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Enhancing Concrete Strength Using Coconut Shell as Coarse Aggregate Replacement and Coir Fibers

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Abstract: Coconut shell can be used as an alternative to soft materials in whole or in part, and coir fiber can be added as reinforcement in normal mixes; hence the need for this study. Research aims to increase the strength of concrete using agricultural waste with various percentages of CS replacement (10%, 15%, 20%) and different CF (0.5%, 1%, 1.5%) based on the volume of concrete) for sustainable construction practices. Mechanical properties of the prepared concrete were evaluated in various areas, including compressive strength, impact strength, and curing ages. The results show that key findings, e.g., partial replacement of coarse aggregate up to a certain percentage of CF, improved the impact strength and impact resistance. The study concluded that the addition of CS and CF in concrete provides a promising approach for the development of enhanced, technologically sustainable, and cost-effective building materials.
Keywords: Coconut shell (CS), coir fibers (CF), compressive strength, flexural strength

I. INTRODUCTION

The construction industry has long sought sustainable and environmentally friendly alternatives to traditional building materials. One promising solution is the use of agricultural by-products such as coconut shells and charcoal fibers. To increase the quality of concrete Waste that is generated in large quantities in the tropics Coconut shells are a lightweight and durable alternative to traditional coarse aggregates. Today, coconut fibers are derived from coconut husks. Excellent tensile strength flexibility This makes it an ideal additive to improve the toughness and hardness of concrete.

This study explores the potential of using part or all of coconut shells in large-scale aggregate concrete. These natural materials are incorporated into concrete with coconut fibers to increase its mechanical properties. The effects of these changes on important parameters such as compressive strength are studied. Tensile strength Flexural strength, power, and durability pave the way for innovative and sustainable construction practices.

II. MATERIAL USED

A. *Description of Materials*

1) Cement: The OPC 53 grade is used in the research work, conforming to IS: 12269:1987.
2) Fine Aggregate: Natural sand of a size that passes through the 4.75mm sieve is taken for research work. The specific gravity of fine aggregate is 2.65. The fine aggregate corresponds to zone II. The unit weight of fine aggregate is 1622 kg/m³. .
3) Coarse Aggregate: The coarse aggregate is a crushed angular that was passing in a 12.5mm sieve and is used in the research work. The specific gravity of fine aggregate is 2.7. The unit weight of fine aggregate is 1800 kg/m³. .
4) Water: The potable water, which is free from deleterious materials, has a pH of 7.
5) Coconut Shell

Coconut shell is a by-product of the coconut fruit, and recently it is growing as an eco-friendly, sustainable material to be employed as construction material with its strength and durability. The hard, outer shell of coconuts is made of wood with a hard exterior; it has a very cellulose-rich content that makes up its structure. Coconut shells are traditionally treated as a waste product but are now being used to help improve concrete in a variety of different construction applications as a partial replacement for coarse aggregates. Their lightness contributes to minimizing the overall mass of the concrete; hence, they are suitable for lightweight construction, which is valuable for reducing structural load. Moreover, the microporous nature of coconut shells provides thermal and acoustic insulation, which can reduce the energy consumption of buildings and allow them to be soundproof.

Coconut shells can bolster sustainability in construction by utilizing agricultural waste and reducing the need for conventional aggregates that can have great environmental costs.

Their compressive strength properties, in comparison to traditional aggregates, come into play here, and hence, such precast concrete products are designed and manufactured in controlled proportions to attain the required structural integrity. If coconut shells get proper treatment and the mix design is maintained, they can be an excellent material.

Figure. 1: Crushed Coconut Shell

6) Coir Fibres

Coconut husk coir fibers have made headlines as a sustainable material in construction. These natural fibers have earned a reputation for durability, tensile strength, and resistance to rotting, making them an eco-friendly substitute for synthetic reinforcement in composite materials. Applications of coir fibers in lightweight concrete, fiberboards, and insulation panels have proven to be useful in improving the structural behavior and lowering environmental impact in industrial sectors. Green construction materials, which are available in abundance, are renewable or require less processing. Also, due to the fact that coir fiber is primarily an agricultural by-product, the utilization of coir fiber in composites for construction materials is in line with the principles underlying the circular economy and green construction practices, as this contributes to minimizing waste accumulation.

Figure. 2: Coir fibre

7) Mix Design: -

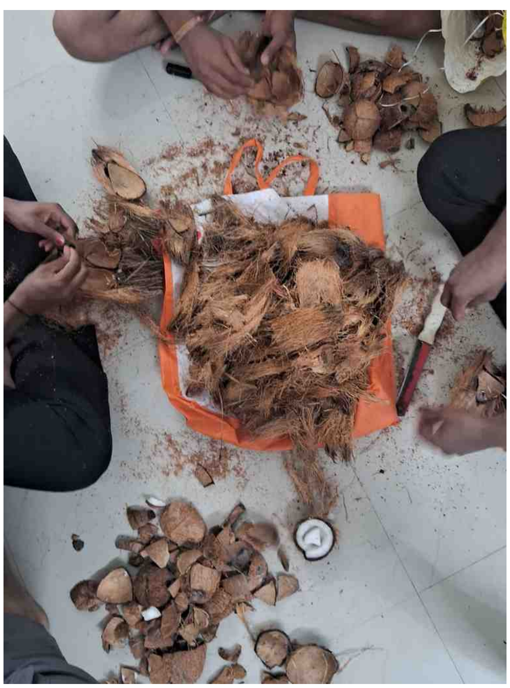
Concrete mix design is the process of finding the right proportions of cement, sand, and aggregates for concrete to achieve target strength in structures. So, concrete mix design can be stated as

Concrete Mix = Cement: Sand: Aggregates
Grade of Concrete = M25
Density of cement = 1440 kg/m3
Density of sand = 1450-1650 kg/m3
Density of aggregate = 1550 kg/m3
Total volume =0.003375m3
For 27 cubes= volume =27×0.003375=0.091125m3
Dry volume = 1.54 ×0.003375 = 5.197×10^{-3} m3
Sum of Ratio = 1+1+2 = 3.25

Table 1: Mix Design Calculation

For Cement Dry volume × $\frac{\text{Ratio of cement}}{\text{Sum of Ratio}}$ × Density of	Coconut Shell 10% = 10÷100×4.0280	Coir Fibers 0.5% = 0.5÷100×4.0280

Cement $0.140325 \times \frac{1}{1+1+2} \times 1440 = 50.51$kg Cement = 51 kg For Sand Dry volume $\times \frac{\text{Ratio of Sand}}{\text{Sum of Ratio}} \times$ Density of Sand $0.140325 \times \frac{1}{1+1+2} \times 1650 = 57.88$kg sand = 88 kg For Aggregate Dry volume $\times \frac{\text{Ratio of Aggregate}}{\text{Sum of Ratio}} \times$ Density of Aggregate $0.140325 \times \frac{2}{1+1+2} \times 1550 = 108.75$kg Aggregate = 109 kg For Water = 0.4 to 0.5 = 0.55× cement in kg = 0.55× 51 kg = 28.05 L Water = 29 L	=0.402 kg = 9×0.402 =3.618 kg Coconut Shell =3.618 kg 15% = 15÷100×4.0280 =0.604 kg = 9×0.604 =5.436 kg Coconut Shell =5.436 kg 20% = 20÷100×4.0280 =0.805 kg = 9×0.805 =7.245 kg Coconut Shell =7.245 kg	=0.0201 kg = 9×0.402 =0.1809 kgm Coir Fibers =0.36252 kg 1% = 1÷100×4.0280 =0.04028 kg = 9×0.04028 =0.36252 kg Coir Fibers =0.36252 kg 1.5% = 1.5÷100×4.0280 =0.06042 kg = 9×0.06042 =0.54378 kg Coir Fibers =0.54378 kg



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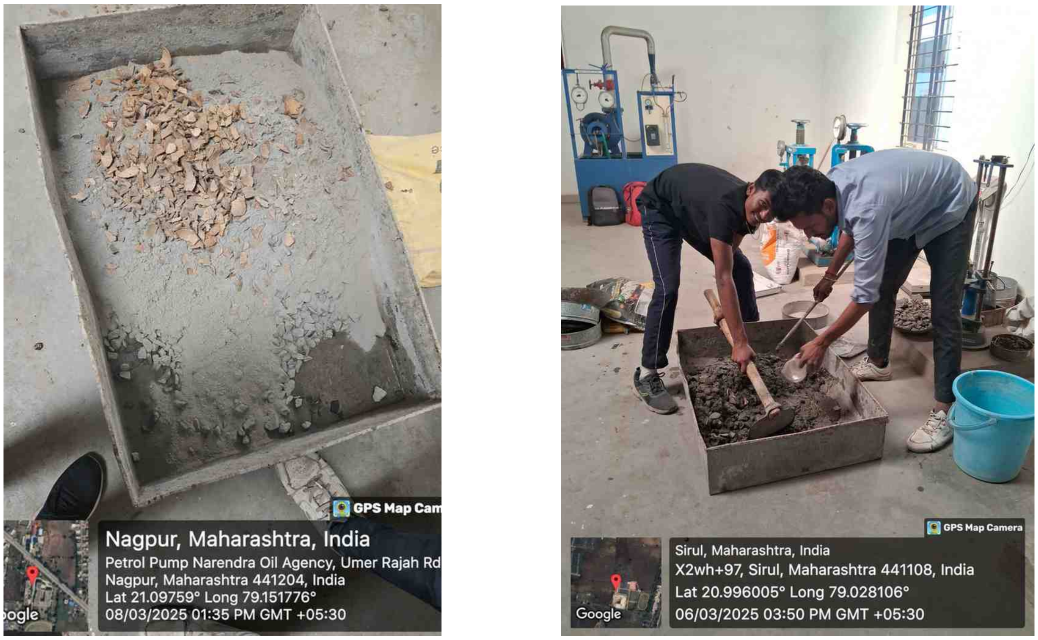

Fig. 3 Material Collection & Material Mixing Process Image

III. METHODOLOGY

1) Collection of Materials

Before making concrete, we collect the necessary materials:

- Cement: Ordinary Portland Cement (OPC) is used as the binding material.
- Fine Aggregates (Sand): Natural river sand is used.
- Coarse Aggregates: Crushed stones (used in normal concrete) are partially replaced with coconut shells.
- Coconut Shells: Collected, cleaned, dried, and crushed into appropriate sizes (similar to coarse aggregate size).
- Coir Fibers: Natural coconut fibers are cleaned, cut into small lengths (e.g., 20–50mm), and dried for use as reinforcement.
- Water: Clean potable water is used for mixing and curing.

2) Mix Design

A concrete mix design is prepared to determine the correct proportion of cement, sand, set, coconut shells, coir fibers, and water.

- The coconut shells replace a certain percentage of coarse aggregates (e.g., 10%, 15%, 20%).
- The coir fibers are added in small percentages (e.g., 0.5%, 1%, 1.5% of concrete volume).
- A control mix (normal concrete without coconut shell or fibers) is prepared for comparison.

3) Mixing Process

- Even cement and sand are first dried to dry ensure distribution.
- Coarse sets (including coconut shells) are added and mixed properly.
- Coir fiber is sprayed into the mixture to prevent clumping.
- The water is gently added when mixing a uniform, practical concrete mixture.

4) Casting and Curing

- The fresh concrete mixture is inserted into standard molds (cubes, cylinders, or beams) for testing.
- Molds are vibrated to remove air bubbles and ensure proper condensation.
- Solid samples are left to set for 24 hours before demolding.
- The samples are then kept in water to fix (usually for 7, 14, and 28 days) to allow proper hydration and strength development.

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5) *Testing of Concrete Samples*

After treatment, solid samples are tested for different properties:

- Compressive Strength Test (Cube Test)
- ➢ Tests how much load the concrete can bear before breaking.
- ➢ Conducted at 7, 14, and 28 days using a compression testing machine (CTM).
- Density and Workability Tests
- ➢ Slump Test: Checks the workability of the fresh concrete mix.
- ➢ Density Test: Measures the weight of the concrete to analyze its effect due to coconut shell replacement.

6) *Data Analysis & Comparison*

- The test results of modified concrete (coconut shell + coir fibers) are compared with normal concrete.
- Graphs and tables are used to analyze trends in **strength, durability, and density**.

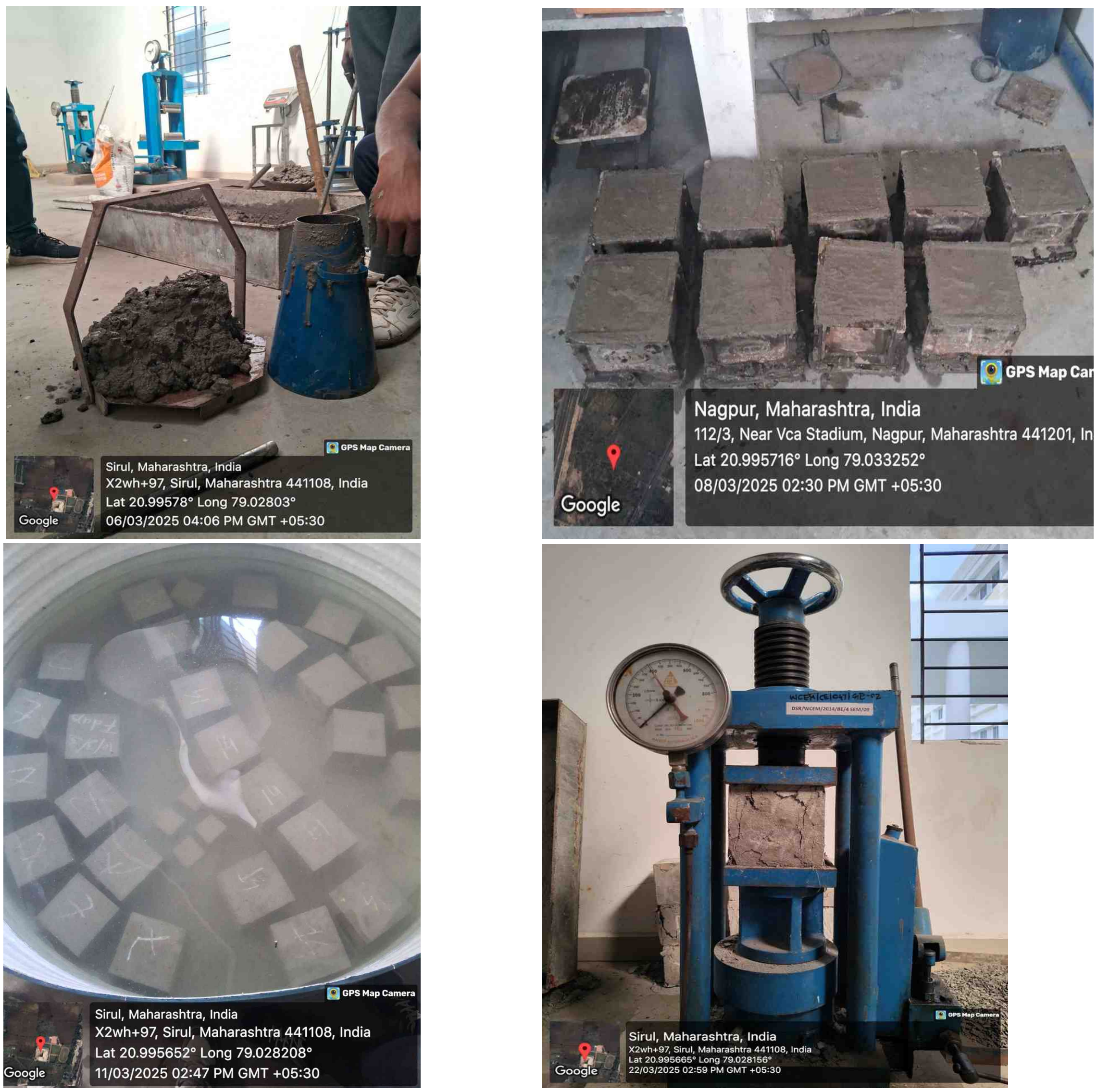

Fig. 4 Example of Cube Casting & Testing Images

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IV. RESULTS AND DISCUSSIONS

The test specimen after 7, 14, and 28 days of curing is tested for compressive strength using a Universal Testing Machine.

Table 2: Compressive Strength at 7 Days for 10% of Coconut shell 0.5% of Coir fiber

S.No	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	360	16.00	**16.44**
2	380	16.88	
3	370	16.44	

Table 3: Compressive Strength at 7 Days for 15% of Coconut shell 1% of Coir fiber

S.No	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	360	16.00	**17.03**
2	390	17.33	
3	400	17.77	

Table 4: Compressive Strength at 7 Days for 20% of Coconut shell 0.5% of Coir fiber

Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	430	19.11	**17.92**
2	400	17.77	
3	380	16.88	

Table 5: Compressive Strength at 14 Days for 10% of Coconut shell 1.5% of Coir fiber

Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	400	17.77	**18.61**
2	420	18.66	
3	440	19.55	

Table 6: Compressive Strength at 14 Days for 15% of Coconut shell1.5% of Coir fiber

Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	430	19.11	**19.07**
2	440	19.55	
3	460	20.44	

Table 7: Compressive Strength at 14 Days for 20% of Coconut shell 1% of Coir fiber

Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	560	20.44	**21.18**
2	500	22.22	
3	470	20.88	

Table 8: Compressive Strength at 28 Days for 10% of Coconut shell 1% of Coir fiber

Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	470	20.88	**21.62**
2	480	21.33	
3	510	22.66	

Table 9: Compressive Strength at 28 Days for 15% of Coconut shell 0.5% of Coir fiber

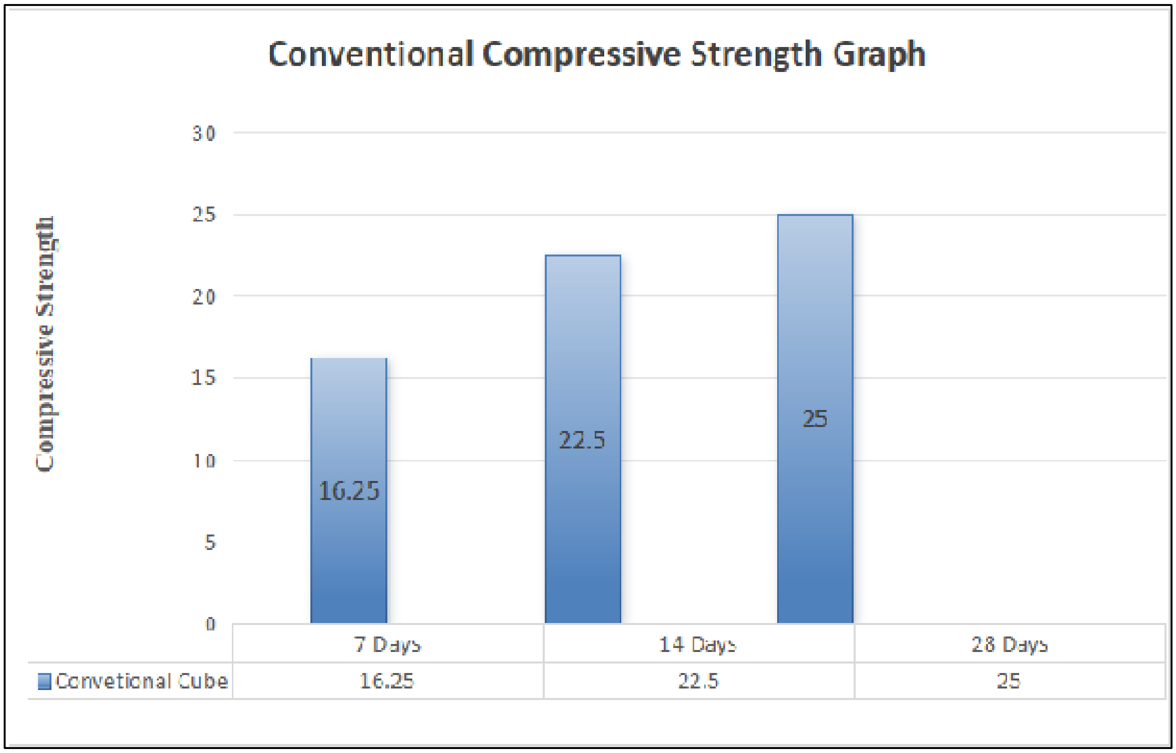
Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	550	24.44	**23.55**
2	510	22.66	
3	530	23.55	

Table 10: Compressive Strength at 28 Days for 20% of Coconut shell 1.5% of Coir fiber

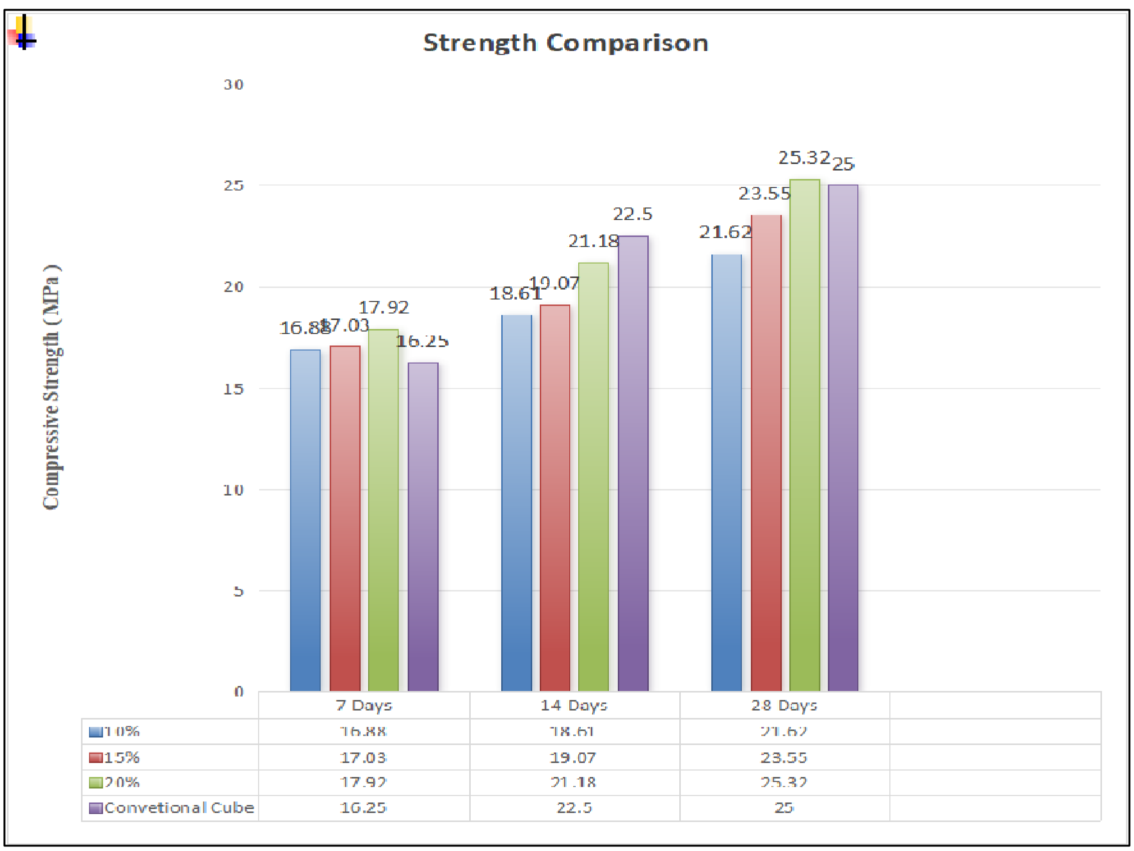
Sr.no	Load at failure (k N)	Compressive strength (N/mm^2)	Average Compressive strength (N/mm^2)
1	560	24.88	**25.32**
2	570	25.33	
3	580	25.77	

Table: 11 Compressive Strength (N/mm2) Convetional Concrete & Coarse aggregate replaced by Coconut shell + coir Fibre

Concrete Mix	Descripition	COMPRESSIVE STRENGTH (N/mm2)			
M25	Convetional Concrete	7 Days		14 Days	28 Days
		16.25		21.5	25
	Coarse aggregate replaced by Coconut shell + coir	10%	16.88	17.03	17.92
		15%	18.61	19.07	21.18
		20%	21.62	23.55	25.32



Graph 1. Graph Showing Compressive Strength in Conventional Concrete



Graph 2. Graph Showing Compressive Strength in of Conventional Concrete
& Coarse Aggregate Replaced by Coconut shell + Coir Fibre

V. CONCLUSIONS

1) Feasibility of Coconut Shell as Aggregate: Coconut shell can effectively replace conventional coarse aggregates in concrete without significantly compromising structural integrity.
2) Improved Strength with Coir Fibers: The addition of coir fibers improved the tensile and flexural strength of the concrete by enhancing crack resistance and bonding.
3) Environmental Sustainability: Utilizing agricultural waste like coconut shells and coir fibers promotes sustainable construction and reduces environmental pollution.
4) Lightweight Properties: Concrete with coconut shell aggregates resulted in a lighter mix compared to conventional concrete, which can reduce dead load in structures.
5) Enhanced Durability: Test results showed better performance in durability parameters such as water absorption and shrinkage resistance.
6) Optimal Replacement Level: Maximum strength was achieved at a specific percentage of coconut shell and coir fiber addition (you can specify the exact percentage here based on your data).
7) Cost-Effectiveness: The use of locally available waste materials can lead to significant cost reduction in concrete production.
8) Recommendation for Application: Suitable for non-load bearing and low-rise structural components, paving blocks, and precast units where lightweight and eco-friendly materials are desired.

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