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Utilization Of Coconut Shell As A Sustainable Alternative Coarse Aggregate In Concrete

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Abstract: The continuous escalation in the cost of conventional construction materials and the depletion of natural aggregate sources have raised significant concerns within the construction industry. This situation necessitates the exploration of sustainable, economical, and environmentally responsible alternatives for concrete production. Numerous waste materials, including fly ash, silica fume, copper slag, brick debris, and demolished concrete, have been studied as substitutes for traditional components in construction materials. Since aggregates occupy nearly 70–80% of the total volume of concrete, identifying suitable alternative coarse aggregates is crucial for ensuring sustainable development in the construction sector. This study investigates the potential of coconut shell, an abundant agricultural by-product, as a replacement for conventional coarse aggregate in concrete. India, being the third-largest coconut-producing country, generates a large volume of coconut shell waste, leading to environmental and disposal challenges. The experimental work examines the mechanical and durability properties of coconut shell concrete (CSC) by partially and fully replacing natural coarse aggregate with processed coconut shells. Parameters studied include compressive strength, split tensile strength, flexural strength, density, and workability at different replacement levels. The experimental results reveal that concrete incorporating coconut shell as coarse aggregate exhibits satisfactory mechanical performance, with a notable reduction in density, making it suitable for lightweight and non-structural applications. Moreover, the utilization of coconut shell reduces the cost of concrete production while addressing solid waste management issues. The findings demonstrate the viability of coconut shell as a sustainable, economical, and eco-friendly material, contributing to the advancement of green construction practices.

Keywords: Coconut shell concrete (CSC); Sustainable materials; Waste utilization; Lightweight aggregate; Eco- friendly construction; Cost-effective concrete

I. INTRODUCTION

Concrete remains the cornerstone of modern infrastructure, being the most widely used construction material globally due to its excellent compressive strength, versatility, and durability. It is a composite material primarily composed of cement, fine aggregates, coarse aggregates, and water. Among these, coarse aggregates occupy about 60–75% of the total concrete volume and significantly influence its mechanical and durability properties. Traditionally, crushed stone and gravel have served as the main sources of coarse aggregate. However, the rapid pace of urbanization and infrastructure expansion has led to the excessive exploitation of these natural aggregates, resulting in depletion of natural resources, higher material costs, and severe environmental degradation due to quarrying and crushing operations. This growing concern over the environmental impact of conventional concrete materials has intensified research into sustainable alternatives that reduce dependence on non-renewable resources. Sustainable construction practices emphasize the efficient use of locally available materials, minimizing waste, and lowering the carbon footprint associated with construction activities. In this context, the reuse of agricultural waste as a substitute for natural aggregates has emerged as a viable approach toward achieving eco-friendly and cost-effective concrete production. One such abundant and underutilized agricultural by-product is the **coconut shell (CS)**. Coconut shells are hard, organic waste materials obtained after extracting the edible portion and water from the coconut fruit. In tropical countries such as India, where coconut production is significant, large quantities of shells are discarded annually. Their improper disposal contributes to environmental pollution and waste management challenges. Incorporating coconut shells in concrete as partial replacement for conventional coarse aggregate not only provides an effective way of waste utilization but also reduces the demand for crushed stone, conserving natural resources and promoting sustainability. Coconut shells possess unique physical and mechanical characteristics that influence concrete performance. They are lighter than traditional aggregates, have a rough surface texture, and exhibit good impact resistance and toughness due to their lignocellulosic composition. These properties make coconut shell concrete (CSC) a potential **lightweight concrete** suitable for non-load-bearing and medium-strength structural applications. However, factors such as water absorption, irregular shape, and organic content can affect the workability, density, and strength of the concrete mix. Therefore, comprehensive evaluation of its mechanical and durability performance is essential before recommending its use in structural concrete.

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Previous studies have demonstrated that partial replacement of coarse aggregate with coconut shell up to 25–30% can yield satisfactory strength values for structural use. Research by **Mannan and Ganapathy (2002)** first established that CSC could achieve compressive strengths between 17–24 MPa, indicating its suitability for lightweight concrete applications. **Gunasekaran et al. (2011)** observed that replacing conventional aggregates with coconut shell reduces density by 6–10%, resulting in lighter concrete without severe loss of compressive strength. **Kambli and Mathapati (2014)** reported that up to 30% replacement achieved comparable mechanical properties, while **Olanipekun et al. (2006)** highlighted its cost efficiency and environmental benefits in tropical regions.

Despite these encouraging findings, further experimental evidence is required to establish standardized guidelines for its practical use in structural-grade concrete. The variability in shell size, shape, and surface texture influences the interfacial transition zone (ITZ) and hence the strength and durability characteristics of CSC. Thus, systematic laboratory investigations are crucial to determine optimal replacement levels that balance mechanical performance, workability, and sustainability.

The present study focuses on **evaluating the feasibility of utilizing coconut shell as a partial replacement for natural coarse aggregate** in M30 grade concrete. Replacement levels of 0%, 10%, 20%, 30%, 40%, and 50% by weight were examined. The investigation emphasizes the effects of coconut shell content on fresh and hardened concrete properties, including **workability, compressive strength, split tensile strength, and flexural strength**. By comparing these results with conventional concrete, the study aims to identify the optimal proportion of coconut shell that achieves satisfactory strength while contributing to sustainable and environmentally responsible construction practices.

Overall, the research seeks to demonstrate that coconut shell—a renewable and locally available agricultural waste— can be effectively utilized in concrete production without substantial compromise in performance. Its successful implementation would contribute to waste minimization, conservation of natural aggregates, and reduction in the environmental footprint of the construction industry, aligning with global sustainability goals.

1.1 IMPORTANCE OF THE STUDY

In the production of conventional crushed stone aggregates, significant energy consumption and environmental degradation occur due to quarrying, blasting, and mechanical crushing. These activities not only deplete finite natural resources but also generate dust, noise, and greenhouse gas emissions. The resulting fugitive dust, if not properly managed, contributes to air pollution and can have adverse health and ecological impacts. In contrast, utilizing agricultural waste materials such as **coconut shells** as partial replacements for conventional coarse aggregates presents an eco-friendly and sustainable alternative that minimizes these negative effects.

Coconut shells are a renewable by-product of the coconut industry, abundantly available in tropical regions such as India. Their utilization in concrete production eliminates the need for energy-intensive aggregate crushing and simultaneously provides an effective waste management solution. Unlike quarried aggregates, which require mining and transportation from distant sources, coconut shells can be locally sourced, thereby reducing both material cost and embodied energy.

Furthermore, coconut shells possess a naturally rough and irregular surface texture that can enhance the bond between the aggregate and the cement paste, contributing to better interfacial adhesion. Their low density results in lighter concrete, which can reduce dead load and improve structural efficiency in certain applications. Additionally, the organic and fibrous nature of the shells contributes to good impact resistance and improved toughness, properties often desirable in lightweight concrete.

From an environmental perspective, incorporating coconut shells into concrete directly supports the principles of sustainable development and circular economy. It reduces solid waste disposal problems, lowers carbon emissions from aggregate production, and conserves natural stone resources. Thus, the use of coconut shells as alternative coarse aggregates is not only an environmentally responsible approach but also a practical step toward achieving **green and sustainable construction materials** for the future.

1.2 OBJECTIVES

1. To determine the fresh and hardened properties of concrete produced using coconut shell as partial replacement for conventional coarse aggregate.
2. To compare the mechanical properties of coconut shell concrete with those of conventional concrete to evaluate its suitability for structural and non-structural applications.

II. MATERIAL AND THEIR PHYSICAL PROPERTIES

The properties of materials used in concrete significantly influence its strength, workability, and durability. Therefore, it is essential to assess each constituent before mix design and casting. In this study, all materials were tested in accordance with relevant Indian

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Standards to ensure their suitability for concrete production. The primary materials used include:

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

2.1 Cement

Cement acts as the binding material in concrete, contributing to the setting, hardening, and overall strength development of the mix. In this research, **Ordinary Portland Cement (OPC) of 53 Grade** was used as the binder. The cement was tested in accordance with **IS 4031–1988**, meeting all specifications as per **IS 12269– 1987**. It was fresh, free from lumps, and stored in dry conditions to prevent hydration prior to use.

Table-1 Physical Properties of OPC (53 Grade Cement)

Properties	Results
28-day Compressive Strength	53 N/mm²
Initial Setting Time	40 min
Final Setting Time	240 min
Fineness	2890 m²/kg
Soundness	2.7 mm

2.2 Water

Water is essential for the hydration of cement and for maintaining the desired workability of the mix. Only clean, potable water free from acids, alkalis, oils, and organic matter was used throughout the study. The use of pure water ensures effective hydration, leading to higher strength and improved durability of concrete. Water content was carefully controlled to maintain the optimum water–cement ratio and prevent excess bleeding or segregation.

2.3 Aggregates

Aggregates serve as the skeletal framework of concrete, providing bulk, strength, and dimensional stability. They constitute nearly three-quarters of the total volume of concrete, and their quality has a direct impact on mechanical and durability properties. In this study, both natural and waste-based aggregates were used — fine aggregate (sand), conventional coarse aggregate (crushed stone), and alternative coarse aggregate (coconut shell). All aggregates were tested in accordance with **IS 2386–1963** for physical properties such as specific gravity, water absorption, and crushing value.

2.3.1 Fine Aggregate (FA)

Fine aggregate is the material that passes through a 4.75 mm IS sieve and primarily fills the voids between coarse aggregates, enhancing workability and surface finish. The natural river sand used in this study was clean, well-graded, and classified under **Zone II** as per **IS 383–1970**. Laboratory tests confirmed that it was free from silt, clay, and organic impurities, ensuring consistent performance in the mix.

Table – 2 Properties of Fine Aggregate (Zone II Sand)

Properties	Results
Specific Gravity (G)	2.67
Bulking	34.30%
Water Absorption (WA)	1.20%
Density (ρ)	1610 kg/m³

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2.3.2 Coarse Aggregate (CA)

Coarse aggregates form the main load-bearing component of concrete and influence its strength, stiffness, and dimensional stability. Crushed angular aggregates of 10 mm nominal size were used in this study. The aggregates were tested as per **IS 2386 (Part III)–1963**, confirming their suitability for M30 grade concrete. Their angularity enhances interlocking and contributes to the desired strength characteristics of the hardened concrete.

Table – 3 Properties of Coarse Aggregate

Properties	**Results**
Specific Gravity (G)	2.74
Aggregate Crushing Value	29.32%
Water Absorption (WA)	0.80%
Density (ρ)	1780 kg/m³

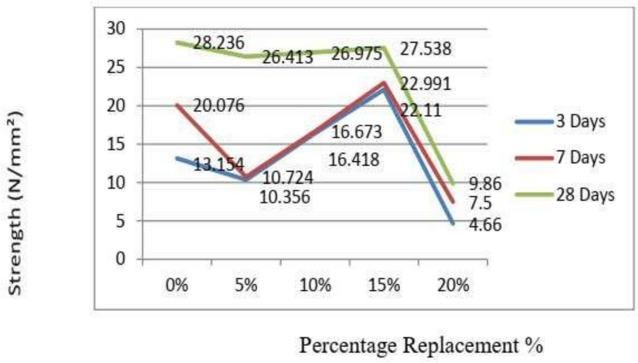
2.3.3 Coconut Shell Aggregate (CSA)

Coconut shells are hard, woody materials derived from the outer covering of the coconut fruit. They are abundantly available as agricultural waste in tropical regions and can be used as a lightweight coarse aggregate. The shells used in this study were cleaned, sun-dried, and crushed into angular pieces of size ranging from **10 mm to 12.5 mm**. Their rough texture promotes better bonding with cement paste, while their low specific gravity contributes to the production of lightweight concrete.

The coconut shell aggregate possesses higher water absorption than conventional crushed stone due to its porous structure. However, this property also enhances internal curing, contributing to better hydration and reduced shrinkage in some cases. Utilizing coconut shell in concrete helps address waste disposal challenges and reduces environmental impacts associated with natural aggregate extraction. Thus, it presents an effective and sustainable alternative for partial replacement in structural and non-structural concrete applications.

III. RESULT ANALYSIS

The compressive strength of concrete mixes with varying percentages of coconut shell replacement (0%, 5%, 10%, 15%, and 20%) was determined at 3, 7, and 28 days to evaluate both early-age and long-term strength development. The control mix (0% replacement) recorded compressive strengths of **13.15 N/mm²**, **20.08 N/mm²**, and **28.23 N/mm²** at 3, 7, and 28 days, respectively.



COMPRESSIVE STRENGTH (GRAPH)

Figure 1 Compressive Strength of M30 Grade Concrete

A 5% replacement slightly reduced strength at early stages, reaching **10.35 N/mm²** (3 days), **10.72 N/mm²** (7 days), and **26.41 N/mm²** (28 days), indicating that minimal coconut shell content may reduce compactness due to higher water absorption. The 10% mix exhibited notable improvement, achieving **16.42 N/mm²** (3 days), **16.67 N/mm²** (7 days), and **26.97 N/mm²** (28 days). The **15% replacement** level delivered the best performance, showing **22.11 N/mm²**, **22.99 N/mm²**, and **27.54 N/mm²** at 3, 7, and 28 days, respectively — almost comparable to the control at 28 days and higher at early curing stages. However, when replacement increased to **20%**, compressive strength dropped sharply to **4.66 N/mm²**, **7.50 N/mm²**, and **9.86 N/mm²**, confirming that excessive coconut shell content weakens concrete due to higher porosity and reduced aggregate interlocking.

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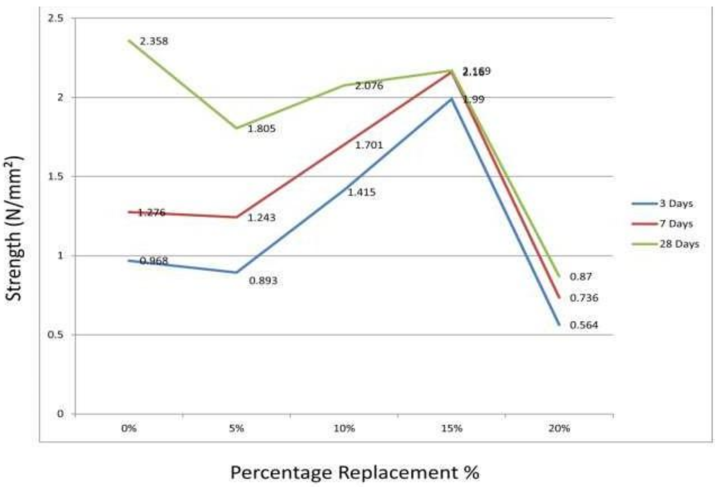
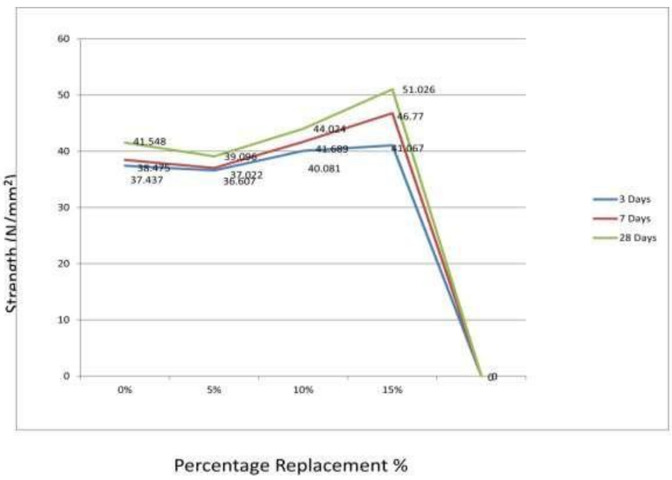
Overall, the results indicate that **10–15% coconut shell replacement** yields satisfactory compressive strength suitable for lightweight structural applications, while simultaneously reducing the self-weight of the concrete mix. Split tensile strength testing was carried out at 3, 7, and 28 days to evaluate the tensile behavior of coconut shell concrete. The control mix achieved **0.97 N/mm²**, **1.28 N/mm²**, and **2.36 N/mm²** at 3, 7, and 28 days, respectively.



SPLIT TENSILE STRENGTH (GRAPH)

Figure 2: Split Tensile Strength of M30 Grade Concrete

At **5% replacement**, values were **0.84 N/mm²**, **1.24 N/mm²**, and **1.80 N/mm²**, indicating a slight reduction. The **10% replacement** mix performed better, with strengths of **1.42 N/mm²**, **1.70 N/mm²**, and **2.08 N/mm²**, showing enhanced tensile bonding due to the rougher surface texture of the crushed shells. The **15% mix** achieved the highest values, recording **1.99 N/mm²**, **2.16 N/mm²**, and **2.17 N/mm²**, signifying improved tensile performance and good interfacial transition between shell and cement matrix. Beyond this level, strength decreased markedly — the **20% mix** achieved only **0.56 N/mm²**, **0.74 N/mm²**, and **0.87 N/mm²** at 3, 7, and 28 days, respectively. The results confirm that **moderate inclusion (up to 15%)** of coconut shell enhances tensile resistance, likely due to effective stress distribution from the shell's fibrous structure, but higher replacement weakens the matrix–aggregate bond.



FLEXURAL STRENGTH (GRAPH)

Flexural strength tests were conducted at 3, 7, and 28 days to assess the concrete's behavior under bending loads. The control mix recorded flexural strengths of **37.44 N/mm²**,
38.48 N/mm², and **41.55 N/mm²** at respective ages. A **5% replacement** showed marginally lower values (**36.61 N/mm²**, **37.02 N/mm²**, **39.10 N/mm²**).
The **10% replacement** mix exhibited improved results with**40.08 N/mm²**, **41.69 N/mm²**, and **44.02 N/mm²**, while the **15% mix** attained the highest performance with **41.07 N/mm²**, **46.77 N/mm²**, and **51.03 N/mm²** at 3, 7, and 28 days, respectively. This

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indicates that moderate incorporation of coconut shell improves flexural capacity due to better energy absorption and ductility imparted by the lignocellulosic composition of the shell.
Beyond 15%, flexural strength is expected to decline due to increased voids and reduced matrix integrity. The results confirm that **15% replacement of coarse aggregate with coconut shell** offers optimal flexural performance and significant reduction in concrete density, making it suitable for lightweight structural members where high bending strength and reduced dead load are desired.

IV. CONCLUSION

The experimental investigation clearly establishes that **coconut shell aggregate (CSA)** can be effectively utilized as a sustainable partial replacement for conventional coarse aggregates in M30 grade concrete. The study demonstrates that the inclusion of coconut shell significantly influences the mechanical performance, workability, and density of concrete—offering both structural and environmental advantages.
Compressive strength results reveal that concrete with **10–15% replacement** of coarse aggregate by coconut shell achieves strength values comparable to, and in some cases slightly exceeding, those of conventional concrete. The **15% CSA mix** achieved a **27.54 N/mm² compressive strength at 28 days**, only **2.5% lower** than the control mix, while producing a **9–10% reduction in density**—highlighting its potential for lightweight concrete applications.
The **split tensile strength** showed an enhancement up to **15% replacement**, where a strength of **2.17 N/mm²** was achieved, indicating improved ductility and crack resistance due to the fibrous and rough texture of the coconut shell surface, which promotes strong interfacial bonding. Similarly, **flexural strength** displayed a remarkable increase, peaking at **51.03 N/mm²** at 15% replacement—approximately **18% higher** than that of normal concrete— demonstrating better energy absorption and toughness.
Beyond 15% replacement, mechanical properties declined due to increased porosity and reduced aggregate interlocking, confirming that the **optimum substitution level** lies between **10% and 15%**. Nevertheless, all mixes exhibited acceptable performance for structural and non-structural applications, particularly where reduced self- weight and improved resilience are advantageous.
From a sustainability perspective, the utilization of coconut shells in concrete addresses two major challenges—**solid waste management and resource conservation**. The approach transforms an agricultural waste product into a valuable construction material, reducing landfill burden, minimizing quarrying of natural aggregates, and lowering embodied energy. This aligns seamlessly with global objectives for **green construction, circular economy, and carbon footprint reduction**.
In summary, the research concludes that:

- **Coconut shell aggregates** can replace **up to 15%** of conventional coarse aggregates without compromising strength.
- The resulting concrete is **lighter, more sustainable, and economically viable**.
- The material exhibits **improved flexural and tensile behavior**, with sufficient compressive capacity for medium-load applications.

Thus, **coconut shell concrete emerges as a promising innovation** in the pursuit of sustainable building materials— offering a perfect blend of **performance, economy, and environmental responsibility** for the future of the construction industry.

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