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Concrete mix rationalization through sustainable ingredient using coconut shell ash

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Abstract
The rationalization of concrete mix components can yield several benefits, encompassing cost efficiency, enhanced performance, and diminished environmental impact. Cement, a primary binding material in concrete, faces challenges in meeting escalating demand due to rapid urbanization. Partial substitution of cement with alternative materials offers a solution. The selection of a suitable replacement material depends on specific requirements and cement conditions. The judicious use of replacement materials can enhance concrete's performance, durability, and workability while meeting strength criteria. Fly ash from thermal power plants is a widely utilized cement admixture, but its availability and environmental sustainability pose challenges. Eco-friendly alternatives, such as coconut shell ash (CSA) derived from coconut shell (CS), present viable options for partial cement replacement. This study employed CSA through a methodology involving CS combustion in a boiler at temperatures ranging from 300°C to 350°C. Ash collected from the boiler bottom, sieved through a 90-micron IS sieve, formed the basis for further investigation. The research focused on ordinary portland cement (OPC), coal ash (CA), and CSA. Chemical tests assessed parameters like loss on ignition (LOI), magnesium oxide (MgO), sulfuric anhydride (SO_3), insoluble residue, percentage of lime (SiO_2, Al_2O_3, and Fe_2O_3), chloride content, and Al_2O_3 to Fe_2O_3 ratio per IS CODE:4032-1985 for material composition. Results were cross-verified against IS CODE 269:2015 (OPC- 43 Grade). Physical tests, including fineness, soundness, initial and final setting and compressive strength, were performed to assess quality aspects. Partial replacement ratios of 0%, 5%, 10%, 15%, and 20% were determined. The chemical test results highlighted a high MgO content in Coconut Shell Ash (approximately 21.8%), exceeding IS 269:2015 standards. Physical tests indicated that MgO prolonged the cement setting time in OPC/Coconut Shell Ash mixes by up to 15%. Compressive strength measurements after 3, 7, and 28 days revealed a 14.42% increase in the average strength of portland cement concrete (PCC) compared to a 6.6% increase for OPC, underscoring the potential benefits of CSA, as a partial cement replacement.

Keywords
Coconut shell ash, Concrete, Chemical test, Physical test, Magnesium oxide, Compressive strength test.

1.Introduction
Due to urbanization, demand for concrete has been increasing up to 10 million cubic meter per year. Therefore, there is an urgent need to reduce the requirement for ingredients such as cement, sand, and aggregate. Cement serves as a binding material in concrete, which is being used in the construction industry since ancient times [1, 2]. The admixtures are added in order to reduce the demand and supply gaps for cement, and the most common admixture is coal ash (CA) obtained from thermal power stations.

Thermal power plants need huge amount of coal thereby affecting massive quarrying which, in turn, causing environmental concerns [3–5]. Most tropical countries, particularly the Indian coastal region, produce 15739 million nuts per year, ranking second. Only to Indonesia, which produces 16,498 million nuts per year.

Coconut shell (CS) is an agricultural biodegradable waste, but because full degradation is not possible, it contributes to solid waste. CS contributes approximately 3.18 million metric tons of solid waste per year [6, 7]. Many researchers have found that 90% of the materials of the coconut trees such as

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coconut fibers, empty fruit bunches, trunks, fronds and shells form solid waste. This solid waste is buried in an open landfill or left to decompose, causing to water pollution in ponds and rivers [8]. Some industries have used coconut waste as a substitute for coal, with varying degrees of carbon dioxide (CO_2) and methane emissions. The time has arrived to think about sustainable management based on economic and environmental issues for the disposal of coconut waste [9]. There are various efforts needed to solve global coconut waste management issues such as storage, utilization, and environmentally friendly decomposition. The elementary purpose of this research is to classify the coconut shell ash (CSA) i.e., to classify its physical and chemical properties. CSA can also be utilized as an alternative pozzolanic material in cement, which enhances the binding properties of the cement. Now a days CA from thermal power plants is a widely used alternative material, likewise CSA can also be used and recommended as cement admixture [10]. This study aims to provide solution to overcome the problem of finding a suitable sustainable substitute to partially replace the cement and simultaneously to check the environmental problem caused by unutilized coconut waste. According to IS 269:2015 physical and chemical tests are done and the permissible limit are recommended for quality control of the ordinary portland cement (OPC) used for concrete. Tests for the physical properties like fineness, soundness, setting time, compressive strength (N/mm^2), and the chemical properties tests of loss on ignition (LOI), magnesium oxide (MgO), sulfuric anhydride (SO_3), insoluble residue and percentage of lime, silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and Iron (III) Oxide (Fe_2O_3) have been done. Further, this research is being conducted to analyze the physical and chemical characteristics of CSA for usage as a partial substitution of cement.

To check the suitability of the substitute material, Various laboratory tests are necessary which provide the basis for furthering the study. Normally, when any material is heated up to a maximum of 1000 °C, it goes through a mass loss, which is normally referred to as LOI.

The LOI method is utilized in the cement industry for measurement of the water presence and/or carbonation, which can degrade the quality of the cement [11]. A high LOI result can point to carbonation and/or pre- hydration, possibly due to improper storage or contamination during transportation or supply. Using the LOI method to test cement can be applied as a quality control tool to monitor and enhance the final product.

MgO, also known as magnesia MgO, is a crucial component used to produce OPC clinker [12]. The majority of the MgO is mined from the magnesium carbonate found in limestone, which makes up about 77% of the raw meal by weight. The raw meal is typically heated to around 1450°C during the clinkering process, causing the magnesia to become dead-burnt and known as “periclase”. This type of magnesia hydrates gradually in water at normal temperature, and its hydration within cement paste is likely to be even slower and can take several years.
The process of grinding Portland cement clinker without adding a retarder often results in a quick set due to rapid reactions with water. To address this, it is common practice to include a retarder in the manufacturing process of Portland cement to control the rate of initial reactions. Currently, the most widely used retarders are gypsum (calcium sulfate dihydrate) and hemihydrate. Adding the appropriate quantity of gypsum to the clinker is a crucial step in cement production [13, 14].

The ultimate sulfur trioxide content in the cement is discovered by the inclusion of additional gypsum and other sulfate sources. The raw materials utilized in the generation of Portland cement clinker and the by-products of fuel combustion are additional sulfate sources present in the clinker. At OPC, a small amount of gypsum is utilized to regulate the primordial hydration reactions of tricalcium aluminate (C_3A) and manage the setting time. Additionally, a limited quantity of gypsum and SO_3 are included to provide adequate protection against abnormal expansion. The American Society for Testing and Materials (ASTM) C150, have a tradition of placing restrictions on the SO_3 content in Portland cement, with a maximum limit of 3.0% for Types I and II cements and 3.5% for Type III cement.

The composites of Portland cement and steel are prone to absorbing chloride from their surrounding environment. This article provides a comprehensive review of the literature outlining degradation processes and testing methods. Chloride has a minimal impact on plain cement paste except for causing the solubility of cement to increase, but it can harm the protective layer around embedded steel. The focus is on understanding the fundamental chemical and physical principles of corrosion and incorporating them into a broader view [15, 16]. Simple testing methods and calculations may not accurately reflect the complicated interactions between the steel-cement interface and cement components. The notion of a "threshold" explained by a specific content of chloride or chloride-to-hydroxide ratio is only an estimate and does not take into account the other cement components or oxygen levels at the interface. In concrete, the movement of chloride can be slowed down by chloride binding, and the results of calculations demonstrate that the main binding mechanism is due to the family of hydrated calcium aluminate (AFm) content of the paste. Recommendations are provided for improving experimental methods for studying corrosion.

1.1Challenges

There are the following challenges that require collaborative efforts among researchers, industry professionals, and regulatory bodies:

- **Availability and consistency of CS:** Generally, the maximum portion of the CS is thrown in the mixed-trash, and sorting thereafter becomes difficult. Social awareness and appropriate waste management system, therefore, needs to be introduced so that sorted CS can be collected before it is thrown into the garbage bins as mixed-trash.
- **Effect on concrete properties, performance and long-term durability:** The incorporation of CSA into concrete mixes affects its properties, and the performance characteristics and behavior of concrete in the long run need to be evaluated. Many factors, such as chloride ion penetration, carbonation resistance, and resistance to chemical reactions, are required to be tested and researched for evaluating the durability and service life of the concrete structures.
- **Compatibility with other ingredients:** The interaction of CSA with other concrete ingredients, that is, cement, water, coarse and fine aggregates, and reinforcement bars, is different. The compatibility issues may affect the compressive strength, workability, and setting time of the concrete.
- **Long-term durability and performance:** Evaluating the long-term durability and performance of CSA mixed concrete is essential for ensuring its suitability for sustainable construction. Many factors, such as chloride ion penetration, carbonation resistance, and resistance to chemical reaction effects, are required to be tested and researched for evaluating the durability and service life of the concrete structures.
- **Cost and economic viability:** Sustainability is the most essential factor for using CSA as a concrete ingredient, but its cost and economic viability should not be ignored in order to justify its practical implementation on a larger scale.
- **Standardization and code compliance:** Global and Indian standardization, regulation, and compliance are required for integrating CSA into concrete mixes for construction. To ensure its safe usage and acceptance for construction practices, proper research, testing, and guidelines must be established.

1.2Motivation

The motivation behind this research on concrete mix rationalization through the sustainable ingredient of CSA emerges from the essential requirements for safe environmental issues and promoting sustainable practices in the construction industry. By integrating CSA as a waste by product, as a sustainable ingredient in concrete mixes, the environmental impact can be minimized while maintaining or maximizing the performance of concrete structures. The motivation is also inspired by the other advantages, such as the minimized heat of hydration and higher resistance to deterioration, that create an opportunity for waste management and integrate value into an otherwise underutilized resource. This motivates significant development to achieve a more sustainable and greener future in the construction industry.

1.3Objectives

The objectives of this article are as follows:

- **To test the natural properties of CSA:** Testing the composition and natural physical properties of CSA is required to evaluate its suitability in construction as a sustainable ingredient and partial substitute in concrete mixes.
- **To optimize concrete mix ratio:** Evaluating the optimal ratio of CSA that is required to be incorporated into concrete mixes to achieve standard performance characteristics such as compressive strength, workability, durability, and initial and final setting times.
- **To evaluate the influence on concrete properties:** Evaluate the impact of CSA on key properties of concrete, having flexural strength, compressive strength, chloride ion penetration, water absorption, and carbonation resistance.

The above objectives outlined the aim to provide a comprehensive understanding of the potential benefits, limitations, and practical considerations of incorporating CSA as a sustainable ingredient in concrete mixes. By achieving these objectives, the study aims to contribute to the promotion and adoption of environmentally friendly and sustainable practices in the construction industry.

This research on the sustainable ingredient of CSA makes the following contributions:

- **Sustainable construction practices:** By exploring the use of CSA as a sustainable ingredient in concrete mixes, the study contributes to the promotion of sustainable construction practices. It offers an eco-friendly alternative to traditional concrete production methods, reducing the reliance on finite resources and minimizing environmental impact.
- **Waste utilization:** The study contributes to waste management efforts by utilizing CSA a waste byproduct, as a valuable ingredient in concrete mixes. This helps in reducing waste generation, promoting circular economy principles, and adding value to an otherwise discarded resource.
- **Performance optimization:** The study aims to optimize the mix design by determining the optimal proportions of CSA in concrete mixes. This contributes to maintaining or enhancing the performance characteristics of concrete structures, such as durability, compressive strength, and workability, while incorporating a sustainable ingredient.
- **Durability assessment:** By evaluating the long-term durability and concrete structures performance incorporating CSA the study provides insights into the material's resistance to chemical attack, carbonation, and other forms of deterioration. This contributes to ensuring the longevity and sustainability of the constructed structure.
- **Guidelines and recommendations:** The study aims to develop minimum practical guidelines, specifications, and recommendations for the implementation of concrete mix rationalization using CSA. This contributes to facilitating the adoption of sustainable practices by providing clear instructions on mix proportions, quality control, and compatibility considerations.

Overall, the study's contribution lies in advancing sustainable construction practices, waste utilization, and optimizing concrete mix design to achieve a balance between environmental considerations and high-performance concrete structures.

The remainder of this paper is organized as follows: Section 2 provides an exploration of the challenges identified in the existing literature. Section 3 outlines the materials and methods utilized. In section 4, findings of this study and the contributions of our research was presented. It is discussed in section 5, with concluding remarks presented in section 6.

2.Literature review

Concrete is the indispensable material used for building construction all over the globe. It is considered a very useful substance for human development. This section surveys the alternative partial substitute materials that can be used in concrete along with cement. In addition to substituting 10%, 20%, 30%, and 40% of fine aggregates with coal bottom ash (CBA), Bheel et al. [17] proposed the experimental analysis and study using rice husk ash to substitute 5%, 10%, and 15% of the cement in concrete. Their results demonstrated that as the dosage of CBA and rice husk ash was increased in concrete, workability and water absorption decreased. However, adding 5% rice husk ash and replacing CBA for 30% of the fine aggregate enhanced the compressive strength and split tensile strengths at 28 days by 9.10% and 7.73%, respectively.

Yun et al. [18] examined the potential of coal fly ash (CFA) and CBA as replacements for Portland cement and sand in the high-volume fly ash (HVFA) mixture of concrete. Both CFA and CBA are considered waste products of coal-fired power plants and are of interest due to the huge amounts generated annually. Their study aimed to promote the application of these waste products to minimize the usage of natural river sand, which is in short supply, and decrease the pollution generated during the manufacturing of Portland cement. A numerical analysis was performed to calculate the optimal CBA substitution percentage based on the experiment's failure load results, and the addition of superplasticizers resulted in improved workability and compressive strength.

Ngohpok et al. [19] presented how effective concrete can be made by substituting the CA with CBA and recycled concrete while using its properties. The aim of their research was to investigate the impact of substituting natural broken limestone aggregate with CBA recycled concrete aggregates on the characteristics of pervious concrete. The need to replace conventional concrete has arisen due to a rise in demand and the depletion of natural resources. To address this issue, Kumar et al. [20] conducted a study using CS as a replacement for coarse aggregate as an agricultural waste in concrete. Prakash et al. [21] examined the density, split tensile strength, compressive strength, and flexural properties of two distinct mixes of CS concrete.

These mixes were designed using various proportions of fly ash as a substitute for cementand tested accordingly. Oyedepo et al. [22] showed that in their study, by using CSA and palm kernel shell ashin place of some cement in concrete, but only in small amounts, it is possible to reduce the quantity of cement needed in the concrete, resulting in reduced production costs and less environmental harm from disposing of agricultural waste.

Vasanthi et al. [23] used 3D graphical analysis to calculate the optimal substitution levels for both cement and coarse aggregate. The agricultural industry produces unavoidable by-products in the form of CS and their ash. To manage these waste materials effectively, a study was conducted to assess the impact of using CSA as a substitute for cement and CS as a substitute for coarse aggregate. The study tested various replacement levels ranging from 5%to 30% for both cement and coarse aggregate.

Ranatunga et al. [24] conducted an assessment of an ideal concrete mix design by incorporating CSA as a partial substitutefor cement. Their findings indicated that cement could be substituted with CSA, reaching up to 20% replacement while still achieving the desired average compressive strength of 25 MPa. This substitution also led to a reduction of over 15% in global warming potential, thus mitigating its environmental impact.

Lumbab et al. [25] incorporated CSA as a partial replacement for cement in the production of concrete hollow blocks. Soundararajan et al. [26] utilized CS with bagasse ash in concrete and achieved a satisfactory level of compressive strength while preserving the material's hardened properties, which contributed to the sustainability of the built environment. Mohamed et al. [27] reviewed an examination of fly ash/fiber as a potential alternative to traditional concrete reinforcement agents, such as fibers, silica fumes, cocoon fibers, and other materials, with a focus on enhancing the mechanical propertiesof concrete. Bheel et al. [28] incorporated agricultural waste, including CSA and groundnut shell ash, into a ternary mixture, offering synergistic advantages when combined with Portland cement. This sustainable blend can be effectively employed as a ternary cementitious component in concrete. Hasan et al. [29] investigated a study that examines the properties of lightweight and eco-friendly concrete by incorporating CS aggregate as a sustainable alternative to traditional aggregates in the construction industry, thus contributing to a more environmentally friendly construction approach. Thilagashanthi et al. [30] examined how the durability performance of concrete produced using treated CS as an aggregate was affected by treating the CSA with six different methods.

Dos et al. [31] conducted a study to explore the behavior and attributes of mortars utilized for rendering and as a component of the sealing system, which were manufactured with varying quantities of coconut fibers. The outcome revealed that such mortars exhibited reduced weight, but achieving the desired workability necessitated the use of additives or an increased water content. Alfar et al. [32] worked on creating concrete block pavement by incorporating limed sugarcane press mud with CSA as additives to the cement and sand mixture. Prayuda et al. [33] investigated and examined research to explore substitute materials for cement in the production of mortar. Their study involved the assessment of both the freshand hardened properties of mortar on a laboratory scale.

Yousefi et al. [34] evaluated how coconut palm leaf ash influenced the mechanical properties of polypropylene fiber-reinforced concrete, encompassing factors such as tensile and compressive strength, permeability, and the impact of sea tidal conditions onthe concrete's strength. Ikeagwuan et al. [35] conducted a comprehensive examination of the stability of modified expansive soil slopes by employing CSA in a study that incorporated laboratory experiments, numerical simulations, and predictive modeling.

Yousheng et al. [36] conducted a review and provided an account of the impact on both the mechanical and physical properties of concrete when crop residues like coconut husk, corn, bagasse, and rice are used as replacements for coarse and fine aggregates or cementitious materials in concrete production. Bhoj et al. [37] investigated the utilization of CS as a substitute for coarse aggregates in concrete. Given the significant water absorption characteristics of CS, pre-soaked CS were employed as replacements for conventional coarse aggregates. Krishnaswami et al. [38] used Glazed Iso Balls as the fine aggregate and

CS as the coarse aggregate, resulting in a substantial reduction in the concrete's overall weight without compromising its strength. Their experimental data demonstrated that the specimens exhibited a maximum compressive strength of 36 N/mm^2 and a minimum compressive strength of 32 N/mm^2. Herring et al. [39] showed that even when CSA exhibits limited pozzolanic reactivity, a reinforced concrete beam containing CS can still maintain its structural performance when subjected to applied loads. Itam et al. [40] conducted research to identify the optimal percentage for partially replacing cement with CSA in concrete. Their findings indicate that as the percentage of CSA in the concrete mix increases, the concrete's strength decreases. Therefore, they determined that a 5% partial replacement of CSA in the concrete mix is the most appropriate option.

Bhuvaneshwari and Sanjeev [41] studied the strength and density properties of CS lightweight concrete based on Alccofine ultrafine ground granulated blast-furnace slag (GGBFS) to assess its flexural characteristics. Tamilselvi et al. [42] conducted an experimental investigation to evaluate the flexural strength, compressive strength, load, and displacement properties of concrete specimens. These specimens were made using crushed CS waste as CA to produce lightweight concrete. Shah et al. [43] examined the mechanical characteristics of concrete incorporating recycled aggregates and coconut fibers. Their primary focus was on advancing the development of sustainable and ductile cementitious composites by repurposing coconut and construction waste materials.

Prakash et al. [44] explored the impact of incorporating fly ash on the mechanical and durability properties of concrete containing CS. The inclusion of fly ash in CS concrete resulted in reduced levels of permeable voids, water absorption, sorptivity, and chloride permeability. Janani et al. [45] carried out a comprehensive review on the mechanical characteristics of concrete when utilizing CS as coarse aggregates. The primary objective of this review was to provide insight into the use of CS as coarse aggregates. Furthermore, the review also addressed the durability properties and elasticity modulus of concrete incorporating CS as coarse aggregates. Aziz et al. [46] effectively utilized CS, a waste industrial by-product, to create lightweight aggregate concrete with acceptable strength. Their investigation assessed the potential of using CS as both lightweight and normal-weight aggregates in concrete, resulting in a composite coarse lightweight aggregate that demonstrated low drying shrinkage and excellent stability in both short- and long-term applications.
Many researchers had done this in order to determine the usefulness of the material as a partial replacement for cement, but few authors had used CSA and conducted physical and chemical tests on it in order to determine its suitability as a partial replacement for cement.

3.Materials and methods

The sample CS waste shown in *Figure 1* weighing approximately 500 kg, was collected from Kali Mata Temple at Jahangirabad, Bhopal. The material CS was left to sun-dry in order to remove the moisture content. After a week, the material was taken for further processing. This dry material of CS was taken into the boiler at a temperature of 300-350 °C, as shown in *Figure 2*, which saved energy because the burning temperature of cement is 1450 °C. After creating CSA, it was sieved using "Indian Standard Sieve Analysis," followed by a chemical composition test to identify the properties of the materials used (*Figure 3*). The boiler is located at R.K.D.F. University in Bhopal, which is Asia's first and the world's third solar integrated carbon capture plant and is funded by the central power research institute (CPRI). After burning, the residual bottom ash ofthe boiler–20 kg of CSA, –was left for cooling for a day. The next day, residual material was sieved by IS-90 microns, and the material that passed was collected, which was up to 7 kg. Material was collected and used for further investigation. The same method was applied for the collection of CA.

Figure 1 Sample (CS) collection

Figure 2 Sample CSA preparation

(a) (b) (c)

Figure 3 (a) CSA, (b) OPC (43-grade), (c) CA

3.1Methodology adaption

The following methodology is followed (presented in the flow chart also, *Figure 4*):

1) The material such as cement, CSA and CA are taken as IS code required is IS Sieve No. 9 of 90 Micron.

2) Chemical test is performed as the method adopted as per IS: 4032-1985.

3) The following are key indicators that have been determined while conducting chemical tests Such as LOI, MgO, SO_3, Insoluble residue, Ratio of % of lime SiO_2, Al_2O_3 & Fe_2O_3, Chloride Content, Ratio of % of Al_2O_3 that Fe_2O_3

4) The test results are verified with the permissible limits as per IS 269:2015 (OPC-43 Grade).

5) Following physical tests are performed to ascertain the quality aspects, and partial replacement proportions as 0%, 5%, 10%, 15%, 20% are decided,

- Fineness Test
- Soundness Test
- Initial and Final Setting Test
- Compressive Strength Test

6)Conclusion are drawn as the per IS Code provisions prescribed in IS: 4031 (Part 1.3, 4, 5 and 6)-1988, IS 10080-1982, IS: 650-1966 and IS: 269-1976 after the result analysis.

3.2Equipment and apparatus details

The list of specific equipment and apparatus used for physical and chemical tests is shown in *Table 1*, which represents test methods, procedures, parameters, and standards. In this research work, cement has been partially replaced with CSA in the proportions of 0%, 5%, 10%, 15%, and 20%. Physical and chemical tests were performed by following the procedure given in the IS code, as shown in *Table 1*. As per IS Code 4031(Part 6)-1988, we have made three specimens' samples to determine the compressive strength for each of the 3 days, 7 days, and 28 days of the curing period. Their average value was taken as a compressive strength result. A total of 45 samples were prepared for the above experimental work.

For chemical tests, standard lab safety precautions are followed. Like gloves to protect hands from contact with chemicals when handling materials, protection will be provided by using dust masks, respirators, and fire safety protocols. The found material can be used to optimize the use of replacement materials. In the context of real-world application or the field of cement research. If a certain replacement proportion shows a significant improvement in properties like strength or durability, it may be applied in practice to increase strength, reduce costs, improve performance, or reduce the environmental impact of construction materials.

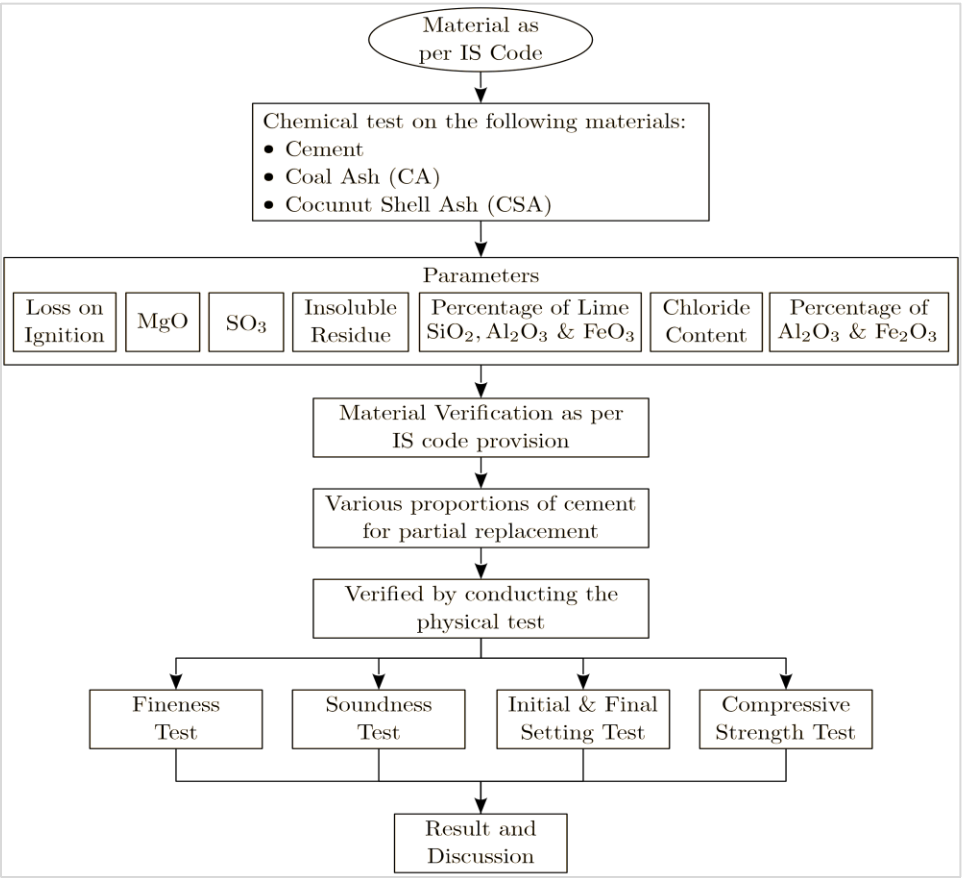

Figure 4 Workflow of methodology

Table 1 Equipment and apparatus used

Test	**Test parameters**	**Test methods/procedures**	**Equipment and apparatus**
Cement (OPC-43) Grade, CSA, CA Chemical Test	LOI	IS:4032-1985	Muffle furnace, weight balance
	Sulphuric Anhydride	IS:4032-1985	Muffle furnace, weight balance
	Insoluble Residue	IS:4032-1985	Muffle furnace
	Ratio SiO_2, Al_2O_3 & Fe_2O_3	IS:4032-1985	Muffle furnace, weight balance)
	Chloride	IS:4032-1985	By titration
	Ratio of Al_2O_3 that Fe_2O_3	IS:4032-1985	Muffle furnace, weight balance
	Fineness test	IS:4031(Part 5) -1988	IS Sieve, weight balance

Test	Test parameters	Test methods/procedures	Equipment and apparatus
Cement, CSA Physical Test	Soundness test	IS:4031(Part 5) -1988	Le-Chateliers, Water bath, Vernier Calliper, weight balance
	Initial and Final setting test	IS:4031(Part 5) -1988	Vicat's Apparatus, Stop watch, Gauging Trowel
	Compressive Strength test	IS:4031(Part 5) -1988	Sand, Vibrating Machine

4.Result and discussion

Chemical composition test result of cement (OPC-43) Grade, CSA and CA their results are shown in the *Table 2.*

Table 2 Chemical composition test result and comparison

S. No.	Compound	Test method	Requirement IS 269:2015 (OPC-43 Grade)	OPC-43 Grade (%)	CSA (%)	CA (%)
1	LOI	IS:4032-1985	5% Max.	1.750	1.210	1.160
2	MgO	IS:4032-1985	6% Max.	4.300	21.800	32.200
3	SO_3	IS:4032-1985	3.5% Max.	0.680	0.260	0.610
4	Insoluble residue	IS:4032-1985	5% Max.	3.340	8.600	85.000
5	Ratio of % of lime SiO_2,Al_2O_3 & FeO_3	–	Ratio% of CaO% of SiO_2, Al_2O_3, Fe_2O_3/ (2.8SiO_2 + 1.2Al_2O_3+0.65Fe_2O_3) (Limit + 0.66-1.02%)	0.990	0.190	0.046
6	Chloride Content	IS:4032-1985	0.1% Max.	0.028	0.082	0.064
7	Ratio of % of Al_2O_3 thatFe_2O_3	–	0.66 % Min	0.330	2.930	3.170

4.1Physical test

4.1.1Fineness test

For fineness of material, both cement and CSA are used after passing an IS sieve of 90 microns. A test on OPC cement was conducted, and it was found to be satisfactory. The fineness of the material (cement) and CSA are important in determining the rate of heat evaluation, the rate of strength gain, and the rate of hydration. The finer the cement particle, the greater the surface area and the faster the strength development. The finesses test was performed on an CSA as presented in *Table 3*. Hence both OPC and CSA are within permissible limit of IS code recommendation of 10% of original weight.

Table 3 Represented percentage fineness of CSA and OPC

Sample	Material weight (W_1)	Residual weight (W_2)	Fineness (%)
OPC	100 gm	0.07 gm	7%
CSA	100 gm	0.09 gm	9%

4.1.2Soundness test

The Le Chatelier method, as per IS: 4031-Part 3-1988, is used to determine the soundness of cement by taking 100 g of sample with a partial percentage mix of CSA as shown in *Table 4*. Water has been added per standard consistency paste, as shown in *Table 4* and the graphical representation in *Figure 5.*

4.1.3Initial and final setting time

The initial setting time is to be adequate for the finishing operations, i.e., repairs, transportations, and placements of the concrete after admixture of coconut ash mix with OPC for a good quality of construction, as shown in *Table 5* and *Figure 6.*

From *Table 4* and the graphical replacement shown in *Figure 7*, the water requirement to make a consistent standard cement paste decreases after a 15% substitution of the cement with coconut ash. This is due to an increase in the pozzolana property of cement, and it also increases the initial/final setting time of the cement up to a level as shown in *Figure 7*. According to research, the setting time of cement after 8% was increased by MgO content, but after 15%, MgO has no effect on the cement's setting time.

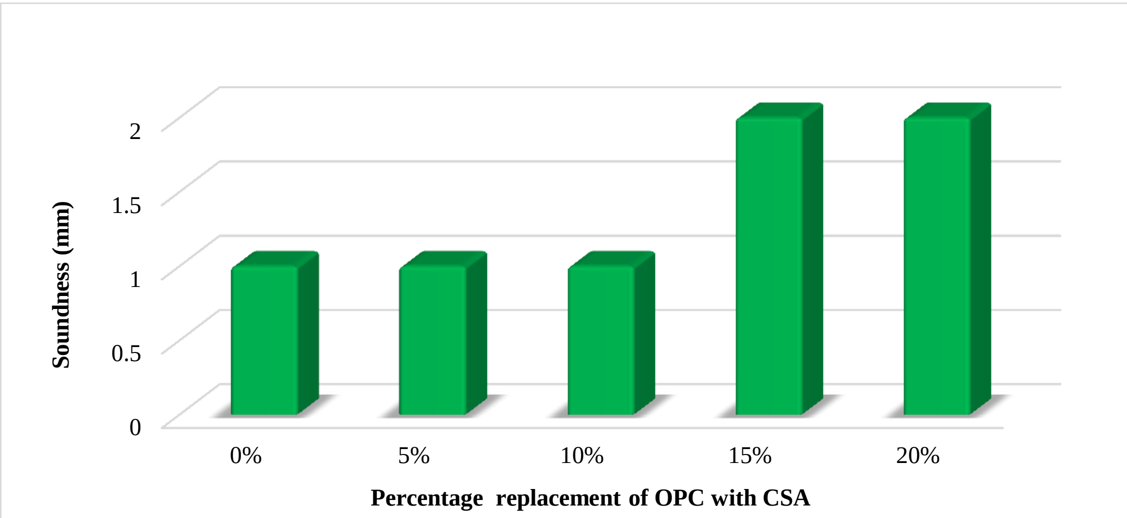

Figure 5 Soundness of percentage replacement of OPC with CSA

Table 4 Soundness test of OPC with partial replacement by CSA

S. No.	OPC (gm)	CSA (gm)	Replacement OPC by CSA%	Distance separating indicator submerge at ordinary temperature water for 24 hr. (L_1)	Distance separating indictor submerge at the boiling for 3 hr. (L_2)	Difference between These 2 Measurement $(L_1 - L_2)$
1	100	0	0%	13	12	1
2	95	5	5%	12	11	1
3	90	10	10%	12	11	1
4	85	15	15%	14	13	2
5	80	20	20%	12	10	2

Table 5 Consistency of the standard cement paste with initial/final setting time of partial substitution of the OPC by CSA

S. No.	OPC (gm)	CSA (gm)	Replaceme nt OPC by CSA %	W/C Ratio for consistence of standard cement paste	Initial setting time (minutes)	Final setting time (minutes)
1	300	0	0%	28	30	600
2	285	15	5%	29	32	630
3	270	30	10%	32	32	650
4	255	45	15%	33	33	690
5	240	60	20%	34	35	750

Table 6 Compressive strength test

S. No.	OPC (gm)	CSA (gm)	Replacement OPC by CSA %	Compressive strength (MPa)			Initial setting time (minutes)
				3 Days	7 Days	28 Days	
1	200	0	0%	15.05	16.05	19.05	6.6
2	190	10	5%	12.04	14.04	26.08	16.61
3	180	20	10%	10.03	12.04	24.07	20.03
4	170	30	15%	10.00	11.03	16.05	10.00
5	160	40	20%	9.03	10.03	14.04	11.07

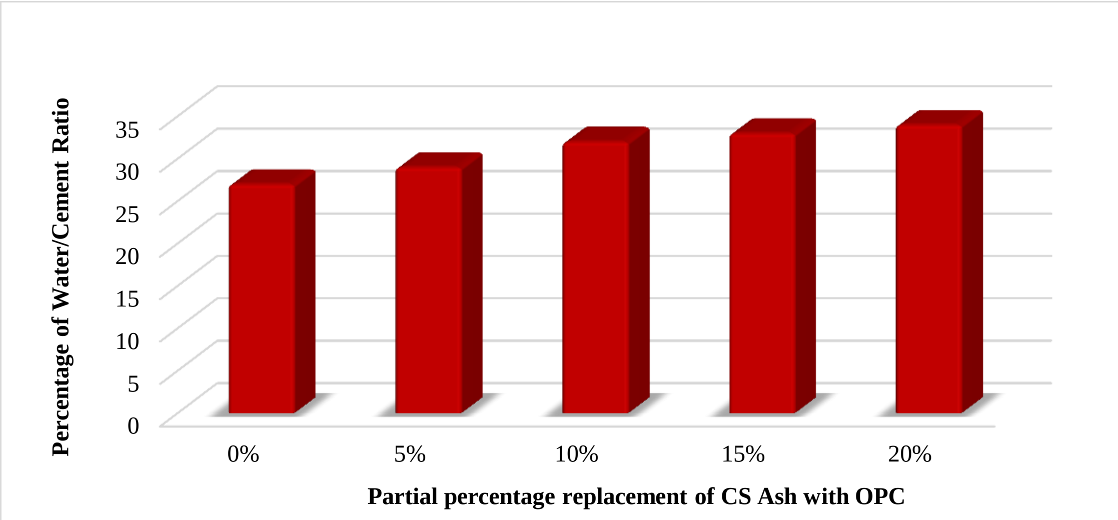

Figure 6 Percentage of W/C ration for making a consistence of standard cement

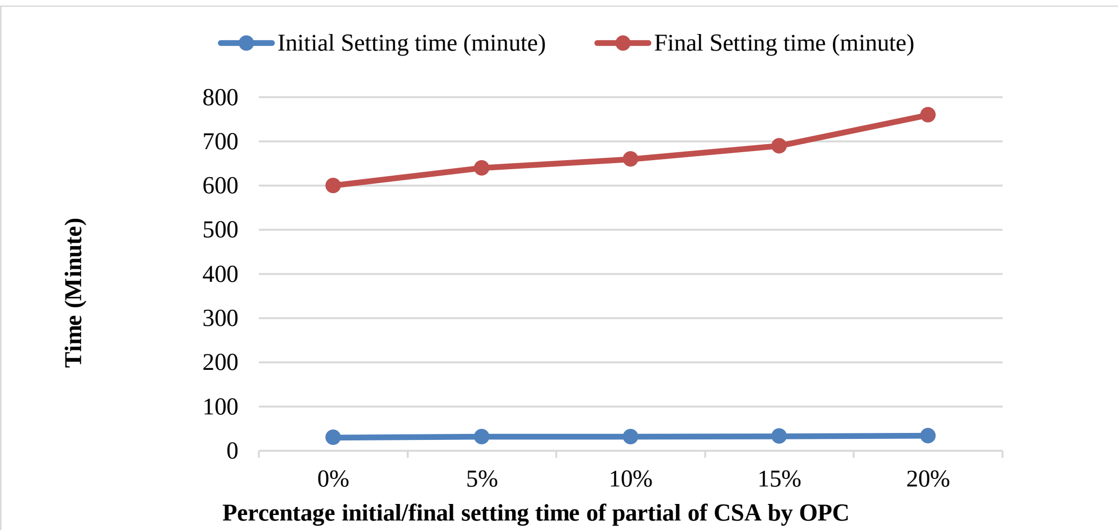

Figure 7 Represented initial/final setting time of partial of CSA by OPC

4.1.4Compressive strength test

In summary, the properties of hardened cement, such as its compressive strength, are evaluated through experiments before it is utilized in crucial projects. The strength of the neat cement paste cannot be measured due to the challenges posed by its excessive shrinkage and subsequent cracking.

Theoretically and experimentally the compressive strength (in N/mm^2) is calculated as:

$$CompressiveStrength = \frac{L_m}{A_c}$$

Where L_m represents maximum applied load and A_c represents area of the cube.

The compressive strength testing machine with cubic samples are presented in *Figure 8*. The compressive strength is determined by making a $70.6 \times 70.6 \times 70.6$ mm cube using a mix of cement, standard sand, and water. The compressive strength was tested after mixing 0%, 5%, 10%, 15%, and 20%; the strength was cheeked 3 days and 7 days after curing, in accordance with IS:4031 (part 6) (1988), IS:10080 (1982), IS:650 (1966), and IS:269 (1976), and the results are shown in *Table 5*. For a standard mix, the increase in strength from 3 days to 7 days is only 6.6%. But for various additive mixtures with CSA as shown in *Table 6*, the average strength increase from 3 days to 7 days is increased by 14.42% as presented in *Figure 9*.

Figure 8 Compressive strength testing

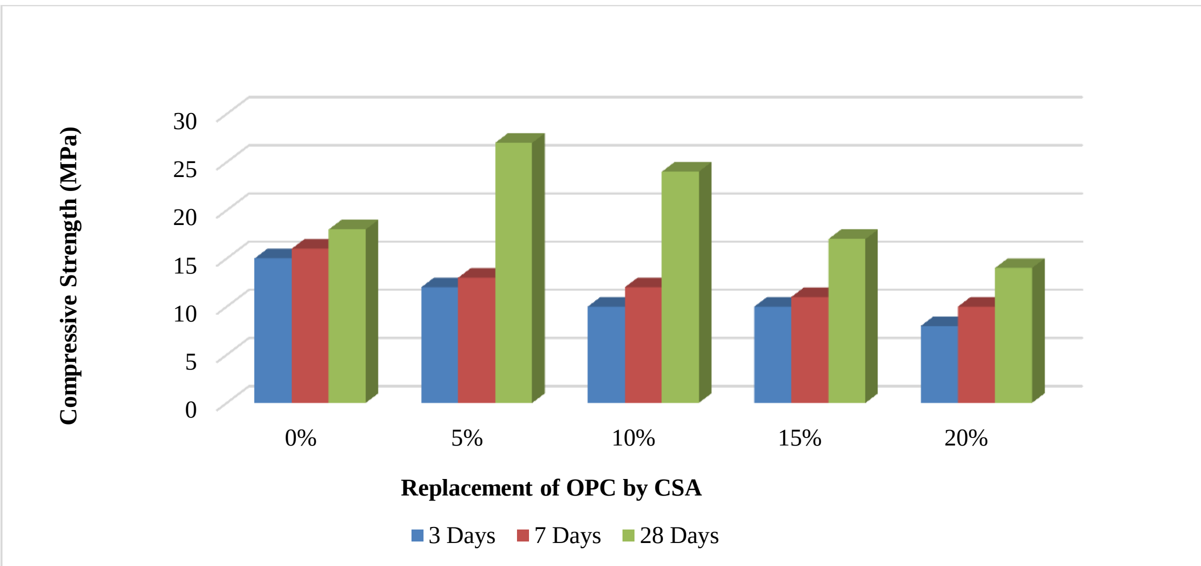

Figure 9 Represented compressive strength test result

From the above research, it can be concluded that an admixture of 5%-10% can produce a desirable strength, which is supported by other authors. The study's strength limitation could have been checked up to 28 days in order to determine the full strength of cement. The compressive strength increases by replacing up to 5-10%.

5.Discussion

5.1Discussion on chemical composition of cement (OPC-43) Grade, CSA and CA.

5.1.1Effect of LOI on cementations properties

Researchers examined the effect of fly ash with a decreased level of ignition on the fresh concrete mixture. They wanted to determine if it could enhance the concrete's properties and make it equal to or better than regular concrete when used under sulfate conditions. Additionally, they were interested in finding out if the fly ash would enhance the workability and productivity of the mixture and reduce its unit weight as the amount of fly ash cement maximized.

The researchers also investigated replacing concrete with 10% and 20% fly ash. Instead, cement in a 5% sodium sulfate solution showed improved compressive strength. In this research, the chemical test of the LOI revealed that coconut ash and CA were 1.21% and 1.16%, respectively, which were within the permissible limit of 5% as per IS Code 269:2015 (OPC-43 Grade), and the sample was tested using IS Code 4032:1985 As a result, CS and fly ash can be applied as a partial substitution for the cement.

5.1.2Effect of MgO on cementations properties

Due to the expansive properties of MgO, it is used to minimize the shrinkage of cement-based materials. It enhances the combustibility of raw meal, boosts the intake of free lime, and fosters the creation of C_2S

and C_4A_3S. Additionally, it strengthens the cement and reduces its setting time. $Mg(OH)_2$ is formed when MgO is hydrated, which results in $Mg(OH)_2$. The stability of $Mg(OH)_2$ hydrates is lower than that of calcium silicate hydrates. It is also critical to maximize the water-binder (W/C) ratio in the following two aspects during the hydration process: When 10% OPC was replaced with MgO, the splitting tensile, compressive strength, ultrasonic pulse velocity and strength modulus of elasticity, decreased by 5-8%. As per the testing method for the determination of MgO, IS code 4032-1985 was adopted.

According to the results obtained, IS code 269-2015 (OPC 43 Grade) recommends 6% MgO. MgO is CSA; CA; and OPC cement, which are 3.80%, 4.20%, and 4.40%, respectively. Fly ash has a low MgO ratio and can be treated as a partial cement substitution.

5.1.3Effect of SO_3 on cementations properties

SO_3 content in various cement brands. To effectively manipulate the timing of cement placement a small amount of calcium sulfate (gypsum) is delivered to the clinker. The maximum perfect SO_3 content material SO_3 that prevents sulfate expansion is between 1.5% and 2.5%.

Increasing the SO_3 content in cement improves the expansion properties and extends the setting time, but if it exceeds 3.5%, it can contribute to a rapid decrement in the 28-day strength of Portland cement. The sample testing method for the determination of SO_3 is described in IS code 4032-1985. As per IS 269:2015 (OPC 43 Grade), 3.55 is the maximum SO_3 in the cement. As per the results obtained from the testing of CSA, CA, and OPC 43 Grade cement, the results are 0.26%, 0.61%, and 0.68%, respectively. From the above results, it is decided that CSA can be applied, which has a lower SO_3 than CA.

5.1.4Insoluble residue effect on cementations properties

The insoluble residue, found in Portland cement, is basically a type of non-cementing material. This residue has an effect on the cement's properties, especially its compressive strength. According to ASTM standards, the amount of insoluble residue should not exceed 0.75% in order to control its impact. While the earliest phases of cement mortar's usual consistency and setting durations are unaffected by the presence of insoluble residue in the range of 0.0 to 7.0% by weight in Portland cement, it does have an impact on the strength later on. As per testing, the IS code is IS 4032:1985. The permissible limit per weight of cement is 5.0 percent; for CSA, CA, and OPC cement, the limits are 8.6%, 85%, and 3.345%, respectively. The CSA is slightly higher, which can be used to vary the quantity of insoluble residue in OPC cement.

5.1.5Effect on ratio of lime SiO_2, Al_2O_3, and Fe_2O_3 on cementations properties

Cement is produced by mixing calcium oxide (CaO) with clay, which contains silica and SiO_2, along with aluminum, iron, and MgO. The silica SiO_2 to alumina Al_2O_3 proportion must be between 2.5 and 4.0 for high-quality cement. Additionally, the lime CaO to the total oxide combination of SiO_2, Al_2O_3, to Fe_2O_3 proportion must be around 2:1:1. If there is too much lime, the cement will crack during application.

As per the IS Code 269:2015 (OPC 43 Grade) limit, it lies between 0.66% and 1.02%. As per testing CSA, CA, and OPC grade, they are found to be 0.19%, 0.046%, and 0.99%, respectively. From the above experiment, it was found that waste CSA can be applied to Portland cement as a partial substitution.

5.1.6Effect of chloride content on cementations properties

In reinforced concrete structures, the presence of chloride ions is a major contributor to the steel corrosion. Assessing the amount of chloride in the concrete cover and in close proximity to the steel reinforcement is crucial for determining the corrosion risk.

In this research, the testing method adopted to determine chloride content in materials is given in IS Code 4032-1985. As per IS 269:20415 (OPC 43 Grade), the permissible limit for chloride content is 0.10% max. By weight, the chloride content obtained in CSA, CA and OPC cement is 0.082%, 0.064%, and 0.028%, respectively. Therefore, it can be experimentally decided that CA is a perfect partial substitution for cement.

The quantity of chloride in the cement is controlled at some stage in the manufacturing technique and is defined as 0.01% or less by weight of cement. Chloride is generally present in various environmental conditions that seep into the concrete. The concrete itself is hardly dilapidated by chloride until its concentration is increased a few moles, but the solubility of Portland cement in pure water is improved even at low levels.

5.1.7Effect of ratio of % of Al_2O_3 that Fe_2O_3 on cementations properties

Many experiments were conducted by the author to reduce Al_2O_3 and increase Fe_2O_3, aiming to incorporate a higher amount of bauxite residue in the raw mix. The author also speculated that the substitution of Al_2O_3 for Fe_2O_3 affected the resulting phases, increasing the formation of elites and leading to the formation of a new phase.

According to IS 269:2015 (OPC-43 Grade), srebrodolskite has a minimum permissible value of 0.66%. But the results obtained by testing CSA,CA, and OPC cement are 2.93%, 3.17%, and 0.33%, respectively. Hence, CSA can be applied as a partial substitution for cement.

The above chemical test indicates that CSA can be used in some proportion, such as MgO, and that the above result is supported by the physical test on the cement and CSA. In the case of CA, MgO is also very high because it was generated by the same boiler, which explains why it is not further investigated.

5.2Discussion on physical test for CSA and OPC

From the above physical tests, which were conducted on the partial replacement of cement by using CSA it has been found that the overall performance of CSA mixed in cement is suitable for the following tests:

- For the fineness of material in CSA and OPC found to be satisfactory, it is within the permissible limit as per IS Code.
- For the soundness tests of CSA and OPC, it has not shown much effect on the soundness of cement; it is within the permissible limit as per the IS Code.
- After conducting consistency testing of the standard cement paste with the initial and final setting times of partial substitution of the OPC by CSA. After replacement of CSA in the OPC up to 15%, there is not much increase in the initial setting time of the mix, but there is an increase in the final setting time of the mix; therefore, one can consider the maximum mixing of partial replacement up to 15% of the desirable strength.
- The permissible limit of CSA is up to 15% in cement. After that effect, the MgO increase in the cement, which is already discussed, increases the water-to-cement ratio for the consistency of standard cement paste, and the final setting time also increases. Further investigation was made by creating a cube of standard size 150×150×150, and compressive strength was determined. For the compressive strength of cement, it has been found that 10% is the permissible limit of replacement.

5.3Limitation of this research

This research may have these limitations that need to be considered in the future when in construction:

- **Reduced compressive strength:** CSA usually contains a substantial amount of organic matter, which can lead to a reduction in the compressive strength of the concrete when partially integrated. This reduction can compromise the structural integrity of the concrete.
- **Delayed setting time:** The use of CSA may result in delayed setting times for concrete, which can impact construction schedules and may require additional curing time to achieve the desired strength.
- **Durability concerns:** While CSA can enhance the durability of concrete by reducing permeability, its effectiveness can be limited in harsh environmental conditions, such as exposure to seawater or acidic environments.
- **Compatibility issues:** Compatibility with other concrete additives, such as superplasticizers or air-entraining agents, can be a concern when partially integrating CSA as it may affect the overall mix design and workability.
- **Mixing issues:** In this research, the mixing was carried out using hands; if mixing were done using a machine, the resultmay be different.

The partially integrated use of CSA in concrete may have these limitations related to reduced compressive strength, delayed setting time, durability concerns, and compatibility issues. Researchers, engineers, and builders should carefully assess these limitations and conduct thorough testing when considering the use of CSA in concrete mixes to ensure it meets the specific requirements of their construction projects.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

An experimental investigation was conducted CSA, CA, and OPC to assess their suitability for partial replacement of CSA with OPC. The key findings drawn from this research are outlined below:

1. Various parameters, including LOI, MgO, SO_3, and insoluble residue, were examined. The percentage of lime (SiO_2, Al_2O_3 and FeO_3), chloride content, and the percentage of Al_2O_3 to Fe_2O_3 fell within IS code limits.
2. CSA, exhibited pozzolana properties, making it suitable as a partial substitution for cement.

3. The chemical test revealed a high MgO content in CSA (approximately 21.8%), exceeding the requirement specified by IS269:2015.
4. Physical tests indicated that MgO increased the setting time of cement in an OPC/ CSA mixture by up to 15% before subsequently decreasing the setting time.
5. Compressive strength measurements after 3 and 7 days indicated that the average strength of plain cement concrete (PCC) increased by 14.42%, compared to a 6.6% increase for OPC alone.
6. While CA has been previously used as a partial replacement in OPC, a direct comparison between CSA and CA was not made in this study.
7. This paper aims to identify a sustainable and environmentally friendly construction material for cement concrete, analysing the applicability of CSA as a partial cement replacement.

Future research suggestions

Future studies are recommended to explore the efficacy of using ‘CS’ and its partial substitution as ‘coarse aggregate’ in concrete. Comparative analyses between CSA and CS Aggregate based on cost-effectiveness and technical properties should be conducted. Properties such as water absorption capacity, moisture-retaining capacity, elongation index, and flakiness index should be experimentally evaluated for 'CS' as 'coarse aggregate.' The potential advantages of concrete made with the partial replacement of ' CS aggregate' with 'natural aggregate,' particularly its suitability as lightweight concrete, warrant further investigation.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

Not applicable.

Author’s contribution statement

Vishnu Prasad Dangi: Experimental investigation, writing of paper and communication with journal. **Sudesh Kumar Sohani:** Problem conceptualization, final review of the work from time to time. **Arun Patel:** Conceptualization, problem formation, interpretation of data and finalization of draft.

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Appendix I

S. No.	Abbreviation	Description
1	3D	Three-Dimensional
2	AFm	Family of Hydrated Calcium Aluminate
3	Al_2O_3	Aluminum Oxide
4	ASTM	American Society for Testing and Materials
5	C_3A	Tricalcium Aluminate
6	CA	Coal Ash
7	CaO	Calcium Oxide
8	CBA	Coal Bottom Ash
9	CFA	Coal Fly Ash
10	CO_2	Carban Dioxide
11	CPRI	Central Power Research Institute
12	CS	Coconut Shell
13	CSA	Coconut Shell Ash
14	Fe_2O_3	Iron (III) Oxide
15	GGBFS	Ground Granulated Blast-Furnace Slag
16	HVFA	High-Volume Fly Ash
17	LOI	Loss on Ignition
18	MgO	Magnesium Oxide
19	OPC	Ordinary Portland Cement
20	PCC	Plain Cement Concrete
21	SiO_2	Silicon Dioxide
22	SO_3	Sulfuric Anhydride