Effect of coconut shell ash as an additive on the properties of green concrete

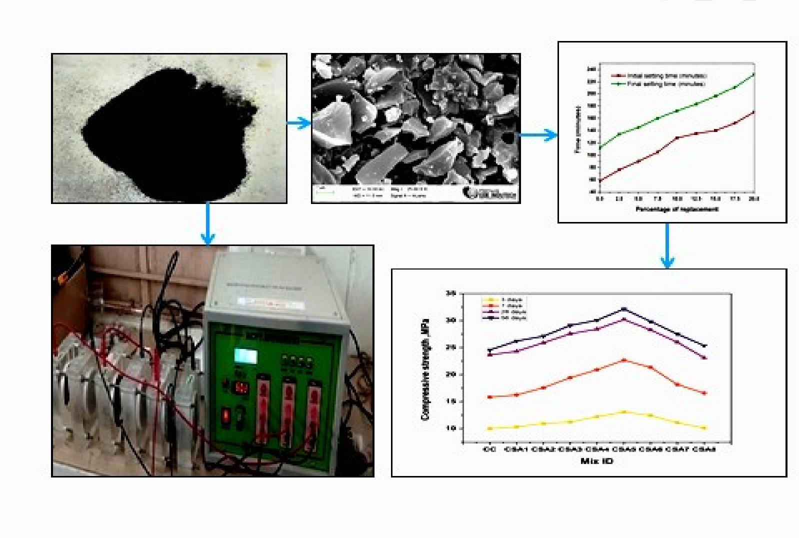
S. Shanmuga Priya [1] & I. Padmanaban [2]

[1] *Assistant professor, Department of Civil Engineering, Jansons Institute of Technology, Coimbatore, India.*

[2] *Professor, Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore, India.*

Corresponding author: S. Shanmuga Priya & Email: shanmugapriyacit@gmail.com

Graphical abstract



Abstract

Concrete is the broadly adopted composite material in the construction arena. The growing need for cost-effective housing is resulting in the depletion of environmental resources such as river sand and gravel, which are essential components in the manufacture of concrete. However, the manufacturing of cement has been proven to have a negative impact on the environment because it contributes to the carbon footprint. The resolution of these environmental issues can be achieved through the implementation of sustainable solutions. This article explores the potential application of coconut shell ash as a substitute for cement in green concrete. Coconut shells (CS) are inevitable by-products derived from the agricultural sector. Coconut shell ash (CSA) was obtained through the combustion of coconut shells. The CSA is substituted by a range of 0 to 20% by weight of cement with a gradual 2.5% increase. The test findings concluded that 12.5% of CSA mix attained the maximum compressive strength. The durability results were found satisfactory in comparison with the normal concrete. The specimens were exposed to different temperatures (i.e., 100 °C, 200 °C, and 300 °C) for a consistent duration of one hour. The CSA concrete exhibited improved residual strength and weight reduction compared to conventional concrete.

Keywords: Coconut shell ash (CSA), greenhouse gas, sustainable solutions, Residual strength and agricultural by-products.

1. Introduction

Concrete is a highly prevalent construction material, occupying the third position in terms of utilization, following air and water [1]. The generation of Portland cement may increase exponentially in the near future due to technological progress and rapid population growth. The current imperative is to address the demand for sustainable pozzolanic materials as a substitute for cement, in order to mitigate the greenhouse effect resulting from the emission of carbon dioxide during the production of clinker. Most developing countries utilize solid agricultural waste for combustion purposes, which in turn produces huge quantities of ash that is disposed of in landfills [2]. A large variety of industrial and agricultural by-products are being utilized and experimented with as supplementary cementitious materials. The commonly used industrial by-products for cement substitution include fly ash, marble dust, coal bottom ash, GGBS and foundry waste powder [3, 4]. The availability of industrial by-products may not be a constant supply to substitute cement in concrete. Hence, utilization of different agricultural wastes may be a feasible solution to get an uninterrupted source of supplementary cementitious material.

India is an agriculture-based country, where the generation of agricultural waste is huge, and often the farmers dump and burn the waste generated during various agricultural activities in open fields. Combustion of the agro-waste in open fields also emits carbon dioxide, harmful gases, and particulates, which create severe health hazards and environmental degradation. The controlled burning of agro waste will be a solution to reduce the environmental hazard, and in the same way, processed ash from controlled burning can also be exploited as a substitute for cementitious material. In India, coconut production is the largest agricultural activity next to the cultivation of wheat, rice, and sugarcane. The southern parts of the country, viz., Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh, contribute 98% of the country's coconut production. Coconut shell is used for a variety of applications, including as coarse aggregate in concrete and, finally, for combustion purposes. The ash produced from the CS (coconut shell) is a promising cementitious ancillary in concrete. Many researchers have focused on the consumption of CS ash as a binding component for construction materials like concrete, bricks, cement blocks, tiles, etc.

Trokon et al. [5] evaluated the structural performance of RCC beams infused with CS Ash. The coarse aggregate was replaced with 5% raw coconut shell particles, and cement was replaced with 10% CSA. The beams have shown improvement in both flexural and shear capacity, and the ductility was improved with a reduction in flexural load of 17.3%. The research findings indicate that incorporating CSA and CSP has increased the ductility with the restricted pozzolanic reaction of CSA. Charitha et al. [6] explored the potential applications of cementitious products made from agricultural waste, such as CS Ash. It was reported that CS Ash has the highest percentage of alumina content and is highly irregular and elongated in shape compared to other agricultural waste ashes, which results in a decrease in slump value. CSA with 10% replacement has shown the highest strength properties, reduced water absorption, and improved durability compared to other combined concretes. Vignesh and Rajesh [7] investigated the cement block with CSA powder and stone powder for its compressive, flexural, and tensile strengths. The authors have incorporated 10, 20, and 30% CSA in different sizes, such as 60, 90, and 120 microns, and subjected them to curing spells of 10, 12, and 14 days. Concrete with 30% CSA of 120-mm-size particles and 14-day curing has shown the highest strength characteristics.

S. Arifin et al. [8] utilized coconut shell ash and flake to partly replace cement and coarse aggregate, respectively, to manufacture pervious concrete. Coarse aggregate was replaced with 0–25% in increments of 2.5% of CS flakes, and cement was replaced with 0%, 2.5%, 5%, and 7.5% coconut shell ash. The compressive strength of pervious concrete exhibits an initial rise of 2.5% with the addition of CSA, followed by a subsequent decreasing trend. As the strength decreases, permeability and porosity have increased for pervious concrete with 5% and 7.5% of CSA, respectively. N. Bheel et al. [9] employed coconut shell ash as an alternative material for cement binder. The mechanical characteristics of CSA concrete increased for 10% replacement by 12%, 10%, and 9% more than normal concrete for compressive, tensile, and flexural strength, respectively. Infusing coconut shell ash in concrete provides a sustainable solution for the reduction of Portland cement concrete as there is a reduction in embodied energy of 5%. Osuji & Ukeme [10] conducted an investigation into the effects of increased temperature on traditional concrete and noted a substantial decrease in compressive strength. The most notable loss, reaching a high of 53.47%, was seen at a temperature of 300 degrees Celsius.

Sen et al. [11] investigated the effect of coconut fiber ash as a cement replacement in concrete and discovered that it decreased the workability of the concrete mix. This article discusses the application of coconut shell ash and evaluates its mechanical, thermal, and durability properties. The utilisation of coconut shell ash derived from agricultural waste presents a viable and sustainable alternative for the construction industry.

1.1 Research significance

The cement industry is recognized as one of the most energy-intensive sectors globally due to the substantial energy need of approximately 4 GJ for manufacturing each metric ton of cement. The outcome of this particular process leads to the emission of a significant quantity of carbon dioxide, which is classified as a greenhouse gas, into the Earth's atmosphere. This study aimed to design an eco-sustainable concrete solution that can be effectively employed within the contemporary construction sector. The present study investigates the viability of using Coconut shell ash (CSA) in concrete. The potential development of sustainable green concrete involves the incorporation of powdered CSA as a partial substitute for Portland cement in concrete.

2. Materials

2.1 Cement

The OPC of 53 grade is the utilized for the investigation. The tests were done as per IS 12269: 2013 [13]

2.2 Coconut Shell Ash (CSA)

The coconut shell (CS) was procured from a nearby agro farm and crushed with a hammer and it was burnt under a controlled environment. After the combustion process of the coconut shells is complete, it is acceptable to allow them to cool entirely. Subsequently, the resulting ashes can be appropriately ground. The ground CSA has been passed through a 75-micron sieve. The sample of CSA is shown in Figure 1. The physical and chemical features of cementitious materials are listed in Tables 1 and 2. According to the ASTM C618 [12] standard, a mineral admixture is deemed suitable for concrete when the combined content of SiO_2, Fe_2O_3, and Al_2O_3 exceeds 70%. The chemical oxide composition of the CSA consisting of (Al_2O_3, SiO_2, and Fe_2O_3) was determined to be 72.34%. This composition proved to be appropriate for use as a cementitious material.

Figure 2 displays the mean setting time for the different combinations of OPC and CSA. The duration of the setting process demonstrates a positive correlation with the quantity of CSA utilized. The duration of the initial setting interval exhibits an increase from 58 minutes when there is no replacement material to 2 hours and 50 minutes when there is a 20% replacement. Similarly, the final setting Interval exhibits an increase from 1 hour and 52 minutes without any replacement to 3 hours and 52 minutes with a 20% replacement. According to the Indian Standard (IS) 12269:2013[13], the prescribed requirement for the initial setting time is a minimum duration of 30 minutes, nevertheless, the final setting period should not surpass 10 hours. All of the experimental values fall within the range specified by the Indian code.

Figure 1 Sample of CSA

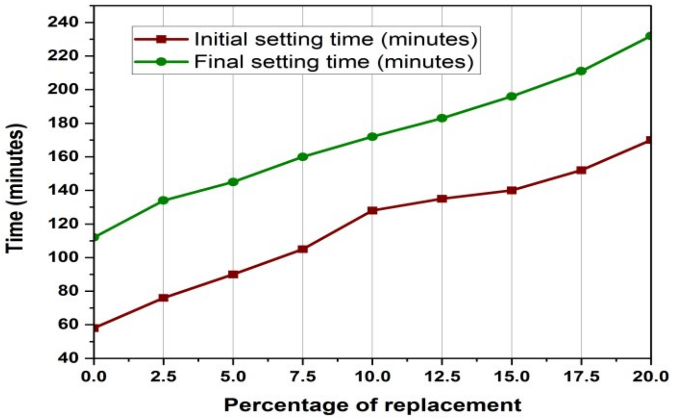


Figure 2 Mean setting time for the different combinations of OPC and CSA

Table 1 Physical characteristics of Cement and CSA

Characteristics	**Cement**	**CSA**
Specific gravity	3.15	1.38
Fineness modulus	6%	9%
Normal consistency	35%	39%
Specific surface area (m^2/kg)	318	863

Table 2 Chemical constituents of CSA and cement

Constituents (%)	(SiO_2)	(Al_2O_3)	(Fe_2O_3)	(CaO)	(MgO)	(SiO_2+Al_2O_3+Fe_2O_3)
Cement	27.51	4.35	5.61	54.68	1.19	37.47
CSA	49.44	18.32	3.45	2.21	0.56	71.21

2.3 Aggregate

The fine aggregate (FA) utilized in this research comprised of river sand obtained from local sources. FA passed through a 4.75mm sieve and complies to IS: 383 – 2016 [14]. grading zone II. The coarse aggregate (CA) utilized in the production of standard concrete consisted of crushed stones with a nominal size of 20mm, fulfilling the requirements outlined in IS 383: 2016[14]. The physical characteristics of the aggregates are summarized in Table 3.

Table 3 Physical characteristics of aggregates

Properties	**CA**	**FA**
Water absorption (%)	0.80	0.50
Fineness modulus	6.98	2.61
Bulk density (kg/m^3)	1569	1730
Specific gravity	2.80	2.58

2.4 Water

The ordinary potable water obtainable at the research laboratory was utilized during the entire investigation.

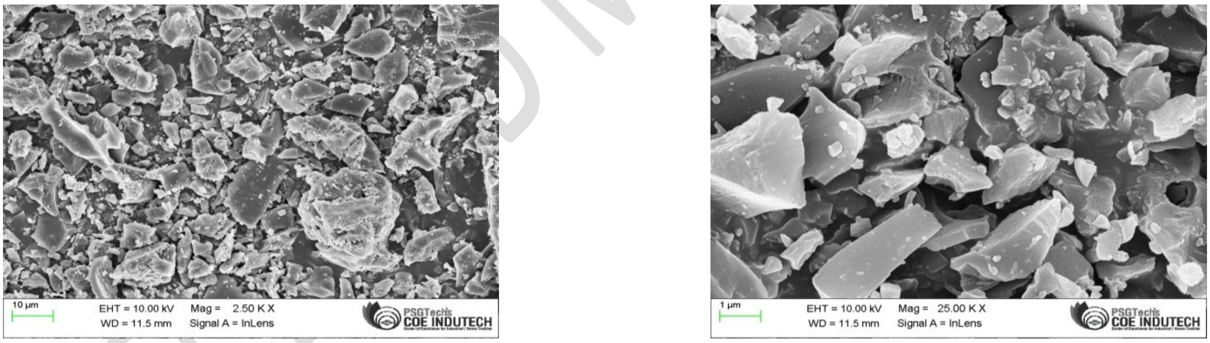
2.5 Material Characterization

The material characterization was performed at PSGTECHS COE INDUTECH, Coimbatore, India. The SEM examination of CSA samples was conducted, and the resulting images at various magnification levels are depicted in Figure 3(a) to Figure 3(d). The utilization of SEM analysis facilitates the investigation of the morphology, dimensions, and spatial arrangement of ash particles. The acquired images have the potential to unveil various characteristics, including but not limited to surface texture, pores, splits, and agglomeration of particles.

The coconut shell ash (CSA) particles were found to possess a solid composition, characterized by irregular sizes. Spherical particles of varying sizes are also observable in Figure 3. This spherical and irregular shape enhances the bonding between particles. The individual particles exhibited a porous morphology, characterized by irregular voids on their surfaces. The observed porosity can potentially contribute to the material's higher surface area. CSA material has finer particle form and large pores, resulting in increased setting time, decreased slump, and increased cement paste consistency in fresh concrete [5].

The X-ray diffraction examination was carried out on the CSA sample, and the resulting XRD spectrum is presented in Figure 4. The starting position of °2θ was recorded as 5.0076, while the ending position was measured as 90.3136. The presence of uranium oxide is confirmed by the identification of high intensity peaks at 2θ values of approximately 23.8, 25.4, and 26.54°. The primary phases that have been identified are the peaks corresponding to Thorium Carbide and Uranium Oxide. It exhibits a significantly elevated melting point and possesses exceptional thermal conductivity, rendering it well-suited for utilization in scenarios involving elevated temperatures. The EDX spectra of CSA sample is depicted in Figure 5. The concentrations of silicon (SiO_2), potassium (K_2O), aluminium (Al_2O_3), sodium (Na_2O), and Iron oxide (Fe_2O_3) were 49.44%, 25.23%, 18.32%, 7.24%, and 3.45% respectively.

a)at 2µm **b)at 20µm**



c) at 10µm **d) at 1µm**

Figure 3 FESEM images of CSA at different magnifications

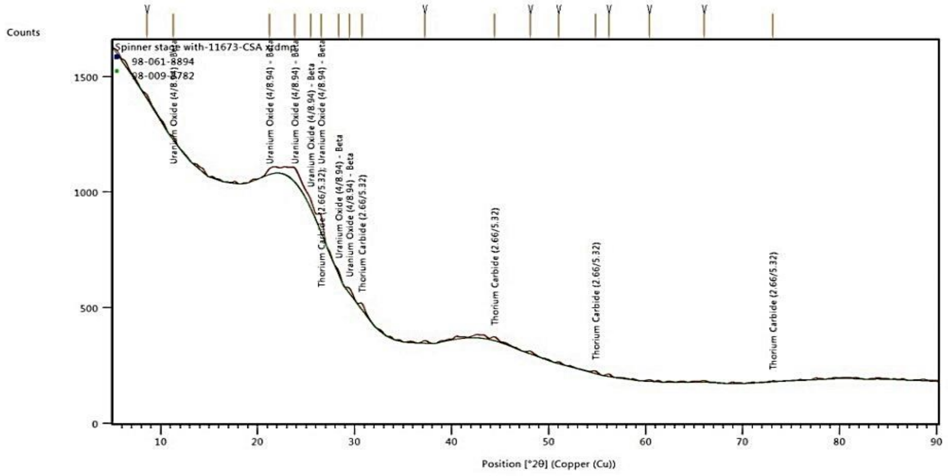


Figure 4 XRD analysis of CSA

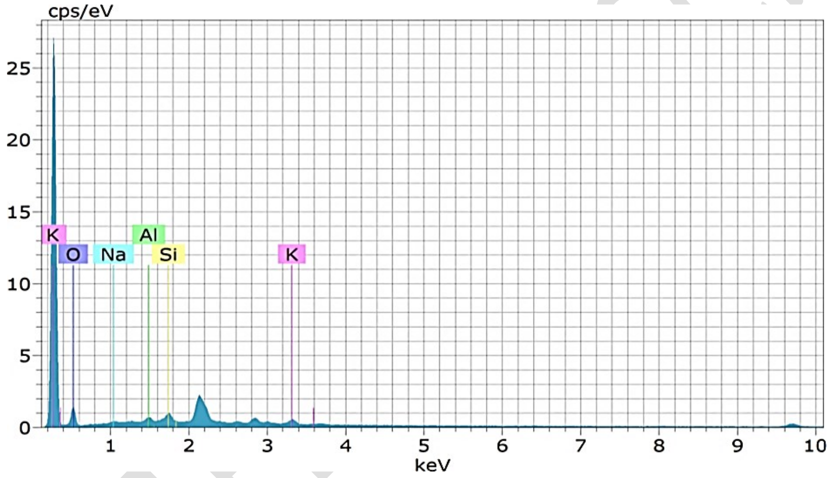


Figure 5 EDX analysis of CSA

2.6 Mix design

The study focused on the normal strength of concrete (M_{20} grade) and identified the suitable mix fraction for the concrete according to IS: 10262-1982 [15] guidelines. The substitution range was determined to be in the CSA range of 2.5% to 20%, with an increasing trend of 2.5% at each interval. The mix proportion adopted in the current investigation was 1:1.79:3.05:0.5. The ingredients required per cubic metre are listed in Table 4.

Table 4 Materials required producing 1m^3 of concrete blend

MIX ID	**C (kg)**	**FA (kg)**	**CA (kg)**	**CSA (kg)**	**WATER (litres)**
CC	384.00	691	1173	0	192
CSA1	374.40	691	1173	9.60	192
CSA2	364.80	691	1173	19.20	192
CSA3	355.20	691	1173	28.80	192
CSA4	345.60	691	1173	38.40	192
CSA5	336.00	691	1173	48.00	192
CSA6	326.40	691	1173	57.60	192
CSA7	316.80	691	1173	67.20	192
CSA8	307.20	691	1173	76.80	192
C- Cement; FA- Fine aggregate; CA- Coarse aggregate; CSA- Coconut shell ash					

3. Experimental Investigation

3.1 Fresh concrete property of CSA concrete

The workability of the concrete was verified by employing slump cone tests, utilizing a slump mould of standard dimensions in accordance with the specifications outlined in IS: 1199-1999[16]. The fresh property evaluated with respect to slump value of concrete in mm is listed in Table 5. Figure 6 illustrates a graphic representation of the trend of workability. The amount of CSA increased was shown to be accompanied by a reduction in slump levels. The fall in slump for the CSA concrete might be linked with the intake of water by CSA as observed by the researchers earlier [17]. The addition of CSA has been emphasized to have a substantial influence on the workability of the concrete, especially attributable to its enhanced water-absorbing properties [18, 32]. The performance variability found can be ascribed to the existence of an irregular surface and uneven particle size in the CSA, which significantly affects the overall texture of the concrete mixture. As a result, the internal friction between particles is sharp, prominent to a reduction in the flowability of fresh concrete.

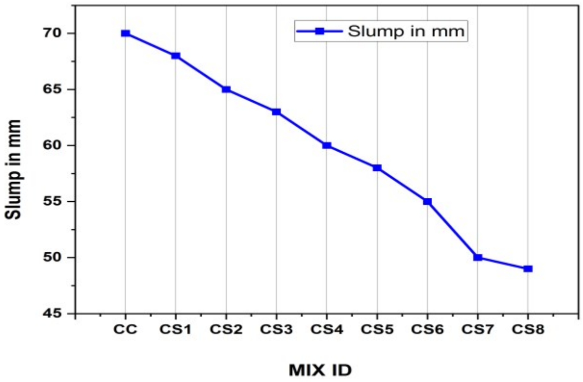


Figure 6 Slump of CSA concrete

3.2 Mechanical characteristics of Concrete with CSA

The assessment of the compressive strength of concrete was conducted by using cubes measuring 15 cm in size. Similarly, the flexural strength was executed using prism specimens measuring 10 cm x 10 cm x 50 cm. Both evaluations were carried out in compliance with the specifications stated in the IS 516-2004 [19]. The tensile strength test and modulus of elasticity was executed using cylinder-shaped specimens measuring 15 cm in diameter and 30 cm in length, in accordance with the IS: 5816-1999 standard. [20]. Figures 7 and 8 depict concrete cube specimens with varying percentages of CSA and tensile strength test configurations.

Figure 7 Concrete cubes with different percentages of CSA

Figure 8 Testing of cylindrical specimen

Table 5 Strength of concrete with CSA

Mix ID	Slump mm	Strength in compression MPa (days)				Strength in tension MPa (days)		Strength in flexure MPa (days)		Modulus of elasticity GPa (days)
		3	7	28	56	7	28	7	28	28
CC	70	9.98	15.81	23.65	24.56	1.91	3.18	3.12	4.85	22.45
CSA1	68	10.32	16.23	24.30	26.21	2.86	3.33	3.29	4.90	22.83
CSA2	65	10.95	17.56	25.89	27.11	3.16	4.12	3.35	5.14	23.17
CSA3	63	11.23	19.41	27.56	29.10	3.48	4.27	3.58	5.65	23.85
CSA4	60	12.19	20.90	28.42	30.06	3.55	4.33	3.90	5.97	24.05
CSA5	58	13.06	22.65	30.19	32.14	3.68	4.45	3.85	5.89	24.65
CSA6	55	12.41	21.33	28.24	29.83	2.76	4.25	3.80	5.73	23.40
CSA7	50	11.08	18.15	25.98	27.50	2.60	4.10	3.67	5.58	22.84
CSA8	49	10.12	16.56	23.12	25.37	2.44	3.97	3.50	5.31	22.29

3.2.1 Test findings of mechanical strength properties

Figure 9 depicts the variations in compressive strength following 3, 7, 28, and 56 days of curing at varying CSA dosage levels. The compressive strength of CSA-concrete was assessed to vary between 24.30 MPa and 30.19 MPa over a duration of 28 days. In comparison, the control mix achieved strength of 23.65 MPa. The CSA mix (CSA5) demonstrated superior strength compared to the other mixtures. The CSA5 mix has demonstrated a substantial enhancement of 27.65% in terms of strength, in comparison to the control mix (CM). The observed enhancement can be ascribed to the pozzolanic reaction occurring between CSA and the confinement of pores within the concrete matrix [18]. Figure 9 clearly depicts the progressive rise in strength up to the 12.5% of CSA replacement level. A further increase in the dosage of CSA has been noted to lead to a decrease in compressive strength. After a period of 28 days, it becomes evident that the compressive strength of concrete containing CSA exhibits good strength compared to the control concrete. Due to hydration of cement and the prolonged pozzolanic reaction of CSA contribute to the dense morphology [21].

Figure 10 exhibits the progression of tensile strength for all mixes. The measured strength values exhibit a range from 3.33 MPa to 4.45 MPa. The Mix CSA5 demonstrated a 39% increase in tensile strength over conventional concrete (CC). The increased tensile strength observed in concrete can be attributed to the influence of CSA as both a pozzolanic material and filler [22].

The progression of flexural strength in CSA and CS specimens is demonstrated in Figure 11. The average flexural strength of prism with CSA was varied between 4.90 MPa to 5.97 MPa. The mix CSA4 (10%CSA) attained the highest compressive strength. According to the findings, there is a positive correlation between the reduction of CSA particle size and the improvement of flexural strength [23]. Concrete's modulus of elasticity is a measurement of its resistance to elastic deformation. In terms of modulus of elasticity, it is evident from Table 5 that up to 12.5% of the CSA-replaced matrix yields better results. When comparing concrete with and without adding CSA, it is observed that concrete containing CSA has the ability to partially substitute ordinary Portland cement (OPC) and emphasize a higher modulus of elasticity [24,32]. Utilizing CSA as an alternative to OPC increases the modulus of elasticity due to the effective pore-filling capacity of CSA particles. The process of pore filling results in the development of a more refined interfacial transitional region among the filler material and the binding matrix [25].

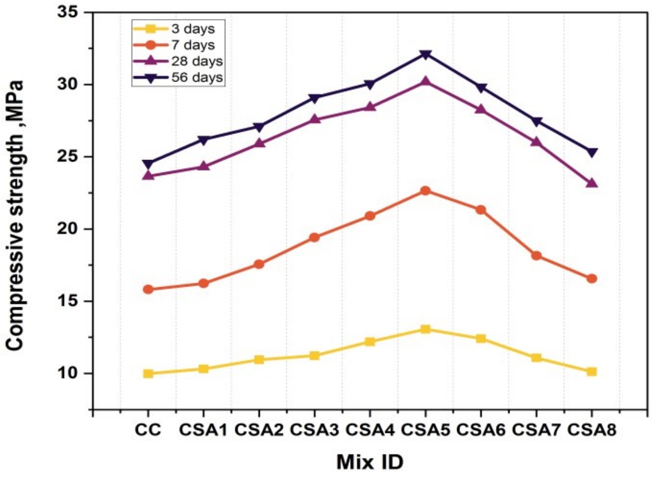


Figure 9 Development of compressive strength for CSA and CC specimens

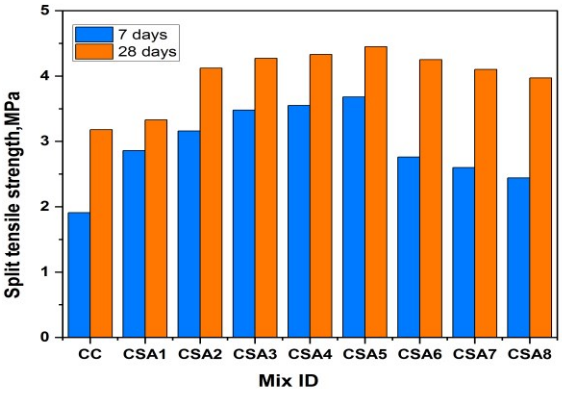


Figure 10 Development in tensile strength for CSA and CC specimens

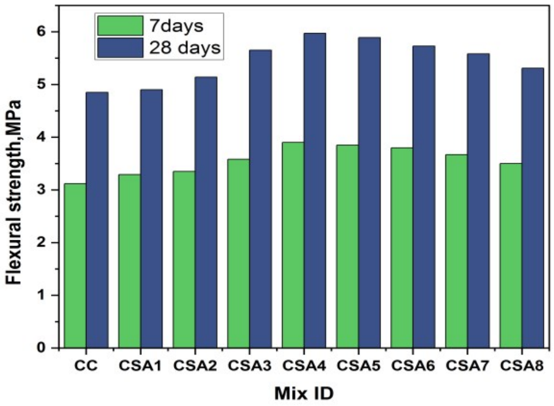


Figure 11 Development of flexural strength of CSA and CC specimens

3.3 Durability performance of CSA concrete

3.3.1 Saturated Water Absorption (SWA)

The Saturated Water Absorption (SWA) test was conducted following the guidelines outlined in ASTM C 642 [26]. The 15 cm cubes underwent a damp curing process for a duration of 28 days, followed by exposure to a temperature of 100°C in an oven for a period of two hours. The sample that had been dried in the oven was measured by weighing it (W_1) and thereafter placed in a receptacle filled with water for a duration of 24 hours in order to determine its final weight (W_2). The setup for a water absorption test is illustrated in Figure 12.

Figure 12 Test setup for water absorption

3.3.2 Acid resistance test

This test was assessed by assessing the loss in weight and residual compressive strength. The experiment was conducted on cubical specimens of size 15 cm in compliance with the standards outlined in ASTM C 267-01[27]. After a 28-day curing period, the specimens were subsequently removed and left to undergo a one-day drying process. The initial weights of the cubes were measured. In the acid attack test, a solution consisting of 5% dilute sulphuric acid (H_2SO_4) by volume was combined with water having a pH value of approximately 2. Following the measurement of initial weights, the cubes were submerged in the aforementioned acid water for duration of 30, 60 and 90days. After a predetermined interval, the loss in weight and residual compressive strength of cubes are evaluated.

3.3.3 Rapid Chloride Permeability Test (RCPT)

The RCPT was executed following the parameters outlined in ASTM C1202 [28]. Figure 13 illustrates the experimental arrangement. This evaluation utilized specimens measuring 10 cm in diameter and 5 cm in thickness.

Figure 13 Test setup for RCPT

3.3.4 Discussion on test findings of durability performance

The test findings of Saturated Water Absorption are depicted in Figure 14. The SWA of standard concrete was 3.25 percent. SWA of CSA blend ranges between 2.98% to 2.26%. As the percentage of CSA rises, the amount of SWA decreases proportionally.

Table 6 Summary of test findings of acid resistance and RCPT

Mix ID	Acid Attack						RCPT at 90 days	
	Loss in weight (%)			Loss in strength (%)				
	Days						Charge flow (Coulomb)	Range as per ASTM C-1202
	30	60	90	30	60	90		
CC	1.83	3.25	4.89	1.17	2.10	4.74	2850	Moderate
CSA1	1.75	2.90	4.62	1.06	2.49	5.10	2720	Moderate
CSA2	1.70	2.82	4.55	0.98	2.54	5.26	2680	Moderate
CSA3	1.64	2.72	4.30	0.85	2.60	5.40	2572	Moderate
CSA4	1.60	2.70	4.25	0.83	2.70	5.48	2480	Moderate
CSA5	1.50	2.65	4.15	0.80	2.76	5.72	2393	Moderate
CSA6	1.45	2.50	3.95	0.75	2.81	5.85	2100	Moderate
CSA7	1.32	2.39	3.80	0.72	2.95	5.90	1920	Low
CSA8	1.26	2.20	3.67	0.68	3.03	5.98	1876	Low

Table 7 displays the summary of test results of acid resistance tests and RCPT conducted on CCA and control concrete mixtures. The assessment of mass and strength reduction percentages was conducted subsequent to the chemical curing process spanning 30, 60, and 90 days. The mass loss of CSA specimens varied from 1.26% to 1.75% after a period of 30 days. The perceived decrease in mass of CC was found to be 1.83%. The rate of mass loss lowers as CSA concentration in concrete rises due to the presence of smaller CSA particles. The strength degradation of CSA specimens ranged from 5.10% to 5.98% after a 90-day period. The strength of the CC specimen endured a reduction of 4.74%. Among all the examined samples, the concrete mix with CSA had the least water absorption value. It was indicated that increased concrete durability can be achieved through reduced water absorption [29].

The observed increase in resistivity can be linked to the higher concentration of C-S-H gel resulting from the pozzolanic response, along with the reduced water absorption capability of

CSA concrete. Under conditions of weak acidity, the calcium-silicate-hydrate compound undergoes a significant release of lime, while simultaneously forming a strong layer of silica and alumina silicate [30]. This protective layer serves to prevent any subsequent corrosion of the cement paste. In contrast, the occurrence of decalcification of C-S-H and the dissolution of calcium hydroxide (Ca(OH)2) contribute to the formation of a porous and deteriorated layer in concrete that is composed entirely of Portland cement [31]

The outcomes of the RCPT for various concrete mixtures are depicted in Table 7. From the table, it is clear that CSA7 and CSA8 exhibited remarkable chloride ion penetration resistance, demonstrating a reduction in penetration of 48% and 51% respectively compared to CC. According to ASTM C1202 [28], these concrete mixes are categorized as having a low level of chloride ion penetration. While other mix combinations possess a moderate classification.

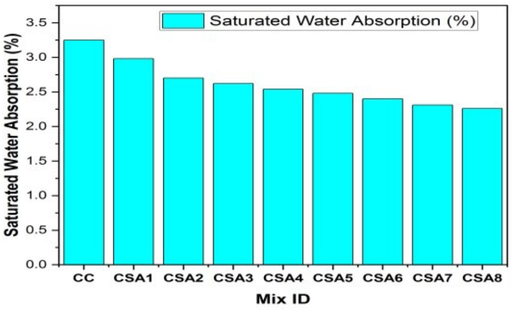


Figure 14 Water absorption of CSA and CC concrete

3.4 Temperature Effect of CSA mixed concrete and Control concrete

Concrete cubes measuring 100 mm in size are subjected to heating at different temperatures, specifically 100°C, 200°C, and 300°C, for a consistent duration of 1 hour. The cubes were placed inside a muffle furnace and subsequently subjected to the application of heat. The specimens were subjected to different firing temperatures while maintaining a consistent time interval. The specimens that were subjected to firing were evaluated for residual strength and reduction in weight after exposing to various temperatures.

Figure 15 illustrates the residual compressive strength observed after subjecting the specimens to different temperatures for one hour constant time following a 28-day period of moist curing. The conventional concrete observed a reduction in strength of 2.29% when subjected to a temperature of 100ºC. The compressive strength of CSA mixed concrete noticed a lower percentage loss when subjected to a temperature of 100ºC compared to CC mix. At 300°C, the CC mix lost 7.99% of its strength, while the CSA mix lost between 0.58 and 3.18 % of its strength. According to the test findings, it can be observed that there exists a negative correlation between the proportion of CSA and the proportion of strength reduction. No substantial decrease in strength was observed until reaching a temperature of 200°C. The impact of temperature on concrete strength is negligible until approximately 250°C. However, temperatures beyond 300 °C lead to a substantial decline in strength [33].

The pozzolanic impact that takes place during the hydration process is primarily responsible for the observed increase in strength. This effect leads to the formation of a significant quantity of C–S–H, which is known to contribute to the development of strength [34]. Furthermore, CSA serves as micro filler, enhancing the microstructure of the system [35]. Figure 16 illustrates the decrease in weight subsequent to exposure to different temperatures. The observed percentage of mass loss at a temperature of 100°C was determined to be negligible. The loss in weight of CSA mixed concrete exhibited a variation ranging from 2.19% to 2.85%. At a temperature of 300°C, the observed loss in weight of the CC mixture was determined to be 3.56%.

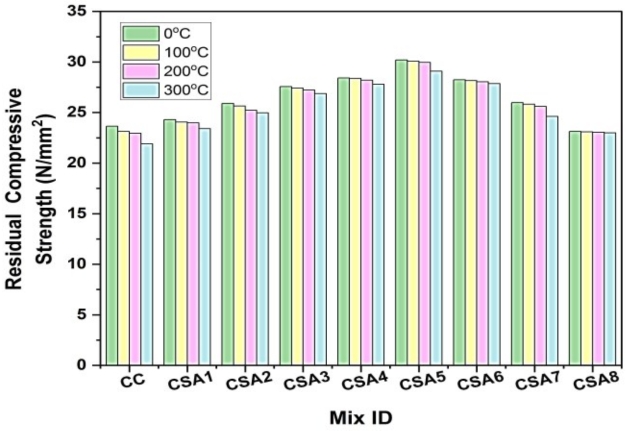


Figure 15 Residual Compressive Strength after exposing to various temperature

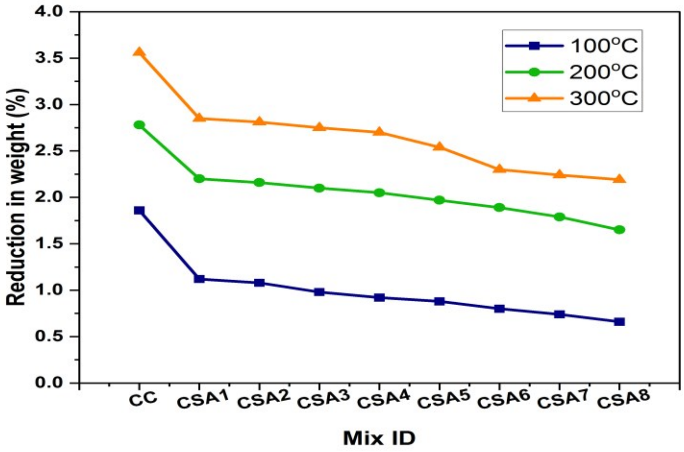


Figure 16 Reduction in weight after exposing to various temperature

4. Conclusion

Coconut shell ash, an agricultural by-product, has been combined into the concrete mixture to generate a cost-effective, energy-efficient solution with enhanced performance. The workability of CSA mixed concrete decreased with increasing the percentage of CSA. This phenomenon is attributable to the finer particle structure and larger pore size of CSA material. The substitution of OPC with CSA has the possible to enhance compressive, tensile, and flexural strength over time, owing to the pozzolanic characteristics of CSA. The mechanical properties were enhanced by the substitution of CSA 12.5%. The Mix ID CSA5 exhibited a significant 39% enhancement in splitting tensile strength as compared to normal concrete.

The concrete blend incorporating CSA showed least water absorption value when compared to all other samples that were assessed. Better acid resistance and RCPT results were seen in the CSA samples. When the specimens were exposed to increased temperature, it was shown that the percentage decrease in both strength and mass may be lower compared to that of ordinary concrete. Hence, it may be inferred that concrete combined with CSA has better thermal resistance qualities. Utilizing CSA in concrete promotes the management of agricultural waste in a sustainable manner. One of the most significant sources of carbon dioxide emissions is Portland cement. Thus, CSA can minimize the cost of concrete production and also its carbon footprint.

Conflicts of Interest:

There are no conflicting interests stated by the authors.

Acknowledgment:

No organization supported the authors' work submission

References

1. Cembureau, T., (2020), The role of cement in the 2050 low carbon economy, Eur. Cement Assoc, 1–64, http:/www.cembureau.cu/activity-report.

2. Nithya, M., Priya, A. K., Muthukumaran, R., Arunvivek, G. K., (2017), Properties of Concrete Containing Waste Foundry Sand for Partial Replacement of Fine Aggregate in Concrete. Indian Journal Enggineering and Material Sciences. **24 (2)**, 162-166.

3. Nithya, M., Maheswaran, G., Senthil Kumar, S., (2016), Experimental Investigation on Impact of Sand Mining in Coastal Regions and Potential Reuse of Silica Sand as Construction Material. Indian journal of Geo-Marine Sciences. **45 (7)**, 885-888.

4. T. C. Herring, T. Nyomboi, and J. N. Thuo, (2022), Ductility and cracking behavior of reinforced coconut shell concrete beams incorporated with coconut shell ash, *Results in Engineering.* **14**, doi: 10.1016/j.rineng.2022.100401.

5. Trokon Cooper Herring , Joseph N. Thuo ,Thimothy Nyomboi, (2022), Engineering and Durability Properties of Modified Coconut Shell Concrete. Civil Engineering Journal, **8(2)**, 362-381.

6. V. Charitha, V. S., Athira, V. Jittin, A. Bahurudeen, and P. Nanthagopalan, (2021), Use of different agro-waste ashes in concrete for effective upcycling of locally available resources, Constrution Building Materials, **285**, 122851, 2021,doi:10.1016/j.conbuildmat.2021.122851.

7. Vignesh Kumar, M., and Rajesh, M., (2021), Analysis the effect of coconut shell ash powder on cement block. Materials Today: Proceedings, doi:10.1016/j.matpr.2020.12.969.

8. S. Arifin, O. Setyandito, E. Prahara, and Y. Wijayanti, (2021), Investigating properties of pervious concretes containing coconut shell flake and ash. IOP Conference Series Earth and Environmental Sciences*,* **729(1)**, doi: 10.1088/1755-1315/729/1/012014.

9. Osuji, S., & Ukeme, U., (2015), Effects of Elevated Temperature on Compressive Strength of Concrete: A Case Study of Grade 40 Concrete. Nigerian Journal of Technology, **34(3)**, 472. doi:10.4314/njt.v34i3.7.

10. N. Bheel, S. K. Mahro, and A. Adesina, (2021), Influence of coconut shell ash on workability, mechanical properties, and embodied carbon of concrete. Environmental Science and Pollution Research, **28(5)**, 5682–5692.
11. Sen, S., and Chandak, R., (2015), Effect of coconut fibre ash on strength properties of concrete. International Journal of Engineering Research and Applications, **5(4)**, 33-35.
12. ASTM C 618-19. Standard specification for coal fly ash and raw or calcined pozzolan for use in concrete, ASTM International, West Conshohocken, United States.
13. IS 12269:2013. Ordinary portland cement, 53 Grade — Specification, Bureau of Indian Standards, New Delhi.
14. IS 386:2016. Coarse and fine aggregate for concrete- Specification, Bureau of Indian Standards, New Delhi.
15. IS10262:2009. Recommended Guidelines for Concrete Mix Design, Bureau of Indian Standards, New Delhi.
16. IS: 1199-1999. Methods of sampling and analysis of concrete, Bureau of Indian Standards, New Delhi.
17. O. Joshua, (2018), Data on the pozzolanic activity in coconut shell ash (CSA) for use in sustainable construction. Data Br., **18**, 1142–1145, doi: 10.1016/j.dib.2018.03.125.
18. Sivakrishna A, Adesina A, Awoyera P O, Kumar, K R., (2020), Green concrete: A review of recent developments. Materials Today proccedings, **27**, 54-58.
19. IS 516-2004. Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi.

20. IS: 5816-2004, Splitting tensile strength of concrete - Method of test, Bureau of Indian Standards, New Delhi.
21. Joorabchian, S. M., (2010), Durability of concrete exposed to sulfuric acid attack. Master Thesis. Ryerson University, Toronto, Ontario, Canada https://doi.org/10.32920/ryerson.14654622.v1.
22. Kumar, R.R., Mahendran, R., Nathan, S.G., Sathya, D., and Thamaraikannan, K., (2017), An experimental study on concrete using coconut shell ash and egg shell powder. South Asian Journal of Engineering and Technology **3(7)**, 151-161.
23. Hasan, S.I., Manon, A.H., Kuddus, M.A. and Hossain, M. M., (2016), Investigation of mechanical behaviour of concrete by replacing cement with coconut shell ash & stone dust. Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development (ICCESD 2016), 2016, KUET, Khulna, Bangladesh, 828-835.
24. Shi, C., & Stegemann, J. A., (2000), Acid corrosion resistance of different cementing materials. Cement and Concrete Research, **30(5)**, 803–808, doi: 10.1016/S0008-8846(00)00234-9.
25. Chakradhara Rao, M., (2021), Influence of brick dust, stone dust, and recycled fine aggregate on properties of natural and recycled aggregate concrete. Structural Concrete, **22(S1)**, 105–120, doi:10.1002/suco.202000103.
26. ASTM C 642. Standard test method for density, absorption and voids in hardened concrete, ASTM International, West Conshohocken, United States.

27. ASTM C 267-01. Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes, ASTM International, West Conshohocken, United States.

28. ASTM C1202. Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration, ASTM International, West Conshohocken, United States.

29. Umamaheswari, R. and Vigneshkumar, M., (2018), Experimental study on partial replacement of cement with coconut shell ash and silica fume in concrete. International Research Journal of Engineering and Technology, **5(7)**, 2175-2179.

30. M. Mohamed Barveen and K. Gunasekaran, (2018), Study on The Effect of Rice Husk Ash in Coconut Shell Concrete. International Journal of Civil Engineering and Technology, **9(5)**, 264–273.

31. M. Uday Bhaskar, S. Manasa & Anith Kumar T., (2019), Concrete mix using solid waste aggregates. International Journal of Innovative Technology and Exploring Engineering **8(10)**, 84-89.

32. Sen, S. and Chandak, R., (2015), Effect of coconut fibre ash on strength properties of concrete. International Journal of Engineering Research and Applications **5(4)**, 33-35.

33. Shetty, M. S., (2000), Concrete Technology Theory and Practice (4thEdition). S.Chand & Company Pvt Ltd. New Delhi, India.

34. Mwilongo, K. P., Machunda, R. L., & Jande, Y. A. C., (2020), Effect of elevated temperature on compressive strength and physical properties of neem seed husk ash concrete. Materials, **13(5)**, 1198. doi:10.3390/ma13051198.

35. Ibrahim, R. K., Ramyar, K., Hamid, R., & Taha, M. R., (2011), The effect of high temperature on mortars containing silica fume. Journal of Applied Sciences, **11(14)**, 2666–2669. doi:10.3923/jas.2011.2666.2669.