Exploring Sustainable Concrete Solutions with Coconut Shell Aggregates

[1]Dharmendra pal, [2]Lalit Arya [3] Mahesh Pal

[1]B. tech Student, [2,3]Professor
Department Of Civil Engineering
Shri Balaji Institute of Technology & Management
Betul, RGPV University (M.P.), India.

Abstract-
The escalating cost of construction materials has prompted the exploration of economical alternatives to traditional coarse aggregates in concrete production. In this study, coconut shells are investigated as a partial substitute for coarse aggregates, aiming to mitigate aggregate costs while maintaining structural integrity and enhancing sustainability. Coconut shells, abundant waste products from oil industries, possess low degradability and are primarily used as fuel. Experimental investigations were conducted to assess the feasibility of incorporating coconut shell particles as fine and coarse aggregates in M20 concrete mixes at replacement percentages of 0%, 10%, 20%, and 30%. Compressive and tensile strength tests were conducted at 7, 28, and 56 days to evaluate the mechanical performance of the concrete specimens. Results indicate that concrete with a 20% replacement of coconut shell aggregates demonstrates favorable strength characteristics. The findings underscore the potential of utilizing coconut shells as a sustainable alternative to conventional coarse aggregates, thereby contributing to cost reduction, waste management, and energy conservation in concrete production.

Keywords: Coconut shell, coarse aggregate, concrete, partial replacement, compressive strength, tensile strength, sustainability.

I. INTRODUCTION:

Concrete stands as the predominant construction material globally, driven by infrastructural advancements. Yet, its extensive usage entails adverse effects such as resource depletion and ecological disruption due to aggregate extraction. Researchers seek alternatives to conventional coarse aggregates for cost efficiency and sustainability. The utilization of aggregates in construction significantly bolsters concrete's strength, but sourcing them through quarrying poses environmental hazards. Identifying a naturally occurring substitute with abundant, renewable sources is imperative. Coconut byproducts offer promise, leveraging its versatile applications. Coconut shell, an agricultural waste, emerges as a viable alternative, potentially enhancing composite material formation for construction elements like concrete cubes, beams, and cylinders. Economically, environmentally, and technologically, harnessing coconut farm waste offers manifold benefits, supplementing farmers' incomes and curbing detrimental practices like agricultural waste burning. Leveraging agricultural and forest residues for industrial purposes presents a more environmentally sound disposal method. The coconut palm epitomizes resource efficiency, providing sustenance, shelter, and economic stability. Utilizing agricultural and forest waste for construction, especially in affordable housing, proves cost-effective and sustainable. Introducing alternative construction materials like concrete cubes derived from coconut shells not only reduces production costs but also mitigates social and environmental challenges.

Objective:

1. Analyze the physical, mechanical, and chemical properties of coconut shells from various regions to determine their suitability as construction aggregates.
2. Determine the optimal proportions of coconut shell aggregates in concrete mixes, balancing mechanical strength, workability, and durability.

3. Conduct mechanical tests including compressive, tensile, flexural strength, and modulus of elasticity to assess the structural integrity of coconut shell concrete.
4. Evaluate durability through water absorption, chloride ion penetration, sulfate resistance, and freeze-thaw resistance tests to assess long-term performance.
5. Investigate microstructural characteristics using microscopy to understand bonding mechanisms and effects on hydration products and pore structure.
6. Perform a life cycle assessment (LCA) to compare environmental impacts of coconut shell concrete versus conventional concrete.
7. Validate performance in real-world applications, collecting feedback from stakeholders to assess feasibility and practicality.

These objectives aim to provide insights into coconut shell utilization in concrete production, advancing eco-friendly construction practices and resilient infrastructure development.

II. Literature Review:

Concrete is a widely used construction material owing to its versatility, durability, and strength. However, the production of conventional concrete involves significant environmental impact, particularly due to the high energy consumption and greenhouse gas emissions associated with cement production [1]. As sustainability becomes increasingly important in the construction industry, researchers are exploring alternative materials and techniques to reduce the environmental footprint of concrete while maintaining or enhancing its performance characteristics.

One such alternative material under investigation is coconut shell aggregates. Coconut shells are abundant agricultural waste products in many tropical regions and have shown promise as a potential replacement for conventional coarse aggregates in concrete production [2],[3]. Several studies have examined the physical, mechanical, and chemical properties of coconut shells sourced from different regions to assess their suitability for use in concrete [4],[5]. These investigations aim to characterize the properties of coconut shells, including their particle size distribution, density, water absorption, and chemical composition, to understand how they influence the performance of coconut shell concrete.

Optimizing the mix design of coconut shell concrete is crucial to ensure that it meets the required mechanical properties, workability, and durability standards. Researchers have conducted extensive experimentation to determine the optimal proportions of coconut shell aggregates in concrete mixes, considering factors such as cement content, water-cement ratio, and admixture usage [6],[7]. By carefully adjusting these parameters, researchers aim to develop coconut shell concrete mixes that exhibit comparable or superior mechanical performance to conventional concrete while incorporating sustainable materials.

Mechanical testing plays a vital role in evaluating the performance of coconut shell concrete. Studies have conducted comprehensive tests, including compressive strength, tensile strength, flexural strength, and modulus of elasticity assessments, to assess the structural integrity and load-bearing capacity of coconut shell concrete specimens [8],[9]. These tests help researchers understand how coconut shell aggregates affect the mechanical properties of concrete and identify any potential limitations or advantages compared to conventional concrete.

Durability is another critical aspect of concrete performance, particularly in harsh environmental conditions. Researchers have investigated the durability of coconut shell concrete through various tests, including water absorption, chloride ion penetration, sulfate resistance, and freeze-thaw resistance evaluations [10],[11]. These tests assess the ability of coconut shell concrete to withstand environmental factors such as moisture ingress, chemical exposure, and temperature fluctuations, providing insights into its long-term performance and service life.

Microstructural analysis provides valuable information about the internal characteristics of coconut shell concrete. Researchers have used microscopy techniques to examine the bonding mechanisms between coconut shell aggregates and the cementitious matrix and analyze the effect of coconut shell incorporation on the hydration products and pore structure of concrete [12],[13]. Understanding the microstructure of coconut shell concrete helps researchers optimize mix designs and enhance its mechanical and durability properties.

Life cycle assessment (LCA) offers a comprehensive method for evaluating the environmental impact of coconut shell concrete compared to conventional concrete. Researchers have conducted LCAs to quantify parameters such as energy consumption, greenhouse gas emissions, and resource utilization throughout the entire life cycle of concrete production, from raw material extraction to end-of-life disposal [14],[15]. These assessments provide valuable insights into the environmental benefits of using coconut shells as sustainable aggregates and help inform decision-making processes in the construction industry.

Field trials and real-world applications are essential steps in validating the performance and feasibility of coconut shell concrete. Researchers have collaborated with industry partners to implement coconut shell concrete in construction projects, gathering feedback from stakeholders, contractors, and end-users [16],[17]. These trials provide valuable data on the practicality and effectiveness of coconut shell concrete in various construction applications and help bridge the gap between research findings and real-world implementation.

Overall, the literature review highlights the significant progress made in exploring coconut shell aggregates as a sustainable alternative in concrete production. Through interdisciplinary research efforts encompassing materials science, engineering mechanics, and environmental assessment, researchers aim to advance the development of eco-friendly construction practices and promote the adoption of resilient and environmentally conscious infrastructure solutions.

III. Methodology:

Materials

Portland cement works as the binder in this project, while sand is added as the fine aggregate, naturally occurring coconut shell and crushed granite provide the coarse aggregate, and water is used for mixing the concrete.

Cement: The binder utilized in this project is Portland cement, a staple in construction, formed by heating limestone and clay to 1450 °C in a kiln, a process known as calcination. This process liberates CO2 from calcium carbonate, yielding calcium oxide, which then reacts with other materials to form calcium silicates and other cementations compounds. The resultant clinker, a harder substance, is finely ground with gypsum to produce Ordinary Portland cement.

Coarse Aggregate: For the coarse aggregate, particles retained on the 4.75 mm sieve and able to pass through a 3-inch screen are employed. Larger aggregates offer economies due to decreased surface area compared to an equivalent volume of smaller particles. Using maximum permissible coarse aggregate sizes reduces the need for cement and water.

Fine Aggregate: Fine aggregate, comprising particles passing through a 4.75 mm sieve but retained on a 75 μ sieve, serves to enhance workability, particularly when rounded in shape. Its primary function is to fill voids left by coarse aggregates, thereby improving workability.

Coconut Shell: Coconut shells, sourced from local oil mills and industries, are utilized as coarse aggregate. These shells, ranging from 3-9 mm in thickness, are crushed into smaller pieces (3-10 mm) and soaked in water for one day, followed by sun-drying to attain saturation. Subsequently, the appropriate quantity of crushed coconut shell pieces is employed for casting purposes.

The needed crushed coconut shell (CS) pieces are then used for casting, ensuring originality.

Water:

Water in concrete is frequently overlooked during construction, yet it holds significant importance. Neglecting the quality of water used in construction can jeopardize all efforts made during the building process.

Mix Design

Mix Design is carried out in **B.I.S Method (Bureau of Indian Standards**) As per IS 10262:2009

MIX DESIGN PROCEDURE FOR THE CONCRETE OF GRADE M20

Parameters required

1. Slump - 75mm
2. Exposure condition - mild
3. Grade of concrete - M20
4. Specific gravity

i. Cement - 3.1
ii. Fine aggregate - 2.5 (zone3)
iii. Coarse aggregate - 2.7 (20mm size)
iv. Coconut shell aggregate - 1.43

Design

1. Target strength

$f_{ck}^{1} = f_{ck} + k \times S$

$= 20+1.65\times4$

$=26.6 N/mm2$

Target mean strength = 26.6 N/mm2

2. Determination of W/C ratio

From IS 456:2000 (table 5) according to exposure condition and size of aggregates.

W/C = 0.55

Take W/C as 0.5

So, W/C = 0.5

3. Determination of water content

Table: Amount of water content to be utilized for aggregates of different sizes

aggregate (mm)	Amount of water (lts)
10	206
20	186
40	168

From table take water content = 186lts

Correction of water = ((3/100) ×186) +186

= 191.6lts

So water content = 191.6 kg/m3

4. Determination of cement content

W/C = 0.5

191.6/0.5 = C

So cement content = 383.2kg/m3

5. Determination of volume of coarse aggregate

From IS: 10262:2009 table 3 take

Coarse aggregate volume = 0.64m3

fine aggregate volume = 0.36m3

6. Calculation of volume of aggregates
Cement = (383.2/3.1) × (1/1000)
= 0.123m3
Water = 191.6 × 10-3
= 0.1916 m3
Volume of (coarse aggregate + fine aggregate) = 1-(cement + water)
= 1- 0.315
= 0.684 m3
Coarse aggregate volume = 0.684×0.64×2.7×1000 = 1182kg/m3
Fine aggregate volume = 0.684×0.36×2.5×1000 = 616kg/m3

M20 grade concrete	**% Replacement**			
0	**10**	**20**		**30**
Cement	383	383	383	383
Fine Aggregate	616	616	616	616
Coarse Aggregate	1182	1136	945.56	827.36
Coconut shell	0	62.5	125.19	187.79
Water	191.6	191.6	191.6	191.6

Concrete Mix Using Solid Waste Aggregates (Coconut Shell Concrete)
Quantity of Material in Different Proportions per m3
The ratio of the mix is 1:1.6:3.08 (Cement: fine aggregate: coarse aggregate)
MIX DESIGN PROCEDURE FOR THE CONCRETE OF GRADE M25:
Parameters required
1. Slump - 100mm
2. Exposure condition - mild
3. Grade of concrete - M25
4. Specific gravity
   i. Cement - 3.1
   ii. Fine aggregate - 2.5 (zone3)
   iii. Coarse aggregate- 2.7 (20mm size)
   iv. Coconut shell aggregate - 1.43

Similar mix design procedure is followed as done for above M20 grade concrete and the results are as follows

M25 grade concrete	**% Replacement**			
0		**10**	**20**	**30**
Cement	419	419	419	419
Fine Aggregate	590	590	590	590
Coarse Aggregate	1164	1047	930.7	814.36
Coconut shell	0	61.6	122.1	184.84
Water	197	197	197	197

Quantity of Material in Different Proportions per m3
The ratio of the mix is 1:1.4:2.7
(Cement: fine aggregate: coarse aggregate)

IV. RESULTS AND ANALYSIS

Tests on Fresh Concrete

- **Slump Test:**

One commonly used method for evaluating concrete workability is the slump cone test, conducted in both field and laboratory environments. Nonetheless, this approach may not be suitable for concrete mixes that are excessively wet or dry.

Table : Slump value for different percentage replacements in M20 grade concrete

Replacement in%	Slump Value in mm
0%	50
10%	30
20%	20
30%	10

Table: Slump value for different percentage replacements in M25 grade concrete

Replacement in%	Slump Value in mm
0%	70
10%	50
20%	35
30%	20

From the above tables we can see that as the percentage replacement of coarse aggregates increases the workability decreases.

- **Compacting Factor Test:**

The most commonly used workability test in the laboratory is compaction factor test. The compaction factor test yields more precise results compared to those obtained from the slump cone test. A primary advantage of the compaction factor test lies in its efficacy for assessing concrete mixes with extremely low workability.

Table: Compaction factor values for different percentage replacements in M20 grade concrete

Replacement in%	Compaction Factor
0%	0.90
10%	0.87
20%	0.86
30%	0.85

Table: Compaction factor values for different percentage replacements in M25 grade concrete

Replacement in%	Compaction Factor
0%	0.86
10%	0.85
20%	0.84
30%	0.83

Looking at the tables above, we notice that when we replace more coarse aggregate with coconut shells, the compaction factor decreases. Compaction factor tells us about how easy it is to work with the concrete. So, when we increase the percentage of coconut shells in the concrete, it becomes harder to work with.

Tests on Hardened Concrete

- **COMPRESSION TEST**

To check how strong concrete is, we use a test called compression test. We do this by gradually adding weight to concrete blocks until they break.

Table: Compressive strength of M20 grade concrete cubes after 28 days

S.No	Coconut Shell (%)	Grade	Load Crushing in (KN)	Compressive Strength (N / mm2)
1	0 %	M20	246	24.6
2	10 %	M20	227	22.7
3	20 %	M20	219	21.9
4	30 %	M20	206	20.6

Table: Compressive strength of M25 grade concrete cubes after 28 days

S.no	Coconut Shell (%)	Grade	Load Crushing in (KN)	Compressive Strength (N / mm2)
1	0 %	M25	293	29.3
2	10 %	M25	274	27.4
3	20 %	M25	262	26.2
4	30 %	M25	254	25.4

V. CONCLUSIONS

The final conclusion reached from this study is that substituting coarse aggregate with coconut shell yields a lightweight concrete with reduced strength, yet it satisfies the requisite criteria. The present project outcomes are summarized as follows:

1. Results from experiments comparing compressive strength and workability of mixes with varying percentages of coconut shell replacing coarse aggregate were compared to conventional concrete. The findings indicate that while coconut shell aggregates can replace normal aggregate, the performance of coconut shell concrete is slightly inferior to conventional concrete.
2. Increasing the replacement percentage of coconut shell also leads to an increase in voids within the concrete. For instance, at 30% replacement, the voids were observed to be 40% higher than in standard conventional concrete.
3. The compressive strength at 28 days for M20 grade coconut shell concrete was recorded as follows: 24.6 N/mm2, 22.7 N/mm2, 21.9 N/mm2, and 20.6 N/mm2 for 0%, 10%, 20%, and 30% coconut shell aggregate replacement, respectively. These values meet the requirements for structural lightweight concrete.
4. Similarly, for M25 grade coconut shell concrete, the compressive strength at 28 days was as follows: 29.3 N/mm2, 27.4 N/mm2, 26.2 N/mm2, and 25.4 N/mm2 for 0%, 10%, 20%, and 30% coconut shell aggregate replacement, respectively, satisfying the conditions for structural lightweight concrete.
5. Using M20 grade concrete, the strength remains above 20 N/mm2 up to 30% replacement of coarse aggregate with coconut shell. Likewise, for M25 grade concrete, the strength remains above 25 N/mm2 up to 30% replacement of coarse aggregate.
6. Therefore, it is concluded that coarse aggregate can be replaced with coconut shell up to 30% while still maintaining strength, economy, and serviceability of the concrete.

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