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Performance of Concrete with Coconut Shell Ash and Retarder, Plasticiser and Super-Plasticiser for Sustainable Concrete Development

[1*]Oriola, Q. O., [2]Adeniran-Bakare S.M., and [3] Adebayo, A. O.

[1, 2] Department of Civil Engineering, Yaba College of Technology, Yaba, Lagos, Nigeria.
[3]Department of Civil Engineering, Ladoke Akintola University of Science and Technology, Ogbomoso, Oyo, Nigeria.

* Corresponding Author E-mail: qudusoriola2020@gmail.com Tel: 07017800371

Abstract

The increasing demand for sustainable construction materials necessitates the evaluation of alternative cementitious materials to improve concrete performance and environmental efficiency. This study investigated the utilization of coconut shell ash as partial cement replacement combined with chemical admixtures such as retarder, plasticiser and super-plasticiser dosage at 0.2%, 0.8% and 0.8% respectively by weight of cement to enhance concrete properties. Concrete materials including sand, granite, cement, and coconut shell ash at 10%,20% and 30% by weight of cement were characterized for moisture content, bulk density, and chemical composition. Mix proportioning of 1:2:4 was adopted, and 36 cubes were cast per mix using varying replacement levels. Fresh concrete properties were assessed through slump, compaction, and setting time tests, while hardened properties were evaluated through density, compressive strength, and soundness at 7, 14, and 28 days curing using standard laboratory equipment. Slump values ranged from 51–143 mm, compaction masses varied between 16.9–18.8 g, and setting times ranged from 220–390 min. Density values ranged from 2.32–2.52 kg/m³, compressive strength varied from 6.60–36.70 N/mm², and soundness ranged between 0.2–0.9 mm across all mixes and curing ages. Coconut shell ash up to 10% replacement improved overall performance, while higher percentages reduced strength. Chemical admixtures enhanced workability and stability, indicating CSA suitability for sustainable concrete development.

Keywords: Coconut shell ash, concrete properties, compressive strength, workability, chemical admixtures, pozzolanic material, sustainability.

Introduction

The increasing demand for sustainable construction materials has intensified the search for environmentally benign alternatives to conventional cementitious constituents, particularly in response to the high carbon emissions associated with Ordinary Portland Cement production (Abera, 2024). Cement manufacturing contributes significantly to global CO_2 emissions, thereby necessitating the exploration of supplementary materials capable of reducing clinker content while maintaining performance characteristics (Abdul-Wahab *et al.*, 2021). Within this context, numerous studies have emphasized the viability of industrial and agricultural by-products such as fly ash, silica fume, and ground granulated blast furnace slag, which exhibit notable pozzolanic or latent hydraulic properties that enhance durability and long-term strength development (Tariq and Bahadori-Jahromi, 2025; Huynh and Van 2025). These materials have demonstrated the capacity to refine pore structure, reduce permeability, and improve resistance to aggressive environmental conditions, thereby forming the foundation of contemporary sustainable concrete technology (Rusnak, 2025).

In parallel, increasing attention has been directed toward bio-based materials derived from agricultural and organic waste streams, which offer the dual advantage of waste valorization and environmental conservation (Blasi *et al.,* 2023). Coconut shell ash, obtained from the controlled combustion of coconut shells, is one such material whose composition is typically rich in silica, alumina, and minor oxides, depending on processing conditions (Ikumapayi *et al.,* 2020). These oxides suggest a potential for pozzolanic reactivity when finely processed and incorporated into cementitious systems. However, unlike extensively studied materials such as rice husk ash and calcined clay, whose reactivity and durability contributions have been well established (Jhatial *et al.,* 2023; Rakhimova, 2020), coconut shell ash remains relatively underexplored, particularly in relation to its long-term durability performance in concrete. Its microstructural behaviour, degree of amorphous silica formation, and interaction with hydration products are still subjects requiring systematic investigation (Ünal, 2024).

Furthermore, the role of chemical admixtures in modifying the performance of cementitious composites has been widely documented, particularly in enhancing workability, controlling setting characteristics, and improving durability-related properties such as resistance to chloride ingress and sulfate attack (Shaik, 2026). Conventional admixtures, including superplasticisers and water-reducing agents, facilitate lower water–cement ratios, thereby contributing to denser microstructures and improved durability (Anudeep *et al.,* 2024). When combined with supplementary cementitious materials, these admixtures can significantly influence hydration kinetics and microstructural development (Raghav *et al.*, 2021). However, the interaction between chemical admixtures and emerging bio-based ashes such as coconut shell ash is not yet fully understood, especially in terms of synergistic or antagonistic effects on durability performance (Bedada *et al.,* 2023).

Moreover, durability remains a critical parameter in assessing the long-term performance of concrete structures, particularly under exposure to aggressive environmental conditions such as carbonation, chloride penetration, and sulfate attack (Ekwuno, 2025). Extensive research on conventional supplementary materials has demonstrated their ability to enhance durability through pore refinement and reduced permeability (Win *et al.,* 2024). In contrast, limited empirical data exist regarding the durability implications of incorporating coconut shell ash, especially when combined with chemical admixtures (Okeke *et al.*, 2025). Consequently, while its chemical composition suggests potential functionality, its actual performance must be rigorously evaluated within established durability frameworks to determine its suitability as a partial cement replacement (Sangoju *et al.,* 2021).

Furthermore, despite the growing body of knowledge on sustainable cementitious materials, there remains a notable gap regarding the integration of less conventional bio-based ashes such as coconut shell ash into durable concrete systems. Existing studies have predominantly focused on widely accepted materials, leaving the behaviour of alternative organic ashes insufficiently characterised. Consequently, the lack of comprehensive data on the durability performance of coconut shell ash, particularly in synergy with chemical admixtures, poses a significant limitation to its adoption in engineering practice. This gap highlights the need for systematic experimental investigations that align with established durability assessment methods.

Thus, the significance of this study lies in its potential to extend the current understanding of sustainable concrete by examining coconut shell ash not as a proven material, but as a promising bio-based alternative whose properties require validation. By situating the investigation within the context of well-documented supplementary cementitious materials, the study contributes to bridging the gap between theoretical potential and practical applicability. Additionally, the findings are expected to provide insights into the role of chemical admixtures in optimizing the performance of such emerging materials, thereby informing sustainable material design strategies.

Materials and Methods

Study Area

The experimental investigation was conducted at the soil mechanics laboratory, Yaba College of Technology, Lagos State, Nigeria. All procedures were executed under controlled laboratory conditions to ensure uniformity in material behaviour and reproducibility of results. The laboratory is equipped with standard facilities for concrete production, curing, and testing in both fresh and hardened states.

Sample Collection and Preservation

Portland Limestone Cement (PLC), fine aggregate (sand), and coarse aggregate (granite) were obtained from certified local suppliers within Ekiti State, Nigeria, while coconut shell ash (CSA) was produced from locally sourced agricultural waste. The CSA was properly calcined, sieved, and stored in airtight containers to prevent moisture ingress and contamination prior to use. Chemical admixtures comprising lignosulfonate (retarder), sulphonated naphthalene formaldehyde (superplasticiser), and plastiment R (plasticiser) were procured from authorised distributors and preserved under ambient laboratory conditions in accordance with manufacturer specifications.

Material Preparation and Mix Proportioning

Prior to concrete production, all aggregates were air-dried and their moisture content determined to ensure appropriate correction during batching. Bulk density measurements were also carried out to establish accurate volumetric-to-mass relationships for mix design. Cement was partially replaced with CSA ash at 10%, 20% and 30% by weight of cement, while chemical admixtures retarder, plasticiser and super-plasticiser were introduced at 0.2%, 0.8% and 0.8% respectively by weight of cement to modify fresh and hardened properties of the concrete. The concrete mix was proportioned using a nominal ratio of 1:2:4 (cement: sand: granite). Batching of materials was performed by weight using a digital weighing balance (EK-2000i, A&D Company Ltd., Japan, accuracy ±0.01 kg). Mixing was carried out manually using shovel until a homogeneous mixture was achieved. Water was added gradually during mixing to attain the desired workability. The fresh concrete was then placed into steel cube moulds of 150 mm × 150 mm × 150 mm conforming to BS EN 12390-2:2019 standards and compacted using steel rod of 20mm to eliminate air voids.

Characterisation of Materials

The chemical composition of PLC and CSA were determined using X-ray fluorescence spectrometry (Axios Max, PANalytical, Netherlands) to establish their oxide composition relevant to cementitious and pozzolanic activity. Aggregate properties, including moisture content and bulk density, were determined using standard laboratory procedures and equipment prior to mix preparation to ensure accuracy in proportioning and water correction.

Experimental Procedures and Testing

Fresh concrete properties were assessed immediately after mixing. Workability was determined using the slump test conducted with a standard slump cone apparatus (300 mm height, BS EN standard, UK), while compaction behaviour was evaluated by comparing fully and partially compacted states of the fresh concrete. Setting time characteristics were determined using a Vicat apparatus, where penetration resistance was measured at regular intervals to obtain both initial and final setting times as shown in Plate 2.

Plate 2: Setting time test.

For hardened concrete evaluation, all specimens were cured in a water curing tank maintained at 27 ± 2°C. Density determination was carried out by measuring the mass and volume of hardened cubes using a digital weighing balance (XK3190-A12E, Yaohua, China). Compressive strength testing was performed using a universal compression testing machine with a capacity of 2000 kN (ADR Touch Control, ELE International, UK) as depicted in Plate 3, in which each specimen was subjected to axial loading until failure. Soundness testing was conducted using the Le Chatelier apparatus (Controls Group, Italy) to evaluate the dimensional stability of the cementitious system under controlled conditions.

Plate 3: Compressive strength test

Results and Discussion

Physical Properties

The moisture content results indicate that sand recorded a value of 3.00%, whereas granite exhibited a lower value of 1.06%. This difference reflects the inherent variability in water retention characteristics between fine and coarse aggregates. Specifically, the higher moisture content in sand can be attributed to its finer particle size and larger specific surface area, which increases its capacity to hold water within intergranular spaces. In contrast, granite, with its coarser texture and reduced surface exposure, retains significantly less moisture. This variation is critical in concrete production, as unaccounted free moisture in sand may alter the effective water content of the mix, thereby influencing workability and hydration behaviour. A similar trend was reported by He *et al.* (2025), who observed that fine aggregates typically contribute more free water to concrete mixtures, thereby necessitating moisture correction during batching to maintain mix consistency.

Similarly, the bulk density results show that sand recorded 1533 kg per cubic metre, while granite recorded 1500 kg per cubic metre as presented in Table 1. The slightly higher bulk density of sand suggests more efficient packing of particles and reduced void content compared to the coarse aggregate. This behaviour can be associated with the better gradation and closer particle arrangement typically observed in fine aggregates. On the other hand, granite exhibits a marginally lower bulk density due to the presence of larger interparticle voids and irregular particle geometry, which reduce overall packing efficiency. This observation aligns with the findings of Dehghan *et al.* (2021) who reported that aggregate size distribution and particle arrangement significantly influence bulk density, which in turn affects concrete proportioning accuracy, workability, and volumetric stability during mixing and placement.

Table 1: Moisture Content of Aggregates

Aggregate Type	Moisture Content (%)	Bulk Density (kg/m³)
Sand (Fine Aggregate)	3.00	1533
Granite (Coarse Aggregate)	1.06	1500

Chemical Composition of Materials

The chemical composition results presented in Table 2 reveal a distinct variation between Portland Limestone Cement (PLC) and Coconut Shell Ash (CSA). PLC was characterized by a dominant calcium oxide content of 64.00 percent, which is essential for primary hydration reactions and early strength development in cementitious systems. In contrast, CSA contains a significantly lower CaO content of 4.95 percent, indicating limited primary hydraulic activity. However, CSA exhibits higher proportions of silica and alumina, with values of 37.67 percent and 24.42 percent respectively, the combined SiO_2, Al_2O_3 and Fe_2O_3 content of CSA was 76.57%, exceeding the minimum 70% requirement specified by ASTM C618 for natural pozzolans. This confirms its potential as a supplementary pozzolanic material capable of participating in secondary hydration reactions. This compositional trend implies that CSA may contribute more significantly to long-term strength development rather than early-age performance. This study was limited to 28-days strength due to project time constraints; further research should evaluate the long-term strength and durability performance of CSA concrete at extended curing ages (56,90 and 180 days). A similar observation was reported by Nadir and Ahmed (2021) who noted that agricultural ashes with elevated SiO_2 and Al_2O_3 contents tend to enhance pozzolanic reactivity when used as partial cement replacements.

Furthermore, the presence of iron oxide at 14.48 percent in CSA is considerably higher than that of PLC, which recorded 3.25 percent. This elevated Fe_2O_3 content may influence the coloration and microstructural characteristics of the resulting concrete matrix, although its direct contribution to strength development is relatively limited. Additionally, the alkali content in CSA is higher at 0.80 percent compared to 0.45 percent in PLC, which may have implications on durability if not properly controlled within mix proportions. Similar findings were reported by Be Okeke *et al.* (2025) who observed that elevated alkali levels in agro-based ashes may affect long-term durability performance if not adequately balanced within cementitious systems.

Table 2: Chemical Composition of Materials

Oxide Composition (%)	PLC	CSA
MgO	1.60	1.79
CaO	64.00	4.95
SiO_2	20.50	37.67
Al_2O_3	6.75	24.42
SO_3	1.75	0.81
MnO	0.30	0.84
Fe_2O_3	3.25	14.48
Alkalis / K_2O	0.45	0.80
Others	1.40	14.24

Fresh Properties of Concrete

Slump Test

The slump test results presented in Table 3 indicate a progressive reduction in workability with increasing coconut shell ash (CSA) content across all mix combinations. For the retarder-based mixes, slump values decreased from 72 mm at 10 percent CSA to 68 mm at 20 percent CSA and further to 51 mm at 30 percent CSA. A similar trend was observed in the superplasticiser mixes, where slump reduced from 143 mm to 125 mm and then to 102 mm as CSA content increased. Likewise, the plasticiser mixes recorded a decrease from 81 mm to 74 mm and 63 mm across the same replacement levels. This reduction in slump can be attributed to the increasing proportion of CSA, which tends to absorb more mixing water due to its porous nature and irregular particle structure, thereby reducing free water available for lubrication within the mix. Comparable behaviour was reported by Mirzaei *et al.* (2025) who observed that agricultural ash incorporation in concrete mixtures generally leads to reduced workability due to increased water demand and particle friction.

Furthermore, the control mixes containing only PLC and admixtures also exhibit relatively higher slump values compared to CSA-modified mixes, with PLC plus superplasticiser recording the highest value of 117 mm. This confirms the effectiveness of chemical admixtures in enhancing workability by dispersing cement particles and reducing flocculation. However, the introduction of CSA consistently offsets this improvement, indicating a dominant influence of the ash on rheological behaviour. Similar findings were documented by Bhandari *et al.* (2023), who reported that while superplasticisers improve flow characteristics of cementitious systems, their effectiveness may be partially reduced in the presence of highly absorptive supplementary cementitious materials.

Table 3: Slump Test Results

Mix Composition	10% CSA	20% CSA	30% CSA
Retarder (Lignosulfonate)	72	68	51
Superplasticiser (SNP)	143	125	102
Plasticiser (Plastiment R)	81	74	63
CSA Only	66	64	57
PLC + Retarder Only	85	80	75
PLC + Superplasticiser Only	117	105	95
PLC + Plasticiser Only	95	88	82

Compaction Factor Test

The compaction test results presented in Table 4 indicate variations in the mass of concrete under fully and partially compacted conditions across different mix compositions and coconut shell ash (CSA) replacement levels. For the retarder-based mixes, the fully compacted values ranged from 18.8 to 18.3 and 18.6 as CSA content increased from 10 percent to 30 percent, while the partially compacted values varied from 18.1 to 17.9 and 18.2. A similar pattern is observed in the superplasticiser and plasticiser mixes, where slight reductions in fully and partially compacted masses occur with increasing CSA content, although the variations are relatively moderate. This behaviour suggests that increasing CSA content influences the internal packing arrangement of the fresh concrete, likely due to the irregular particle shape and higher surface area of the ash, which affects particle mobility during compaction. Comparable observations were reported by Meko *et al.*, (2021), who noted that supplementary cementitious materials tend to modify compaction behaviour by increasing internal friction and reducing ease of particle rearrangement in fresh concrete.

In contrast, the CSA-only mixes recorded lower compaction values compared to PLC-based systems with chemical admixtures, with fully compacted values ranging from 17.3 to 17.7 and partially compacted values from 16.9 to 17.2. This reduction reflects the absence of cement and admixture enhancement, resulting in reduced cohesion and less efficient particle packing. However, a slight increase in compaction values with higher CSA content was observed within the CSA-only mixes, which may be associated with marginal improvements in particle gradation and packing density at higher replacement levels. Similar findings were documented by Bedada *et al.* (2023), who reported that ash-based concrete systems may exhibit variable compaction characteristics depending on particle distribution and binder interaction, although chemical admixtures generally improve overall compaction efficiency.

Table 4: Compaction Factor Test Results

Mix Composition	Condition	10% CSA	20% CSA	30% CSA
Retarder	Fully	18.8	18.3	18.6
Retarder	Partially	18.1	17.9	18.2
Superplasticiser	Fully	18.8	18.5	18.3
Superplasticiser	Partially	18.3	18.1	18.1
Plasticiser	Fully	18.8	18.4	18.8
Plasticiser	Partially	18.6	17.9	18.6
CSA Only	Fully	17.3	17.4	17.7
CSA Only	Partially	16.9	16.9	17.2

Setting Time Test

The setting time results presented in Table 5 indicate that both initial and final setting times are influenced by the incorporation of coconut shell ash (CSA) and the type of chemical admixture used. For the CSA-based mixes, the final setting time ranges from 365 minutes for CSA with retarder, 335 minutes for CSA with superplasticiser, and 315 minutes for CSA with plasticiser, while the corresponding initial setting times are 275 minutes, 235 minutes, and 220 minutes respectively. This trend suggests that the inclusion of CSA contributes to a reduction in setting time when compared to retarder-controlled systems, particularly when combined with plasticiser and superplasticiser. This behaviour may be attributed to the partial replacement of cement with a supplementary material that alters the hydration kinetics of the binder system, thereby modifying the rate of stiffening. A similar observation was reported by Asante *et al.* (2025) who noted that agricultural-based pozzolanic materials can accelerate or retard setting depending on their interaction with chemical admixtures and cement hydration processes.

In comparison, the PLC control mixes exhibit slightly higher final setting times, particularly the retarder-based mix with a value of 390 minutes, while the superplasticiser and plasticiser mixes recorded 330 minutes and 335 minutes respectively. The corresponding initial setting times also show a similar pattern, with values ranging from 285 minutes to 210 minutes. This indicates that the presence of admixtures significantly influences the hydration process of PLC, with retarders extending the setting duration due to delayed hydration reactions, while plasticiser and superplasticiser reduce the water demand and promote earlier stiffening. This behaviour is consistent with the findings of Raghav *et al.* (2021), who reported that chemical admixtures play a dominant role in controlling cement hydration rates, thereby influencing both initial and final setting times in conventional concrete systems.

Table 5: Setting Time Results

Mix Composition	Final Setting Time (min)	Initial Setting Time (min)
CSA + Retarder	365	275
CSA + Superplasticiser	335	235
CSA + Plasticiser	315	220
PLC + Retarder Only	390	285
PLC + Superplasticiser Only	330	230
PLC + Plasticiser Only	335	210

Hardened Properties of Concrete

Density Test

The density results presented in Table 6 indicate that concrete density varies with both curing age and coconut shell ash (CSA) replacement level across different admixture systems. For the 10% CSA mixes with retarder, density increased slightly from 2.490 at 7 days to 2.515 at 28 days, indicating progressive densification with curing age. However, at higher CSA contents such as 20% and 30%, a general reduction in density was observed across the curing periods, with values reducing from 2.464 to 2.419 and 2.395 to 2.359 respectively. This trend suggests that higher CSA incorporation may introduce increased porosity within the cement matrix, thereby reducing overall unit weight. This behaviour is consistent with the findings of Aggarwal *et al.* (2025), who reported that partial replacement of cement with agro-based pozzolans often results in reduced density due to lower clinker content and incomplete hydration products.

Similarly, the plasticiser and superplasticiser modified mixes show a more stable density development with curing age, particularly at lower CSA replacement levels. For instance, the 20% CSA plus plasticiser mix increased from 2.468 at 7 days to 2.494 at 28 days, while the 10% CSA plus superplasticiser mix recorded relatively stable values around 2.472 to 2.494. This suggests that chemical admixtures improve particle dispersion and packing efficiency, thereby reducing internal voids and enhancing matrix densification. In contrast, the control mix with 0% CSA maintained the highest and most stable density values, ranging from 2.510 to 2.515, indicating the effect of a fully cementitious system without pozzolanic substitution. A similar trend was observed by Wang *et al.* (2026), who noted that admixture-enhanced concrete systems tend to exhibit improved density stability due to better particle distribution and reduced entrapped air content.

Table 6: Density Results

Mix Composition	7 days	14 days	28 days
10% CSA + Retarder	2.490	2.505	2.515
20% CSA + Retarder	2.464	2.441	2.419
30% CSA + Retarder	2.395	2.386	2.359
10% CSA + Plasticiser	2.444	2.464	2.484
20% CSA + Plasticiser	2.468	2.471	2.494
30% CSA + Plasticiser	2.434	2.446	2.495
10% CSA + Superplasticiser	2.472	2.482	2.494
20% CSA + Superplasticiser	2.425	2.454	2.474
30% CSA + Superplasticiser	2.445	2.452	2.461
0% CSA	2.515	2.510	2.514
10% CSA	2.500	2.516	2.519
20% CSA	2.446	2.423	2.395
30% CSA	2.320	2.324	2.540

Compressive Strength

The compressive strength results presented in Table 7 indicate a consistent increase in strength with curing age across all mix compositions, reflecting the progressive hydration of cementitious materials and the contribution of pozzolanic reactions from coconut shell ash (CSA). For the 10% CSA mixes with retarder, strength increased from 22.52 N/mm² at 7 days to 36.70 N/mm² at 28 days, while the superplasticiser mix recorded a similar development from 22.60 N/mm² to 36.60 N/mm² over the same curing period. This indicates that low-level CSA replacement, when combined with chemical admixtures, can still support substantial strength gain, particularly at later ages. A comparable observation was reported by Khanna and Kasilingam, (2025), who noted that low percentage incorporation of agro-based pozzolans can enhance long-term strength due to delayed but continuous pozzolanic activity.

In contrast, increasing CSA content to 20% and 30% resulted in a noticeable reduction in compressive strength across all admixture types. For instance, the 30% CSA plasticiser mix recorded 16.01 N/mm² at 7 days and 24.32 N/mm² at 28 days, while the corresponding superplasticiser mix reached 25.80 N/mm² at 28 days. This reduction may be attributed to the dilution of cement content and insufficient availability of calcium hydroxide for complete pozzolanic reaction at higher replacement levels. Nevertheless, the presence of superplasticiser consistently improved strength development compared to plasticiser and retarder systems, suggesting enhanced particle dispersion and reduced entrapped air. This behaviour aligns with the findings of Wang *et al.* (2024), who reported that high-range water-reducing admixtures significantly improve compressive strength by enhancing workability and promoting denser microstructural formation.

Furthermore, the control mixes containing 0% CSA exhibited mixed performance, with a relatively high 28-day strength of 34.20 N/mm² but lower early-age strengths compared to CSA-modified mixes. This suggests that while PLC-based systems develop strength steadily, the incorporation of CSA at optimal levels can enhance later-age performance through secondary hydration processes. Similar trends were documented by Izadifar *et al.* (2026) who observed that pozzolanic materials may contribute to long-term strength gain even when early-age strength appears lower due to slower reaction kinetics.

Table 7: Compressive Strength Results

Mix Composition	7 days	14 days	28 days
10% CSA + Retarder	22.52	26.12	36.70
20% CSA + Retarder	20.40	23.60	29.60
30% CSA + Retarder	19.40	21.71	26.14
10% CSA + Plasticiser	20.10	24.70	33.70
20% CSA + Plasticiser	17.97	21.10	27.80
30% CSA + Plasticiser	16.01	19.24	24.32
10% CSA + Superplasticiser	22.60	26.90	36.60
20% CSA + Superplasticiser	19.84	24.40	30.60
30% CSA + Superplasticiser	17.30	20.54	25.80
0% CSA	13.66	18.70	34.20
10% CSA	12.90	17.51	31.80
20% CSA	8.64	12.41	19.95
30% CSA	6.60	8.69	13.05

Soundness Test

The soundness results presented in Table 8 indicate variations in dimensional stability across different mix compositions containing coconut shell ash (CSA) and chemical admixtures. For the CSA-retarder mixes, soundness values decreased progressively from 0.7 mm at 10% CSA to 0.4 mm at 20% CSA and further to 0.2 mm at 30% CSA. A similar reduction trend is observed in the plasticiser and superplasticiser mixes, where values decreased with increasing CSA content, ranging from 0.9 mm to 0.4 mm and 0.8 mm to 0.3 mm respectively. This reduction in expansion values suggests an improvement in volumetric stability with higher CSA incorporation, which may be associated with reduced free lime content and enhanced pozzolanic reaction leading to a denser matrix. A comparable observation was reported by Fode *et al.* (2023). who noted that supplementary cementitious materials often contribute to improved dimensional stability by reducing excess calcium hydroxide and refining pore structure.

In comparison, the PLC control mixes recorded relatively higher or moderate soundness values, with the retarder mix at 0.40 mm, superplasticiser at 0.75 mm, and plasticiser at 0.60 mm. These values indicate that chemical admixtures influence the stability of cement paste, with superplasticiser systems exhibiting slightly higher expansion tendencies compared to other mixes. However, when CSA is introduced, a more stable and reduced expansion behaviour is observed, particularly at higher replacement levels. This suggests that CSA contributes positively to long-term dimensional stability despite its partial replacement of cement. Similar findings were documented by Haruna *et al.* (2023), who reported that pozzolanic materials tend to enhance soundness performance by limiting expansive hydration products and improving microstructural integrity in cement-based composites.

Table 8: Soundness Results

Mix Composition	Soundness (mm)
10% CSA + Retarder	0.7
20% CSA + Retarder	0.4

30% CSA + Retarder	0.2
10% CSA + Plasticiser	0.9
20% CSA + Plasticiser	0.6
30% CSA + Plasticiser	0.4
10% CSA + Superplasticiser	0.8
20% CSA + Superplasticiser	0.6
30% CSA + Superplasticiser	0.3
PLC + Retarder Only	0.40
PLC + Superplasticiser Only	0.75
PLC + Plasticiser Only	0.60

Conclusion

The study examined the effect of coconut shell ash (CSA) as a partial cement replacement in concrete with different chemical admixtures, and the results show that CSA significantly influences both fresh and hardened properties of concrete. The main conclusions are:

i. Aggregate properties such as moisture content and bulk density strongly influenced mix proportioning and workability control.
ii. CSA reduced workability due to its porous and absorptive nature, while chemical admixtures, especially superplasticisers, improved flow characteristics.
iii. Setting time increased with CSA inclusion, indicating delayed hydration and slower pozzolanic reaction.
iv. Compressive strength generally decreased with higher CSA replacement, although 10% CSA showed relatively better long-term performance due to secondary pozzolanic activity.
v. Density reduced slightly at higher CSA levels, reflecting increased porosity in the matrix.
vi. Soundness improved with increasing CSA content, suggesting enhanced volumetric stability.

References

Abdul-Wahab, S. A., Al-Dhamri, H., Ram, G., & Chatterjee, V. P. (2021). An overview of alternative raw materials used in cement and clinker manufacturing. *International Journal of Sustainable Engineering*, *14*(4), 743-760.

Abera, Y. A. (2024). Sustainable building materials: A comprehensive study on eco-friendly alternatives for construction. *Composites and Advanced Materials*, *33*, 26349833241255957.

Aggarwal, J., Goyal, S., & Kumar, M. (2025). Utilization of Industrial and Agro-based By-products to Develop Sustainable Controlled Low Strength Material. *Arabian Journal for Science and Engineering*, *50*(11), 8225-8253.

Anudeep, P., Reddy, M. A. K., Khed, V. C., Adamu, M., Varalakshmi, M., Ibrahim, Y. E., & Ahmed, O. S. (2024). Effect of superplasticizer in geopolymer and alkali-activated cement mortar/concrete: A review. *Reviews on Advanced Materials Science, 63*(1), 20230173.

Asante, B., Durlo Tambara, L. U., Soria-Castro, M., Ramírez, A., Castro-Borges, P., & Schmidt, W. (2025). Evaluation of admixtures from agricultural and aquacultural sources on hydration and mechanical properties of Portland cement based materials. *Materials and Structures*, *58*(10), 359.

Bedada, K., Nyabuto, A., Kınotı, I., & Marangu, J. (2023). Review on advances in bio-based admixtures for concrete. *Journal of Sustainable Construction Materials and Technologies*, *8*(4), 344-367.

Bhandari, I., Kumar, R., Sofi, A., & Nighot, N. S. (2023). A systematic study on sustainable low carbon cement–Superplasticizer interaction: Fresh, mechanical, microstructural and durability characteristics. *Heliyon*, *9*(9).

Blasi, A., Verardi, A., Lopresto, C. G., Siciliano, S., & Sangiorgio, P. (2023). Lignocellulosic agricultural waste valorization to obtain valuable products: An overview. *Recycling*, *8*(4), 61.

Dehghan, A. M. M. N. M., Maher, M. L. J., & Navarra, M. (2021, May). The effects of aggregate properties on concrete mix design and behaviour. In *Canadian Society of Civil Engineering Annual Conference* (pp. 457-468). Singapore: Springer Nature Singapore.

Ekwuno, A. O. (2025). A Review of the Consequences of Harsh Environmental Factors on Concrete's Life Span. *International Journal of Advanced Multidisciplinary Research Studies*, *5*(1), 910-919.

Fode, T. A., Jande, Y. A. C., & Kivevele, T. (2023). Effects of different supplementary cementitious materials on durability and mechanical properties of cement composite–Comprehensive review. *Heliyon*, *9*(7).

Haruna, S., Adamu, M., Ibrahim, Y. E., Haruna, S. I., Seif ElDin, H. M., Hamza, M. F., & Azab, M. (2023). Multifunctional engineered cementitious composites modified with nanomaterials and their applications: An overview. *Reviews on Advanced Materials Science*, *62*(1), 20220309.

He, R., Nantung, T., & Lu, N. L. (2025). Determining the Water-to-Cement Ratio of Freshly Mixed Concrete: Applying the Modified Coarse Aggregate Correction Factor to the AASHTO T 318 Method. *Journal of Materials in Civil Engineering*, *37*(6), 04025135.

Huynh, T. P., & Van Ho, Q. (2025). Systematic assessment of the technical performance, durability, cost, and environmental impact of sustainable concrete incorporating fly ash and ground granulated blast-furnace slag. *Environmental Progress & Sustainable Energy*, *44*(5), e70050.

Ikumapayi, O. M., Akinlabi, E. T., Majumdar, J. D., & Akinlabi, S. A. (2020). Applications of coconut shell ash/particles in modern manufacturing: a case study of friction stir processing. In *Modern Manufacturing Processes* (pp. 69-95). Woodhead Publishing.

Izadifar, M., Khorshidi, R., Ukrainczyk, N., Alborz, R., & Koenders, E. (2026). Dissolution of pozzolanic materials: a critical review. *Materials Advances*.

Jhatial, A. A., Nováková, I., & Gjerløw, E. (2023). A review on emerging cementitious materials, reactivity evaluation and treatment methods. *Buildings*, *13*(2), 526.

Khanna, M., & Kasilingam, S. (2025). Performance of agro-waste cementitious material in the high-strength reinforced concrete applications: a review. *Acta Scientiarum Polonorum. Architectura*, *24*, 102-113.

Meko, B., Ighalo, J. O., & Ofuyatan, O. M. (2021). Enhancement of self-compactability of fresh self-compacting concrete: A review. *Cleaner materials*, *1*, 100019.

Mirzaei, L., Ghebrab, T., & Fedler, C. B. (2025). Review and evaluation of agricultural biomass ashes as supplementary cementitious materials for sustainable concrete. *Processes*, *13*(11), 3571.

Nadir, H. M., & Ahmed, A. (2021). Comparative evaluation of potential impacts of agricultural and industrial waste pozzolanic binders on strengths of concrete. *Journal of Material Sciences & Manufacturing Research*, *2*(2), 1-8.

Okeke, F. O., Ahmed, A., Imam, A., & Hassanin, H. (2025). Calcination optimisation of corncob ash for sustainable cementitious applications: a pathway to low-carbon construction. *Sustainability*, *18*(1), 311.

Okeke, T. E., Okafor, F. O., & Onyia, M. E. (2025). Optimizing concrete block properties through the use of coconut shell and coconut shell ash: a multilayer perceptron approach. *Mathematical Models in Engineering*, *11*(3), 155-175.

Raghav, M., Park, T., Yang, H. M., Lee, S. Y., Karthick, S., & Lee, H. S. (2021). Review of the effects of supplementary cementitious materials and chemical additives on the physical, mechanical and durability properties of hydraulic concrete. *Materials*, *14*(23), 7270.

Raghav, M., Park, T., Yang, H. M., Lee, S. Y., Karthick, S., & Lee, H. S. (2021). Review of the effects of supplementary cementitious materials and chemical additives on the physical, mechanical and durability properties of hydraulic concrete. *Materials*, *14*(23), 7270.

Rakhimova, N. R. (2020). A review of calcined clays and ceramic wastes as sources for alkali-activated materials. *Geosystem Engineering*, *23*(5), 287-298.

Rusnak, C. R. (2025). Sustainable strategies for concrete infrastructure preservation: A comprehensive review and perspective. *Infrastructures*, *10*(4), 99.

Sangoju, B., Gopal, R., & Bhajantri H, B. (2021). A review on performance-based specifications toward concrete durability. *Structural Concrete*, *22*(5), 2526-2538.

Shaik, S. B. (2026). Durability Performance of Supplementary Cementitious Materials in Aggressive Environments: A Critical Review. *Saudi J Civ Eng*, *10*(1), 1-11.

Tariq, Z., & Bahadori-Jahromi, A. (2025). Incorporating ground granulated blast furnace slag & fly ash in concrete production for sustainable construction: a review. *Engineering Future Sustainability*, 1-30.

Ünal, M. T. (2024). *Optimizing Fiber-Reinforced Lightweight High Strength Concrete: the Role of Coconut Shells, Ground Granulated Blast-Furnace Slag, and Basalt Fiber in Low Cement Content Mixes* (Doctoral dissertation, University of Malaya (Malaysia)).

Wang, X. H., Fang, Z. C., & Zheng, L. (2024). Effect of dose and types of the water reducing admixtures and superplasticizers on concrete strength and durability behaviour: a review. *Journal of Civil Engineering and Management*, *30*(1), 33-48.

Wang, X., Guo, R., Xia, H., Guan, D., & Liu, Z. (2026). Multifractal Characteristics of the Pore Structure and Resistance to Chloride Ion Penetration of Cement Mortar Modified with a Waterborne Nanosilicate-Based Densifier. *Fractal and Fractional*, *10*(1), 58.

Win, T. T., Prasittisopin, L., Jongvivatsakul, P., & Likitlersuang, S. (2024). Investigating the role of steel and polypropylene fibers for enhancing mechanical properties and microstructural performance in mitigating conversion effects in calcium aluminate cement. *Construction and Building Materials*, *430*, 136515.