparable to or exceeding conventional OPC concrete, demonstrating its potential for sustainable construction applications (Siddique & Khan, 2011; Temuujin et al., 2010).

II. MATERIALS AND METHODS

2.1 Binder Materials

Sugarcane Bagasse Ash (SBA) was collected as a by-product from the combustion of sugarcane bagasse at a local sugar processing plant. The ash was first air-dried and then subjected to controlled calcination at 600°C to remove unburned residues. It was subsequently passed through a 75 µm sieve to ensure uniform particle size. It had a bulk density of 1020kgm^3 and specific gravity of 2.2. X-ray fluorescence (XRF) analysis revealed that SBA is primarily composed of silica (SiO_2), which makes it suitable as a binder and contributes to strength development in geopolymer concrete (Siddique & Khan, 2011).

Calcium Carbide Waste (CCW) was obtained from acetylene gas production and processed by drying and fine grinding to improve its reactivity in the concrete matrix. It had a bulk density of 1200kgm^3 and specific gravity of 2.50. XRF results confirmed that CCW contains a high proportion of calcium, mainly in the form of calcium hydroxide ($Ca(OH)_2$). The presence of this calcium phase enhances the formation of binding gels and contributes to the compressive strength of the geopolymer concrete (Temuujin et al., 2010). The prepared SBA and CCW powders are shown together in Fig. 1.

Fig. 1: Prepared binder materials: SBA and CCW

2.2 Alkaline Activators

The geopolymerization process requires a highly alkaline environment, which was provided using a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. The NaOH solution was prepared at a concentration of 16 M, while the sodium silicate solution had a SiO_2/Na_2O ratio of 2.5, based on prior studies showing optimal strength development (Siddique & Khan, 2011). Sodium hydroxide was obtained in flake form with 99% purity and dissolved in tap water to prepare the 16 M solution. For this, 640 g of NaOH flakes were dissolved per liter of water, calculated from the product of molarity and molecular weight (40 g/mol). The solution was allowed to cool to room temperature before mixing with the sodium silicate solution and binder materials.

2.3 Aggregates

Both fine and coarse aggregates were used in the mix. The fine aggregate consisted of river sand passing through a 4.75 mm sieve, while the coarse aggregate comprised crushed granite with a maximum size of 20 mm. The aggregates were analyzed to ensure compliance with ASTM C33 requirements for particle size distribution.

2.4 Mix Proportions

Unlike ordinary Portland cement (OPC) concrete, geopolymer concrete does not have a universally established mix design method. In this study, Scheffé's simplex lattice design was employed to generate the mix proportions. This statistical approach is particularly suitable for mixture experiments, where the performance of the system depends on the relative proportions of the components rather than their absolute quantities (Siddique & Khan, 2011). Sugarcane Bagasse Ash (SBA) and Calcium Carbide Waste (CCW) were used as the binder system, with CCW replacing SBA at 0%, 5%, 10%, and 15% by weight. Fine and coarse aggregates were kept constant across all mixes. The alkaline activator solution, consisting of 16 M sodium hydroxide and sodium silicate ($SiO_2/Na_2O = 2.5$), was added at a fixed solution-to-binder ratio to maintain workability and ensure adequate geopolymerization. The final mix proportions were determined based on the optimization procedure, aiming to maximize compressive strength while maintaining consistency and workability. Cubes were cast for testing at 7, 14, 28, and 56 days of curing to evaluate the compressive strength development.

For the seven-component system studied, a polynomial degree of three was used in the simplex lattice design. Each vertex of the simplex corresponds to a pseudo-component (X_i), which was mapped to actual material components (Z_i) as follows: X_1 → water-to-binder ratio (W/B), X_2 → sodium hydroxide (NaOH, kg/L of water), X_3 → sodium silicate (Na_2SiO_3, kg/L of water), X_4 → sugarcane bagasse ash (SBA), X_5 → calcium carbide waste (CCW), X_6 → fine aggregate (sand), and X_7 → coarse aggregate (granite). The mixture fractions were constrained to satisfy $\sum_1^7 x_i = 1$ with $x_i \geq 0$ for all i, ensuring positive and normalized proportions. The transformation from pseudo-components (X_i) to actual component values (Z_i) was performed using the linear relation $Z = X A^T$, where X is the vector of pseudo-components, A^T is the transpose of the trial coefficient matrix, and Z represents the actual material quantities. Four representative mixes were achieved for experimental evaluation: the control mix (Z1) and three variations where SBA was partially replaced with CCW at 5%, 10%, and 15% (Z2, Z3 and Z4). The details of these selected mixes are provided in Table 1 and table 2.

Table 1: Selected Geopolymer Concrete Mixes for Experimental Study

	Pseudo Components							Real Components						
Mix	X1	X2	X3	X4	X5	X6	X7	Z1	Z2	Z3	Z4	Z5	Z6	Z7
Z1	1	0	0	0	0	0	0	0.51	0.04	0.09	1	0	1	2
Z2	0	1	0	0	0	0	0	0.52	0.04	0.09	0.95	0.05	1	2
Z3	0	0	1	0	0	0	0	0.53	0.04	0.09	0.9	0.1	1	2
Z4	0	0	0	1	0	0	0	0.54	0.04	0.1	0.85	0.15	1	2

Table 2: Laboratory quantities for Sample Production

Mix	Water	NaOH (kg/L of Water)	Na2SiO3 (kg/L of Water)	SBA	CCW	Fine Aggregate	Coarse Aggregate	Unit
Z1	0.4516	0.231	0.5776	0.8856	0	1.4326	3.0388	kg
Z2	0.4646	0.2423	0.6058	0.8413	0.0521	1.4326	3.0388	kg
Z3	0.4776	0.2539	0.6348	0.797	0.1042	1.4326	3.0388	kg
Z4	0.4909	0.2659	0.6647	0.7527	0.1563	1.4326	3.0388	kg

2.5 Mixing, Casting, and Curing of Geopolymer Concrete

All geopolymer concrete specimens were prepared in accordance with ASTM C192/C192M-19. Aggregates were first brought to a saturated surface dry (SSD) condition. The control mix consisted of a binder containing only sugarcane bagasse ash (SBA), while other mixes incorporated partial replacement of SBA with calcium carbide waste (CCW) at 5%, 10%, and 15%. The dry binder was first combined with fine and coarse aggregates, after which the alkaline activator solution, prepared by mixing 16 M sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) at a fixed ratio of 2.5, was gradually added. The NaOH solution was prepared in advance by dissolving flakes with 99% purity in potable water and allowing it to cool to room temperature. Additional water was added as needed to achieve a uniform and workable mix. The fresh geopolymer concrete was cast into 150 mm × 150 mm cube molds and compacted to remove entrapped air and ensure proper consolidation. A total of 48 cubes were cast for compressive strength evaluation at 7, 14, 28, and 56 days. After casting, the specimens were left in the molds under ambient laboratory conditions for 24 hours to allow initial setting, followed by heat curing in an oven at 60 °C for 48 hours to promote geopolymerization, enhance early-age strength development, and ensure uniform hardening. After heat curing, specimens were stored under ambient laboratory conditions until the designated compressive strength testing ages.

2.6 Compressive Strength Testing

The density of the hardened geopolymer concrete specimens were first determined according to ASTM C1326 (2003). After an initial setting period of 24 hours, all specimens were subjected to oven curing at 60 °C for 48 hours and then allowed to air-dry at room temperature until the designated testing ages. The density was calculated using the relationship: Density= M/V. Where M is the mass of the concrete specimen in kilograms (kg) and V is its volume in cubic meters (m^3). Density values were recorded to monitor changes over time, with slight reductions expected due to continued drying.

Compressive strength was then determined in accordance with ASTM C39/C39M-20. Cube specimens measuring 150 mm × 150 mm × 150 mm were tested at curing ages of 7, 14, 28, and 56 days using a universal testing machine (UTM) at a constant loading rate of 0.5 MPa/s. The maximum load at failure (P) was recorded in kilonewtons (k_N), and the compressive strength was calculated using the formula: Fc = P/A. where A is the cross-sectional area of the cube. The resulting compressive strength values are reported in megapascals (MPa). For each curing age, the average of three specimens per mix was taken to ensure reliability and reproducibility of the results.

III. RESULTS AND DISCUSSIONS

3.1 Chemical Compositions (XRF)

XRF analysis of the sugarcane bagasse ash (SBA), summarized in Table 3, shows that the combined content of the major oxides (SiO_2 + Al_2O_3 + Fe_2O_3) is 58.7%. The SBA was calcined at 600 °C before testing to reduce unburnt carbon and increase its amorphous silica content, thereby improving its reactivity. According to ASTM C618, the material falls under Class C pozzolana, indicating its suitability as a reactive precursor for geopolymer binders. The calcium carbide waste (CCW) results, also presented in Table 3, reveal a high concentration of calcium oxide (CaO) at 75.67%, classifying it as a highly calcareous material. Although not pozzolanic, its elevated calcium content facilitates the formation of C–A–S–H and N–C–A–S–H gels, enhancing early strength development in geopolymer concrete. Overall, the silica-rich SBA and calcium-rich CCW complement each other, making them suitable for blended geopolymer binder systems.

Table: 3: Chemical Properties of SBA and CCW

Property	SBA	CCW
SiO_2 (%)	50.08	6.13
Fe_2O_3 (%)	5.21	0.5
Al_2O_3 (%)	3.39	1.24
SO_3	0.10	0.29
CaO (%)	4.30	75.67
MgO (%)	7.42	1.14
CeO_2	4.84	4.80
K_2O	9.61	0.10
LOI (%)	4.00	-

3.2 Flow Characteristics of Geopolymer Concrete

The fresh concrete properties of the geopolymer concrete (GPC) were evaluated using the flow table test in accordance with BS 1881-105 (1984) to assess its ease of handling, placement, and compaction. The results illustrated in Fig. 2, show a gradual increase in flow spread with increasing CCW content. This improvement in flow is attributed to the optimized mix proportions, which introduced slightly higher quantities of water and alkaline activator to balance the finer particle size and higher density of CCW compared to SBA. While SBA tends to absorb part of the available liquid due to its porous structure, CCW can chemically bind water through the conversion of CaO to $Ca(OH)_2$. The optimization method ensured that all mixtures retained adequate plasticity despite these differences in material behavior. Overall, the measured flow values place the mixes within the low-to-medium flow range, which is suitable for proper placement and compaction of geopolymer concrete.

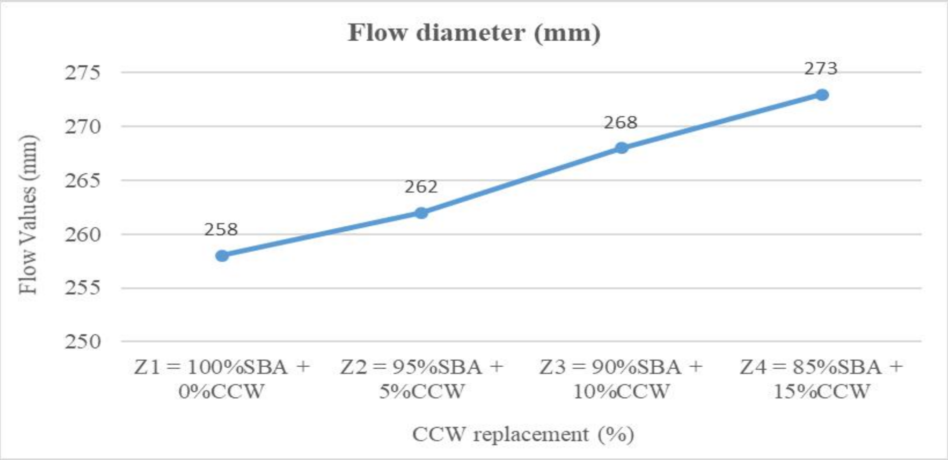


Fig. 2: Flow values of fresh concrete mix

3.3 Density of Hardened Geopolymer Concrete

The densities of the hardened GPC specimens were measured at 7, 14, 28, and 56 days, using the average of three cubes per age. All specimens were oven-cured at 60 °C for 48 hours after the initial 24-hour set and then air-dried until testing. As shown in Fig. 4.3, density slightly decreased with age due to gradual moisture loss. Mixes containing higher CCW levels recorded marginally higher densities, reflecting the higher specific gravity and finer particle packing of CCW compared to SBA. Overall densities ranged from about 2040 to 2060 kg/m³, indicating a lighter-weight geopolymer concrete relative to conventional OPC concrete (~2400 kg/m³), while still maintaining good matrix compactness.

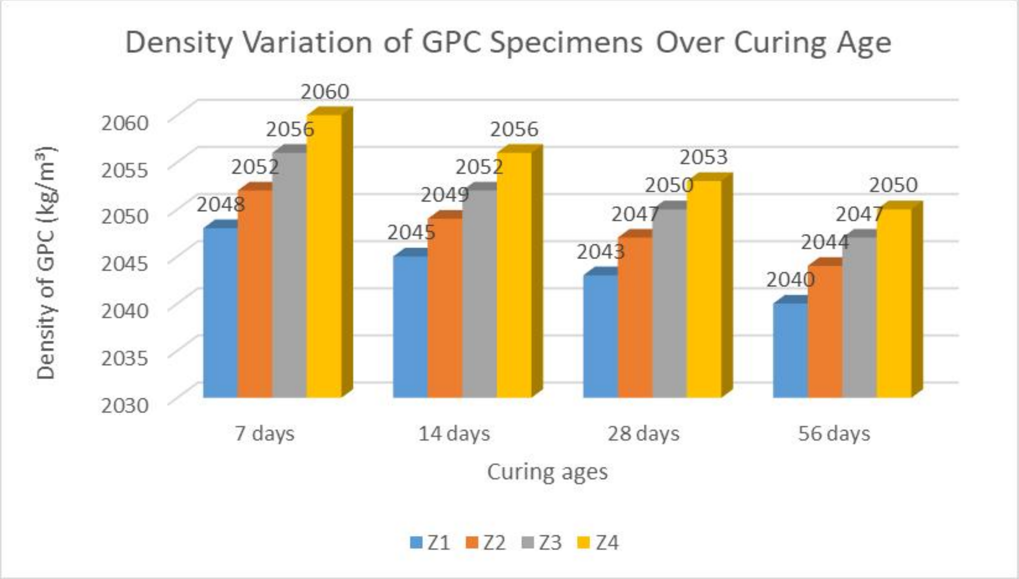
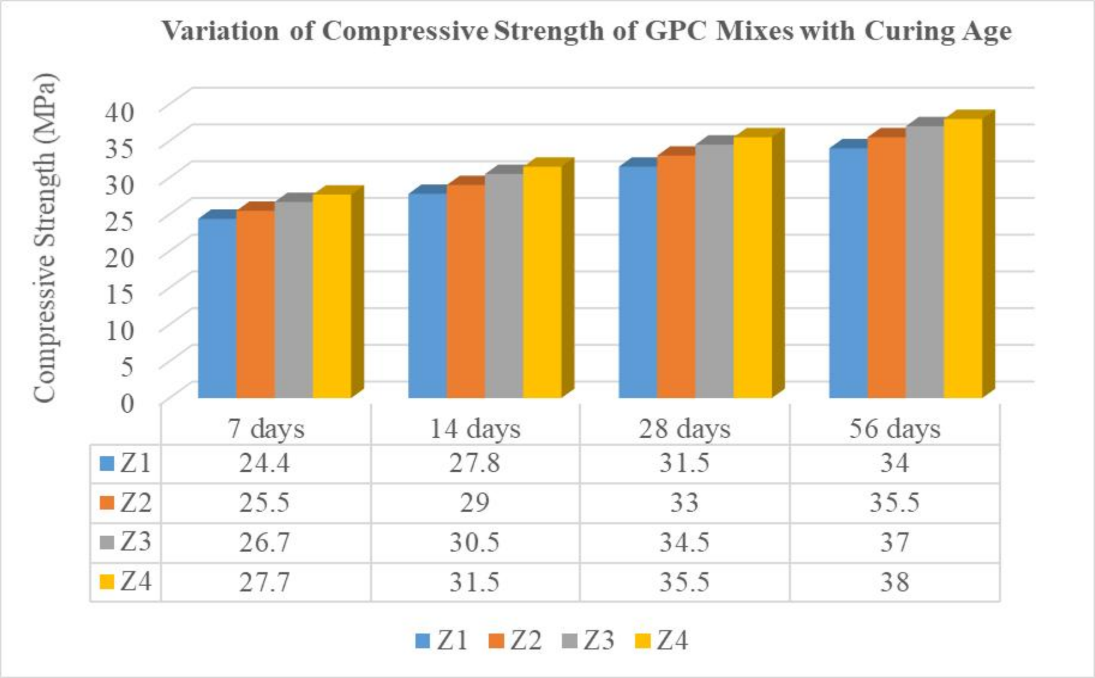


Fig. 3: Density variation of GPC Specimens over curing age

3.4 Compressive Strength Development

The compressive strength of the geopolymer concrete mixes Z_1 (0% CCW), Z_2 (5% CCW), Z_3 (10% CCW), and Z_4 (15% CCW) was evaluated at 7, 14, 28, and 56 days. All mixes showed a steady increase in strength with curing age, reflecting the continued geopolymerization process and the progressive formation of binding gels such as N–A–S–H and C–A–S–H. At 7 days, the mixes developed moderate early strength, which increased substantially by 14 days. This early strength improvement is linked to the high alkalinity of the 16M NaOH activator, which enhances dissolution of the SBA and CCW particles. Similar findings were reported in previous studies [50, 51], where higher NaOH molarity and the combined use of NaOH and Na_2SiO_3 significantly improved strength development in geopolymer systems. The heat-curing regime used (60 °C for 48 hours) further accelerated reaction rates and promoted faster strength gain, consistent with observations in earlier research [45]. Fig. 4. illustrates the compressive strength variation with curing age for all mixes (Z_1–Z_4). The results confirm that SBA and CCW are compatible and effective as geopolymer precursors, producing concrete with satisfactory and steadily increasing strength over time.



	7 days	14 days	28 days	56 days
■ Z1	24.4	27.8	31.5	34
■ Z2	25.5	29	33	35.5
■ Z3	26.7	30.5	34.5	37
■ Z4	27.7	31.5	35.5	38

Fig.4: Variation of Compressive Strength of GPC Mixes with Curing Age

3.5.1 Effect of CCW on Compressive Strength Development

Fig. 5 shows the percentage increase in compressive strength of the CCW-modified mixes (Z_2–Z_4) relative to the control mix (Z_1) at 7, 14, 28, and 56 days. All mixes recorded steady strength development with age, confirming ongoing geopolymerization throughout the curing period. Incorporating CCW led to consistent strength improvement up to 15% replacement, with gains of 13.5%, 13.3%, 12.7%, and 11.8% at 7, 14, 28, and 56 days, respectively, compared to the control. The enhancement is attributed to the high calcium content of CCW, which promotes additional formation of C–A–S–H and N–C–A–S–H gels, thereby accelerating the geopolymerization process. This agrees with previous findings by (Ganesan et al., 2018) who showed that calcium-rich additives increase reactivity and contribute to improved matrix densification. Although strength increased with higher CCW content, the incremental percentage gain decreased as the replacement level approached 15%. At 7 days, the increase from Z_2 to Z_3 was 4.7%, but reduced to 3.7% from Z_3 to Z_4. Similar reductions were observed at later ages:

- 14 days: 5.2% ($Z_2 \rightarrow Z_3$) dropping to 3.3% ($Z_3 \rightarrow Z_4$)
- 28 days: 4.5% reducing to 2.9%
- 56 days: 4.2% reducing to 2.7%

This indicates that although CCW improves compressive strength, the efficiency of improvement diminishes at higher replacement levels. Such behavior aligns with observations by (Gaddam Kalpana et al., 2025) who reported a decline in strength beyond optimal CCW dosage (e.g., at 20% replacement) in fly ash–CCW geopolymer systems. Overall, CCW contributes positively to both early and later-age strength development, but its optimal effect is achieved at moderate replacement levels.

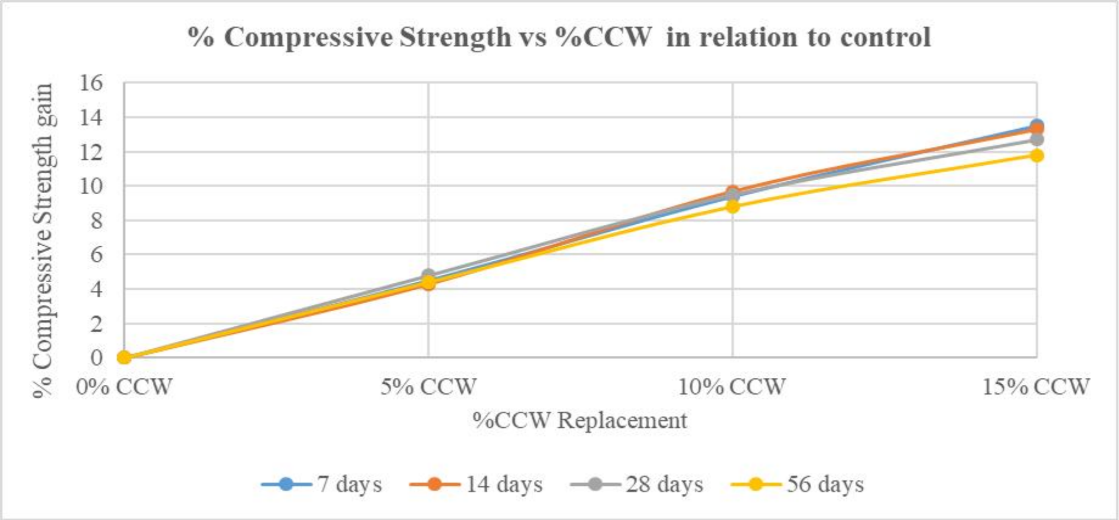


Fig.5: Effect of CCW on Compressive Strength

IV. CONCLUSION & RECOMMENDATIONS

4.1 Conclusion

Based on the results of this study on geopolymer concrete produced with sugarcane bagasse ash (SBA) and calcium carbide waste (CCW), the following conclusions can be drawn:

i. XRF analysis showed that SBA is rich in silica, alumina, and iron oxides, with a combined content of 58.7%, while CCW is predominantly calcium oxide (75.67%), supporting their complementary use as geopolymer precursors.

ii. The fresh geopolymer concrete exhibited satisfactory flow, which increased with CCW content, ranging from 258 mm for the control mix (0% CCW) to 273 mm for the 15% CCW mix, indicating adequate workability for all mixes.

iii. The density of hardened geopolymer concrete increased slightly with CCW replacement, ranging from approximately 2040 kg/m³ for the control mix to 2060 kg/m³ for the 15% CCW mix at 56 days, reflecting the denser nature of CCW compared to SBA.

iv. Compressive strength improved progressively with curing age for all mixes. The control mix (0% CCW) increased from 24.4 MPa at 7 days to 34 MPa at 56 days, while the 15% CCW mix increased from 27.7 MPa at 7 days to 38 MPa at 56 days.

v. Partial replacement of SBA with CCW enhanced compressive strength, with the greatest gains observed at 15% replacement. CCW, being calcium-rich, contributed to improved gel formation and matrix densification, supporting stronger geopolymer concrete.

4.2 Recommendations

Partial replacement of sugarcane bagasse ash with calcium carbide waste (CCW) up to 15% is recommended to enhance compressive strength and density while maintaining adequate workability in geopolymer concrete production. Future studies should focus on determining the optimal CCW replacement level for maximizing mechanical performance, as well as optimizing curing conditions, assessing long-term strength, and conducting field trials to validate practical applicability.

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