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ENHANCING CONCRETE PERFORMANCE WITH COCONUT SHELL ASH: A SUSTAINABLE APPROACH TO CEMENT REPLACEMENT

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ABSTRACT

To improve the performance characteristics of both lightweight and heavyweight concrete structures, this study explores the possibility of using Coconut Shell Ash (CSA) in substitution of some of the Ordinary Portland Cement (OPC) in concrete. After 28 days of curing, compressive strength tests were performed on concrete samples. The results showed that the best compressive strength was achieved by adding 10% to 15% CSA with a water-to-cement (W/C) ratio of 0.4. The results of the study show that concrete with 10% CSA has less water absorption, which increases durability. On the other hand, it was discovered that CSA content increases lengthened setting times and reduces workability. All things considered, the study shows that CSA can function as a useful addition to concrete mixtures, supporting environmentally friendly building methods. It is advised to conduct additional research to investigate.

Keywords: coconut shell ash (CSA), ordinary Portland cement (OPC), concrete performance, compressive strength, sustainable construction.

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1. INTRODUCTION

Concrete is a widely used construction material known for its durability and strength. Historically regarded as a low-maintenance option, its robust nature has made it a preferred choice for various structures. It ranks just behind water in global consumption among man-made materials. However, with rising demand, innovative methods and materials for concrete production are being explored.

The cement production process is energy-intensive, contributing significantly to greenhouse gas emissions and environmental degradation. Additionally, the rising costs of cement production, along with the depletion of natural raw materials, have intensified the search for waste materials or by-products that can partially replace cement in concrete without compromising its strength.

Despite its durability, the increasing costs and environmental impact associated with traditional concrete structures necessitate alternatives. A typical concrete mix using only cement requires a high volume of paste, leading to issues such as excessive shrinkage and heat evolution. This study aims to investigate the use of coconut shell ash (CSA) as a mineral admixture for partial cement replacement in concrete mixes.

1.1 Production of Coconut

In 2018, global coconut production reached 62 million tons, with Indonesia, the Philippines, and India being the top producers. In India, the primary coconut-growing states include Kerala, Tamil Nadu, Karnataka, and several others. While Kerala has the highest number of coconut trees, Tamil Nadu leads in production per hectare, particularly in the Coimbatore and Tirupur districts. Recent policy changes in Goa have reclassified coconut trees, allowing for easier land clearing. The husks and shells of coconuts are valuable as fuel sources and for charcoal production, while coconut shell products are recognized for their effectiveness in contaminant removal.

1.2 CSA Properties

A common natural filler in tropical areas like Malaysia, Indonesia, Thailand, and Sri Lanka is coconut shell. Recent research has indicated that because its high strength, modulus characteristics, and substantial lignin content improve durability and qualify it for construction applications has promise in composite materials. Furthermore, goods like furniture and ropes are made using coconut shell flour. Because of their low cellulose content, the shells also show low moisture absorption, which makes them a suitable natural material for improving flexural capabilities in construction applications and reinforcing epoxy resins.

1.2.1 Properties of coconut shell ash (CSA) and strength analysis

A significant natural filler, coconut shell is imported from tropical nations including Malaysia, Indonesia, Thailand, and Sri Lanka. Numerous natural fillers have been investigated in recent studies for use in composite materials; one potential alternative is coconut shell filler. Because of its high strength, modulus characteristics, and substantial lignin content, composites are becoming more and more durable and appropriate for use in construction.

Coconut shell flour is frequently used to make goods like furniture and ropes in addition to being a filler. Coconut shells are useful because they absorb less moisture because of their low cellulose content. The usefulness of coconut shell particles as a naturally occurring reinforcement material for epoxy resins is the main topic of this paper, with a focus on how well they improve flexural qualities.

Table-1. Chemical composition of cement and Coconut Shell Ash (CSA).

Oxide	Coconut Shell Ash (CSA)	Ordinary Portland Cement (OPC)
SiO_2	20.70%	37.97%
Al_2O_3	5.75%	24.12%
Fe_2O_3	2.50%	15.48%
CaO	64.00%	4.98%
MgO	1.00%	1.89%
MnO	0.20%	0.81%
Na_2O	0.60%	0.95%
K_2O	0.15%	0.83%
P_2O_5	0.05%	0.32%
SO_3	2.75%	0.71%
Loss on Ignition (LOI)	2.30%	11.94%

1.2.2 Pozzolanic properties and chemical characteristics

The capacity of pozzolanic materials, such volcanic ash, to react with calcium hydroxide and generate calcium silicate hydrate (C-S-H) is one of their defining characteristics. Analyzing a material's chemical makeup is often necessary to evaluate its pozzolanic capabilities. Effective pozzolanic materials should have a silica, alumina, and iron oxide content of roughly 70%, according ASTM C618.

These elements are found in large amounts in coconut shell ash (CSA), according to chemical research, suggesting that CSA has pozzolanic potential. Ordinary Portland Cement (OPC) typically contains silica, which is essential for the early strength of mortar and concrete. Therefore, CSA's high silica content suggests that it can be used as a cement alternative. CSA meets the requirements for Class N pozzolan status based on the chemical characteristics listed in ASTM C618.

Natural materials including diatomite, volcanic ash, and pumice that have not been processed or calcined, as well as some clay and slate that could need to be calcined, are classified as class N pozzolans. The Class N volcanic ash exhibits a loss on ignition of less than 10%, which suggests a limited amount of unburned carbon. Higher combustion losses indicate a substantial amount of unburned carbon, which might lower pozzolanic activity, hence this is a desirable characteristic (Nagarajan *et al*., 2014).

Concrete strength may be negatively impacted by a decrease in pozzolanic activity. Moreover, CSA frequently has a moisture content that is higher than that of Class N volcanic ash, which means that it must be dried in an oven before use (Adajar *et al*., 2020). Table-1 provides specifics on the binder's chemical makeup.

2. LITERATURE REVIEW

Because of its possible environmental advantages and affordability, the use of coconut shell ash (CSA) as a partial substitute for ordinary Portland cement (OPC) in the manufacturing of concrete has attracted a lot of attention recently. The viability of utilizing CSA as a partial replacement for OPC was examined by Adeala *et al*. [1], who found that concrete's mechanical qualities had improved. Their research shows that CSA has a favorable impact on compressive strength, suggesting that it can be used as a sustainable building material.

Further supporting this notion, Yerramala *et al*. [3] explored the properties of concrete incorporating coconut shells as aggregate replacement. They found that not only does CSA enhance the durability of concrete, but it also contributes to the overall strength of concrete mixtures. These findings are echoed by Gummadi and Srikanth [8], who examined the effects of CSA and silica fume in concrete, concluding that both additives effectively improve performance characteristics, particularly in terms of workability and compressive strength.

In addition to its strength properties, the durability of concrete incorporating CSA is also noteworthy. Desai *et al*. [7] provided a comprehensive review of studies on the replacement of cement with CSA, focusing on its interaction with steel fibers. Their findings suggest that CSA not only enhances the mechanical properties of concrete but also improves its resistance to environmental degradation, making it suitable for various structural applications.

The pozzolanic activity of CSA is a crucial factor that contributes to its effectiveness in concrete. Joshua *et al*. [10] examined the pozzolanic properties of CSA and its role in sustainable construction, highlighting its ability to react with calcium hydroxide, thus enhancing the strength and durability of concrete mixtures. Similarly, Adajar [11] emphasized the compressive strength and durability benefits of incorporating CSA, confirming its potential as a partial replacement for OPC.

Additionally, Kumar *et al*. [24] studied the properties of concrete's strength utilizing CSA in addition to other agricultural wastes including fly ash and groundnut shell ash. According to their research, mixing these components can improve the performance of concrete and encourage the use of industrial byproducts in buildings.

Bheel *et al.*'s investigation of the effects of CSA on workability and mechanical qualities [13] revealed notable increases in workability without sacrificing the concrete's mechanical integrity. These results are consistent with the study conducted by Nagarajan *et al.* [14], who found that adding CSA to concrete mixtures improves their workability.

Oyedepo *et al*. [16] evaluated the effectiveness of CSA and palm kernel shell ash as cement substitutes in terms of real-world applications, highlighting the advantages of employing regional resources in the manufacturing of concrete. Their research indicates the possibility of lowering the carbon footprints connected to traditional methods of producing concrete.

Overall, the existing literature suggests that incorporating coconut shell ash into concrete formulations offers a sustainable alternative to traditional materials, enhancing both performance and durability. Continued research and practical implementations are essential for optimizing CSA's benefits in the construction sector.

3. OBJECTIVES

a) To assess the effect on concrete's compressive strength by partially substituting Coconut Shell Ash (CSA) for Ordinary Portland Cement (OPC).

b) To examine how CSA affects fresh and hardened concrete's workability, setting time, and water absorption characteristics.

c) To figure out the ideal replacement % of CSA that will maximize the strength and longevity of concrete.

d) To determine if CSA-modified concrete is appropriate for usage in applications involving both lightweight and heavyweight construction.

e) To investigate substitute cementitious materials that lessen reliance on conventional cement to support sustainable building practices.

4. EXPERIMENT ANALYSIS

Figure-1. Cube casting.

Tests on Concrete

Figure-2. Cubes curing.

Slump Cone Test

Figure-3. Slump cone test.

Table-2. Slump values for various mix percentage of CSA.

Mix no.	% replacement of CSA	Water cement ratio	Slump test
1	0	0.40	90
2	5	0.40	90
3	10	0.40	85
4	15	0.40	85

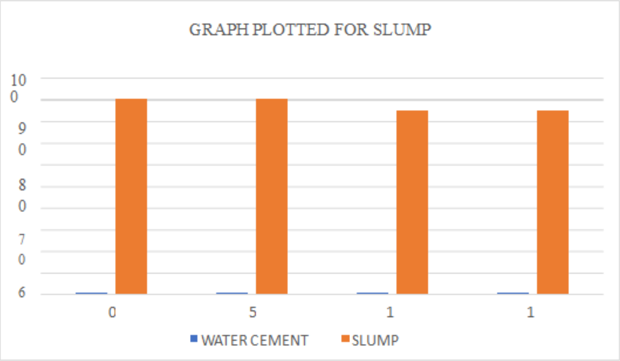

Figure-4. Graphical representation of the slump values for various mix percentages of CSA.

Compression Strength Test

Figure-5. Compression strength machine.

Table-3. Compressive strength values for various days.

% replacement of CSA	Compressive Strength (7,14 and 28 days) (N/mm^2)		
	7 days	14 days	28 days
00	35.53	39.60	43.3
05	33.33	31.85	40
10	28.87	28.89	28.21
15	39.63	21.11	26.22

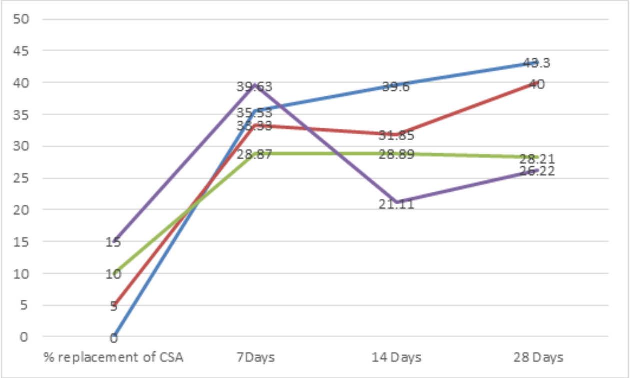

Figure-6. Graphical representation of the compression test values for various mix percentages of CSA.

Figure-7. Split tensile strength test.

Split Tensile Strength Test

Table-4. Split tensile strength values for various days.

% Replacement of CSA	Comparison of Split Tensile Strength (Mpa)		
	7 days	14days	28days
00	1.414	1.696	1.414
05	0.848	1.414	1.414
10	1.272	1.696	1.325
15	1.470	1.414	1.484

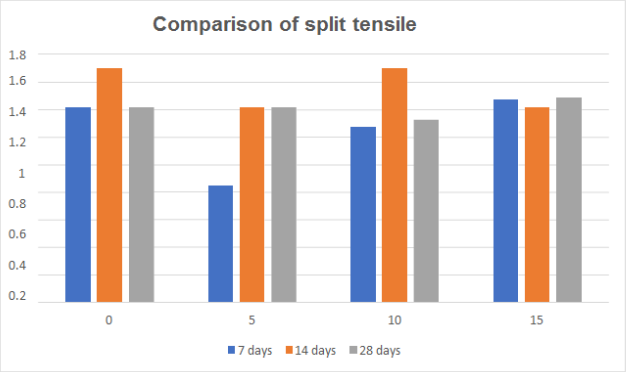

Figure-8. Graphical representation of the split tensile strength test values for various mix percentage of CSA.

5. RESULTS AND DISCUSSIONS

The tables illustrate the oxide composition of CSA (Calcium Sulfoaluminate) and OPC (Ordinary Portland Cement) separately. From the data, CSA contains 37.97% SiO2, 24.12% Al2O3, and 15.48% Fe2O3, resulting in a combined total of 77.57% for SiO2 + Al2O3 + Fe2O3. This meets the ASTM C 618-78 requirement, which mandates a minimum of 70% for these oxides to qualify as a pozzolanic material, indicating that CSA complies with the standard. The Loss on Ignition (LOI) value of 11.94 and SO3 content of 0.71% also fall within acceptable limits.

As the percentage of OPC that is replaced with CSA rises, the pozzolanic activity index at different OPC-CSA substitution levels and curing ages decreases. As the curing age increases, the pozzolanic activity index falls at 15% and 25% substitution levels. However, no discernible pattern of an increase in curing age is seen at replacement levels of 5%, 10%, and 15%. As expected given that an increase in CSA content typically results in a drop in overall strength, Tables 3 and 4 show that the pozzolanic activity declines with larger replacement rates of OPC with CSA.

The compressive strength also declines as the proportion of OPC replaced by CSA increases. For instance, the 7-day compressive strength decreases from 17.55 N/mm² for pure OPC to 9.25 N/mm² at 25% CSA replacement. Similarly, the 28-day compressive strength decreases from 33.46 N/mm² for pure OPC to 24.59 N/mm² when 10% of OPC is substituted with CSA, as shown in the tables.

6. CONCLUSIONS

In conclusion, the results of this study show that using Coconut Shell Ash (CSA) in combination with Ordinary Portland Cement (OPC) can improve the performance of mass and traditional concrete buildings during construction. Both lightweight and heavyweight concrete can be produced by partially replacing OPC with 10% to 15% CSA using water-to-cement (W/C) ratio of 0.4, according to compressive strength tests performed after 28 days of curing.

Key conclusions drawn from this study include:

- Concrete incorporating 10% CSA exhibits the lowest water absorption rate, indicating improved durability.
- The inclusion of CSA in the concrete mix influences workability, with an increase in CSA content resulting in reduced workability.
- An increase in the proportion of CSA correlates with a longer setting time for the concrete.
- The optimum compressive strength at 28 days for the OPC-CSA blend is achieved with a 10-15% replacement of OPC.
- The CSA-modified concrete is suitable for applications requiring both lightweight and heavyweight characteristics.
- Overall, partial replacement of OPC with CSA yields an average optimum compressive strength at 28 days, highlighting its viability as a supplementary cementitious material.

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