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Experimental Study on the Feasibility of Coconut Waste as a Coarse Aggregate Replacement in Concrete

Bilal Ahmad[1], Deepak Aggarwal[2], Rahul kumar[3]

[1]Scholar, B.Tech in Civil Engineering, Sanskar College of Engineering and Technology, Uttar Pradesh, India
[2] Assistant professor, Dept. of Civil Engineering, Sanskar College of Engineering and Technology, Uttar Pradesh, India
[3]Assistant professor, Dept. of Civil Engineering, Sanskar College of Engineering and Technology, Uttar Pradesh, India

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Abstract - *This paper presents a theoretical exploration of the potential use of coconut waste as a partial replacement for coarse aggregate in concrete construction. It examines the comprehensive application of coconut waste in this context, drawing conclusions and results from prior experimental studies that investigated key properties of concrete, such as compressive strength (CS), with partial incorporation of coconut waste. The study aims to evaluate the impact of such replacements on the compressive strength and density of concrete.*

The research highlights numerous advantages, including the efficient utilization of coconut waste, conservation of natural resources, and enhanced sustainability. These findings provide guidance on determining the optimal proportion of coconut waste to use as a substitute for coarse aggregate in concrete production.

Coconut shells, abundantly available in tropical regions, often remain as waste in the environment. Repurposing these materials for construction offers a significant opportunity to promote eco-friendly and sustainable practices. This study investigates the feasibility of using coconut shells as a partial replacement for coarse aggregate, demonstrating the potential to produce lightweight, cost-effective construction materials. An analysis of economic benefits was also conducted.

***Keywords**:** *coarse aggregate, compressive strength, density, coconut waste, concrete production, coconut shell, workability, sustainability, construction materials.*

1. INTRODUCTION

India ranks as the third-largest coconut-producing country in the world, following Indonesia and the Philippines. According to 2021-22 data, India contributes 31.45% of the global coconut production, with an annual yield exceeding 19,000 million coconuts. While 17 Indian states cultivate coconuts, 90% of the production is concentrated in Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh. In Bengaluru alone, 200-300 metric tons of tender coconut waste is generated daily, as reported by an official from Bengaluru SWM Ltd.

The increasing concerns over resource depletion and global pollution have driven researchers to explore and develop alternative materials utilizing renewable resources. This includes the innovative use of by-products and waste materials in the construction industry. Additionally, the high cost of conventional building materials significantly impacts construction activities in India. In developing countries, where vast amounts of agricultural and industrial waste are generated, these materials offer a sustainable and cost-effective alternative for construction applications.

Figure-1: Coconut waste (shell+husk)

Coconut shell, a palm-related agricultural waste, is commonly sourced from temples, coconut oil producers, and other locations. Coconut cultivation spans over 90 countries, including India, the Philippines, and the Americas, with significant availability in Asia, Africa, and America. It is believed that the first coconuts originated in Southeast Asia. While coconut shells are abundantly available as waste from local coconut industries, their improper disposal poses environmental challenges.

In many developing nations, where surplus coconut shell waste accumulates, this material has the potential to be utilized as a sustainable alternative in the construction industry. Repurposing coconut shells not only reduces the cost of construction materials but also provides an eco-friendly solution to waste management challenges.

1.1 Concrete

Concrete is a construction material made by combining cement, fine aggregates, coarse aggregates, and water, which solidifies over time. It is widely used in building construction for structural elements such as foundations, columns, beams, slabs, and other load-bearing components.

1.2 Coarse Aggregate

Coarse aggregates with a maximum size of 20 mm were utilized in this study. Various tests were conducted on the coarse aggregates, including fineness, specific gravity, water absorption, and impact tests.

1.3 Coconut shell

Coconut shells, already broken into two pieces, were collected from nearby hotels and the college canteen. These shells were air-dried for approximately five days at a temperature of 25–100°C. After drying, the fiber and husk were removed, and the shells were further broken into smaller chips manually using a hammer, then sieved through a 20 mm sieve.

Coconut shells can serve as coarse aggregates due to their abundant availability and durability. As they do not decompose, they can be effectively incorporated into concrete, meeting most of the properties of conventional concrete. In developed countries, the construction industry has adopted various lightweight aggregate materials as substitutes for traditional aggregates, reducing the size and weight of structural elements. Coconut shells possess desirable characteristics such as non-biodegradability, excellent strength, high weather resistance, and low cellulose content, which minimizes water absorption. These properties make coconut shells a viable alternative for coarse aggregates in concrete production.

Figure -2: Coconut Shell

1.4 Materials Used

- Ordinary Portland Cement (53 Grade)
- Coarse Aggregate
- Fine Aggregate
- Water
- Coconut Shell
- Sand

Coconut shells are widely utilized in the production of various products, including furnishing materials and other valuable items.

The chemical composition of coconut shells includes elements such as carbon, potassium, chloride, iron oxide, sodium oxide, and calcium oxide, measured in percentage values.

Table -1: Chemical Properties of Coconut Shell

Property	Value
Carbon	10.00%
Potassium	1.21%
Chloride	0.79%
Iron Oxide	0.31%
Sodium Oxide	0.29%
Calcium Oxide	0.23%

Following are the properties of coarse aggregate that are found in coarse aggregate such as water absorption, specific gravity, fineness modulus, bulk density(loose and compacted).

Table 2. Properties of Coarse Aggregate

S No.	Parameters	Result
1	Water absorption	1.35%
2	Specific gravity	2.76
3	Fineness modulus	6.5
4	Bulk density Loose Compacted	 1600 kg/cm^3 1790 kg/cm^3

1.5 Impacts of Coconut Waste over Environment

Improper disposal of coconut waste can adversely impact the environment, contributing to issues such as air pollution, land and water contamination, and excessive landfilling. These practices can lead to problems like pollution, unmanaged waste dumps, and health hazards. However, utilizing coconut waste (CW) as a sustainable construction material can mitigate these negative effects by reducing the reliance on non-renewable resources that harm the environment.

1.6 Coconut Waste as a Substitute of Natural Aggregate in Concrete

Coconut waste (CW) is increasingly being recognized as a viable substitute for natural aggregates in concrete, particularly in developing regions where waste management poses significant challenges. The use of coconut waste not only addresses environmental issues related to waste disposal but also promotes sustainable concrete production. Studies indicate that incorporating coconut waste can enhance the mechanical properties and workability of concrete mixtures, potentially influencing the durability and micro-structural characteristics of the concrete.

2. Literature Review

1. In March 2014, Vignesh Kumar Nagarajan, Assistant Professor at KCET, Virudhunagar, India, and his team studied the partial replacement of cement with coconut shell ash (CSA) in concrete. Their findings revealed that compressive strength decreased as the percentage of Ordinary Portland Cement (OPC) replaced with CSA increased. Strength tests were conducted at 7 and 28 days.

2. Olugbenga O. Amu (2011), a Senior Lecturer at Obafemi Awolowo University, Nigeria, evaluated the potential of coconut shell and husk ash (CSHA) for improving the geotechnical properties of lateritic soil in road construction. The study found that adding CSHA increased the unit weight and shear strength of the samples, with optimal performance at 4% CSHA. Additionally, California Bearing Ratio (CBR) values showed a gradual increase with higher CSHA percentages.

3. Daniel Yaw Osei (2013), from the Department of Civil Engineering at Cape Coast Polytechnic, Ghana, conducted an experimental assessment of coconut shells as aggregate in concrete. The results demonstrated that replacing granite with palm kernel shells by volume produced better-performing concrete than replacing by weight.

4. In 2012, Amarnath Yerramala and Ramachandrudu investigated the properties of concrete using coconut shells as aggregate replacement. The study aimed to evaluate the performance of coconut shell concrete in terms of strength and transport properties under normal water curing without chemical admixtures. Compression and split tensile strength tests were conducted at 1, 7, and 28 days, with results based on the average of two measurements.

5. Sanjay Kumar Verma and his team (2019) explored the partial substitution of coarse aggregate with coconut shell to assess the characteristic strength of M-20 grade concrete at a water-cement ratio of 0.50. This research highlighted the potential of using coconut shells as a sustainable replacement for conventional aggregates, addressing environmental and social concerns.

6. In 2021, Kajal Bansal, a Civil Engineering student at AIETM Jaipur, Rajasthan, and her team investigated the partial replacement of coarse aggregate with coconut shells. The study concluded that coconut shells have potential as lightweight aggregate in concrete. However, compressive strength and workability decreased as the percentage of coconut shell increased.

7. Vivek Kumar Kashyap (2017), a Master's student in Structural Engineering at Lovely Professional University, studied the partial replacement of coarse aggregate with coconut shells and cement with rice husk ash (RHA). The research demonstrated that coconut shells contribute to lightweight concrete, while RHA can partially replace cement without significantly affecting its properties.

8. Sourav Ghosal and S.C. Moulik examined the use of coconut shells as a partial replacement for conventional coarse aggregates. Their research suggested that incorporating coconut shells in concrete could reduce the environmental impact of waste while enabling the development of lightweight, precast construction units. The study also explored key properties like compressive strength, split tensile strength, and flexural strength.

9. Parag S. Kambli and Sandhya R. Mathapati (March 2014) focused on the compressive strength of concrete made with crushed, granular coconut shells as partial replacements for traditional coarse aggregates. Their findings indicated that coconut shells have potential as a lightweight aggregate, helping reduce construction material costs due to their low price and availability.

10. B. Damodhara Reddy, S. Aruna Jyothy, and Fawaz Shaik analyzed the flexural and compressive strength of M30-grade concrete partially replaced with coconut shells. Their study revealed that coconut shell concrete exhibited better workability due to the smooth surface of the shells, making it suitable for applications requiring high workability.

11. Sangeetha G. et al. (2016) investigated the partial substitution of aggregate with coconut shells and cement with clay to produce M-20 grade concrete. Replacement percentages of 0%, 10%, 20%, and 30% were tested, and the compressive strength was evaluated at 7, 14, and 28 days. The results demonstrated the potential for eco-friendly and economical construction using these materials.

12. Sabarudin Bin Mohd and Tukiman (2009) studied the use of grained palm kernel shell and coconut shell as substitutes for aggregates in concrete. Five mixes with varying percentages (0%, 25%, 50%, 75%, and 100%) were tested. The research concluded that these materials could serve as lightweight aggregates, reducing material costs due to their availability as agricultural waste.

13. K. Gunasekaran et al. (2013) examined the durability characteristics of Coconut Shell Aggregate Concrete (CSAC). The study assessed parameters such as chloride penetration, sorptivity, water absorption, and salt resistance, concluding that CSAC has comparable durability to other lightweight concretes.

14. Apeksha Kanojia and Sarvesh K. Jain (2017) evaluated the use of coconut shells as partial replacements for coarse aggregate in M-20 grade concrete. Concrete with replacement levels of 10%, 20%, 30%, and 40% was tested with different water-cement ratios (0.55, 0.50, and 0.45). The study showed a reduction in density and noted that a 5% replacement required no additional cement, while a 10% replacement increased cement demand by 3.6%.

15. Jerin M. George et al. (2016) explored the use of crushed coconut shells as coarse aggregate in concrete. Replacement levels of 25%, 50%, and 100% were tested. The results indicated that a 25% replacement achieved similar properties to standard concrete, demonstrating the feasibility of using coconut shells in construction.

3. Methodology

Step 1: Collection of Materials

The first and essential step in this research involves gathering coconut shell samples. This is a challenging and time-consuming process. The coconut waste is sourced from local temples, as well as a few other locations where coconut waste is readily available.

Step 2: Material Testing

Once the coconut waste is collected, it undergoes a testing phase to identify the most suitable shells for partial replacement of coarse aggregate in concrete. After evaluating and selecting the appropriate materials, they are then used in the mix proportioning process.

Step 3: Mix Proportioning

The mix proportioning phase determines the ratio of various ingredients required to create the concrete mixture. This includes cement, sand, aggregate, coconut shell, and water. The mix ratio plays a crucial role in influencing concrete's strength, workability, and durability. Different ratios are applied depending on the specific requirements of the investigation.

Step 4: Cube Casting

Following mix proportioning, concrete cubes are cast to evaluate the performance of the concrete with partial replacement of coarse aggregate using coconut shells. After casting, the cubes are cured for different periods, and their strength is measured at 7, 14, and 28 days. Once this step is completed, the process moves to the next stage.

Step 5: Observation

After testing the specimens, they are carefully observed to understand the behavior of concrete when coarse aggregate is partially replaced by coconut shells. The observations form the basis for analyzing and discussing the results derived from the tests on the prepared specimens.

Step 6: Results and Discussion

In this step, various properties of concrete are studied, focusing on the effects of partially replacing coarse aggregate with coconut shells. Balancing the trade-offs between strength, workability, and durability is critical, which is achieved by selecting suitable mix proportions and material processing methods. Moreover, using coconut shells as an aggregate can reduce construction material costs due to their abundance and low cost, thus offering an eco-friendly solution.

The main stages which are concerned within the project are as follows:

- Collection of coconut sample.
- Collection of coconut location details.
- Laboratory analysis.
- Observation.
- Result and Discussion.

Following is the flowchart that shows the various steps that are included in the investigation:

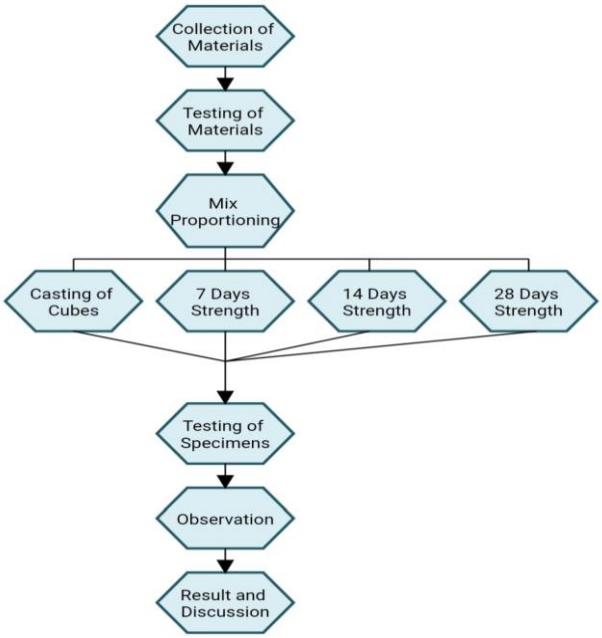

Figure 3: Flow chart of the experiment work

4. Result and Discussion

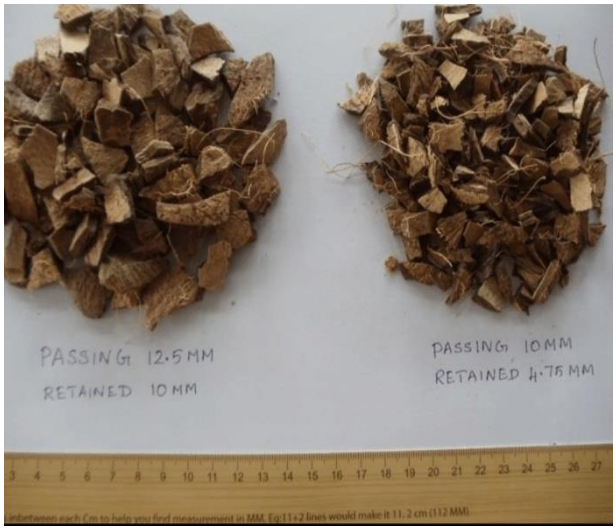

Figure 4: Processed Coconut Shell Aggregates

Table -3: Compressive strength of concrete

Mix Name	Compressive Strength (MPa) 7 days	14 days	28 days
M 1	16.9	19	24.2
M 2	12.4	16.25	23.5
M 3	10.2	15	21.5
M 4	9.3	12.5	16.5

The data from the table indicates that the compressive strength remains stable with up to a 10% replacement of coarse aggregate with coconut waste. However, beyond this percentage, the compressive strength noticeably declines. The concrete demonstrates good strength after 14 days of curing. Coconut shell concrete exhibits improved workability due to the smooth surface on one side of the shells and their smaller size. As a result, coconut shell concrete can be effectively used in applications where high workability is required. Furthermore, incorporating coconut shells as an aggregate in cement can reduce material costs due to their affordability and the abundant availability of agricultural waste.

Figure 5: Testing machine

Figure 6: Coconut Shells

Table -4: Average Compressive Strength of Concrete

% Replacement of Aggregate	Serial No.	Load (KN)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
0	1 2 3	378 428 532	16.8 19 23.68	19.82
10	1 2 3	281 365 510	12.5 16.23 22.7	17.35

20	1 2 3	227 339 452	10 15.2 20.11	15.95
30	1 2 3	207 280 318	9.1 12.5 14.19	11.93

From the above table the compressive strength holds well only up to 10% replacement of coarse aggregate by coconut waste.

Figure 7: Testing of Concrete Cube

From the experimental work it is clear that with CS (compressive strength) percentage increases the 7 days strength gain also.

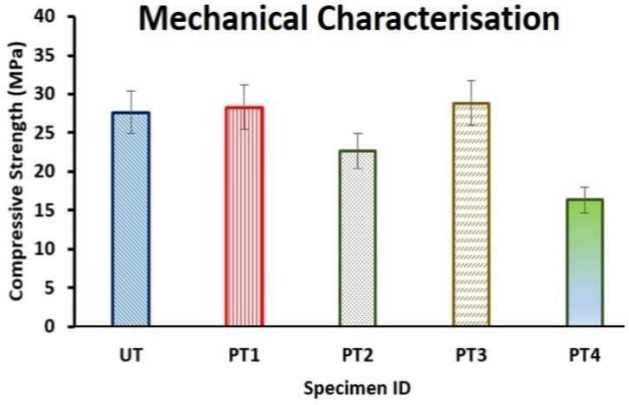

Chart -1: Mechanical Characterisation

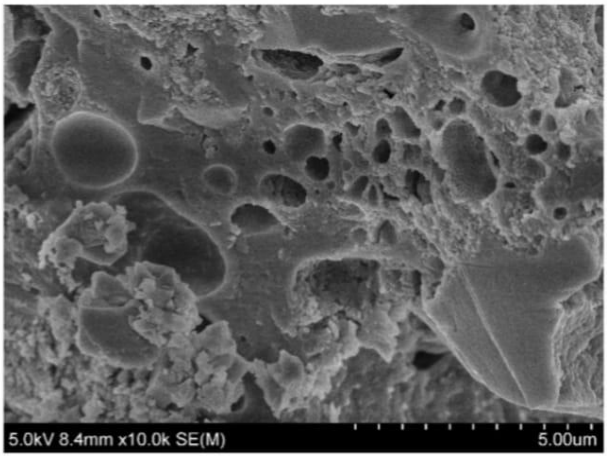

Figure -8: Micro - Structural Characterisation

Figure 9: Testing Machine (sample)

Coconut waste is sourced from coconut processing industries or local markets, then thoroughly cleaned and dried before being crushed into suitable pieces to replace coarse aggregates. Standard-grade cement is used in the concrete mix. Clean and dry fine aggregates are incorporated, along with clean, potable water for mixing the concrete.

5. CONCLUSIONS

Replacing a portion of coarse aggregate with coconut waste in concrete presents an innovative method that could support sustainable construction, particularly in areas where coconut waste is plentiful. However, a careful balance between strength, workability, and durability must be maintained through careful selection of mix proportions and material processing. Experimental research is crucial to optimize the mix design and identify the ideal replacement percentage that provides a satisfactory balance between performance and environmental sustainability.

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Author Details

1.

Mr. Bilal Ahmad, currently pursing B.Tech in Civil Engineering (Final year) from SANSKAR College of Engineering & Technology, Ghaziabad. He has deep interest in research.

2.

Mr. Deepak Aggarwal, currently serving as an Assistant Professor in the Department of Civil Engineering at Sanskar College, affiliated with Dr. A.P.J. Abdul Kalam Technical University (AKTU), Lucknow.

He has published books on Hydraulics Engineering and machines and several other research papers.

3.

Mr. Rahul Kumar is presently working as an Assistant Professor & Head in the Department of Civil Engineering at Sanskar College of Engineering and Technology, Ghaziabad, UP, India. He has published so many research papers in national and international journals.