Innovative Mix Designs Using Coconut Shell, Sawdust, and Fibers for Lightweight High-Strength Concrete

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ABSTRACT
Being the most widely used construction material, concrete is basically strong in compression but weak in tension and heavy in weight. Hence lightweight concrete was developed as an alternative. This work studies the use of sustainable materials such as coconut shell and sawdust-the agricultural and industrial waste-for the purposes of reducing the density of concrete and enhancing its property. The coconut shell was used as a replacement of coarse aggregate and it reduces the weight of concrete by about 25%. Sawdust was used to replace partially the fine aggregate at four levels: 0, 5, 10, and 20% in both normal concrete and coconut shell concrete. The M25 mix was adopted, and determination of compressive strength was made after 3, 7, and 28 days. The results indicated that the compressive strength decreases with the increase in sawdust content and the best replacement was found to be 5% for either concrete. At this sawdust level, coconut fiber was added at 1, 2, 3, 4, and 5% to enhance tensile properties and crack resistance. Adding coconut fiber improved the strength properties with the notable improvement observed at 2% fiber in coconut shell concrete and 3% in normal concrete. This research clearly emphasizes the prospects of utilization of agricultural waste materials toward the development of eco-friendly, lightweight, and high-strength concrete, while retaining environmental problems with related to waste disposal.

Keywords: *Coconut shell, Sawdust, Coconut fiber, Lightweight concrete, Compressive strength, Waste materials, Sustainable construction, Fiber-reinforced concrete, Aggregate replacement, Eco-friendly concrete.*

1. INTRODUCTION

Concrete remains the most widely used construction material globally due to its excellent compressive strength, durability, and versatility [1]. However, it is inherently brittle, weak in tension, and has a relatively high self-weight, which increases structural load and construction costs [2]. To overcome these limitations, researchers have explored lightweight concrete incorporating natural and industrial by-products as alternative materials [3]. The growing concern over environmental sustainability has further accelerated the use of waste materials in concrete production to reduce landfill usage, conserve natural resources, and lower carbon emissions [4].

In this context, coconut shell and sawdust-agricultural and industrial wastes-are being increasingly investigated for their potential as lightweight aggregate replacements in concrete [5]. Coconut shells, when used as coarse aggregate, can reduce concrete density by up to 25% [6], while sawdust serves as a viable partial replacement for fine aggregates, contributing to lighter and more thermally insulating concrete mixes [7]. Additionally, the inclusion of natural fibers such as coconut fiber (coir) helps improve tensile strength and crack resistance, making the composite more ductile and durable [8].

This study focuses on evaluating the performance of high-strength coconut fiber-reinforced concrete incorporating mineral admixtures and varying percentages of sawdust as fine aggregate replacement. The investigation aims to optimize the mix proportions for enhanced mechanical properties while promoting sustainable construction practices through waste utilization [9].

2. MATERIALS AND METHODOLOGY

2.1 MATERIALS

a) Cement

The cement used for this research work was 53-grade OPC cement. The properties of cement tabulated in Table 1.

Table 1 Properties of cement

S. No	Description	Values
1	Normal Consistency of cement	30%
2	Specific Gravity	3.27
3	Fineness	6%
4	Initial Setting Time	30 min
5	Final Setting Time	250 min

b) Fine Aggregate

Sand includes quartz as its constituent mineral while clay consists of many other more active minerals such as illite, kaolinite and so forth. Sand particles are retained on 4.75mm sieve. Natural sand can be mined from the river beds or from pits locally. An

assessment needs to be done on the degree of sand's fineness and based on the gradation of fineness zone will be determined. The characteristics are in table 2.

Table 2 Properties of Fine Aggregate

S.No	Description	Values
1	Specific Gravity	2.69
2	Sieve Analysis of sand	ZONE -II
3	Bulking of Sand	7.45
4	Water Absorption	3.36%

c) Coarse Aggregate

Another fundamental component while making concrete is coarse aggregate. While there are several options available to substitute for coarse aggregate due to environmental concerns, in this specific research work, the coarse aggregate chosen has a size of 12.5mm and its properties are listed in the subsequent Table 3.

Table 3 Properties of Coarse aggregate

S. No	Description	Values
1	Specific Gravity of CoarseAggregates	2.61
2	Water Absorption of CoarseAggregates	0.4%
3	Impact Test	23.48%
4	Los Angeles Test	32.42%
5	Aggregate Crushing test	28.62%
6	Flakiness index	22%
7	Elongation index	17%

d) Coconut Shell

The coconut shell was obtained from the local coconut oil mill industry. The coconut shell there was crushed and made to pass through a 12.5mm sieve. The inner side was polished while the rough outer side was left as is. The CS has high water adsorption is expected due to its porosity CS was proactively dipped in water for 24 hours before its use to eliminate this problem. The properties of used coarse aggregate coconut shell are listed in Table 4.

Table 4 Properties of Coconut Shell

S. No	Description	Values
1	Maximumsizeused(mm)	12.500
2	WaterAbsorption (%)	24.00
3	Sp. Gravity	1.100
4	Finenessmodulus	6.26
5	Crushingvalue(%)	2.58
6	Shellthickness(mm)	2.-8

e) Sawdust

This type of saw dust came from Sri Chakra timber shed which is located in S.P Koil region in Kancheepuram Dt. The powder was captured from different species of wood like Oak, Mahogany, Mulberry, and Axle wood. Furthermore, the sawmill put them under blades in order to collect the powder. The cumulated powder was collected in a waterproofing pouch to ensure that fungus would not appear. The saw dust powder was further dipped in water for approximately 4 to 5 hours before preparation of concrete.The properties of sawdust are as followed in the table 5.

Table 5 Properties of sawdust

S. No	Description	Value
1	MaximumSizeused(mm)	>4.75
2	WaterContent(%)	25.580
3	Sp.Gravity	0.370

f) Coconut fiber

It is a fiber that naturally occurs and is obtained from the coconut husk. It serves many purposes such as floor mats, brushes, door mats, and even mattresses, but the brittle nature is what drew concrete research workers, seeking to make concrete stronger in tension. The fiber used in this project have a diameter of 0.2-0.5 mm and were cut to a length of 50mm. The fiber was then added to the concrete at proportions of 1%, 2%, 3%, 4%, and 5% of the concrete volume.

2.2 METHODOLOGY

The flowchart explains the procedure for an experimental study. First, one carries out a Literature Survey to acquire background information. Then follows an instance of Material Selection, wherein one selects appropriate materials. Next comes Specimen Casting, for the preparation of concrete samples. These specimens are cured to allow the property to develop optimally. After curing, Testing Methods are applied to test the performance of these specimens. Finally, all results are analyzed during the Result Analysis period for drawing conclusions and insights.

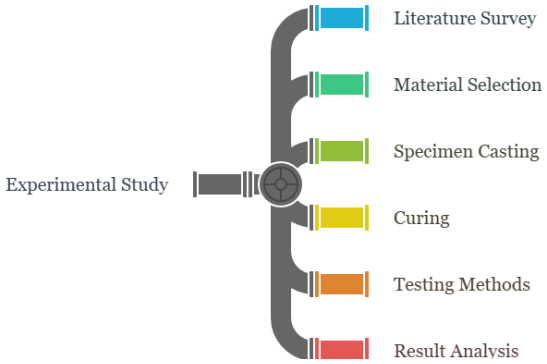

Fig 1 Flow Chart for Methodology

2.3 MIX DESIGN

The materials used in this project are collected from the nearby sources. The concrete mix M25 was designed according to IS 10262(2009) and the mix ratio is as follows. The project is for investigation on mechanical properties of lightweight concrete using coconut shell, sawdust and coconut fiber.

Grade of concrete = M25

Normal concrete = 1:2.22:2.60:0.55

Coconut shell concrete=1:1.47:0.65:0.42

For this concrete mix sand was partially replaced with sawdust by volume and coconut fibre was used in the proportions of 1%, 2%, 3%, 4% and 5% by volume of concrete.

3. RESULTS AND DISCUSSION

This study assesses the influence of incorporating coconut shell, sawdust, and coconut fiber on the mechanical properties of concrete, including compressive strength, flexural strength, split tensile strength, and impact resistance. Compressive strength was evaluated at 3, 7, and 28 days of curing. Flexural strength, split tensile strength, and impact tests were conducted to analyze the performance of coconut fiber-reinforced concrete with partial replacements of coarse aggregate (coconut shell) and fine aggregate (sawdust). The findings will demonstrate how these natural materials enhance the structural behaviour of concrete and contribute to sustainable construction practices.

3.1 Compression Strength

This is the method applied to assess the internal equilibrium frictional force a body or an object has when a load is applied on it. The concrete specimens were cast into cubes measuring 150×150×150mm, were cured and tested at ages of 3, 7 and 28 days. The percentage of sawdust replacement is at 5%, 10%, 15%, and 20% for both types of concrete; the conventional and the coconut shell concrete. The following is the table which show the compressive strength of cubes with varying percentages of sawdust replacement and volume replacement at different percentages.

Fig 2 Compression Strength Testing

Table 6 Compressive strength test results for partial replacement of sawdust in CC and CSC

Compressivestrength(Mpa)				
Mix	**Sawdust%**	**3rd day**	**7th day**	**28th day**
Conventionalconcretewithsawdust	0	13.69	19.73	30.23
	5	14.23	18.17	29.47
	10	12.1	16.2	25.9
	15	9.93	15.16	21.7
	20	7.17	12.57	18.47
Coconutshellconcretewithsawdust	0	12.98	18.73	28.23
	5	14.47	19.43	25.23
	10	10.53	14.03	19.93
	15	9.27	12.2	16.5

	20	2.67	2.67	4.63

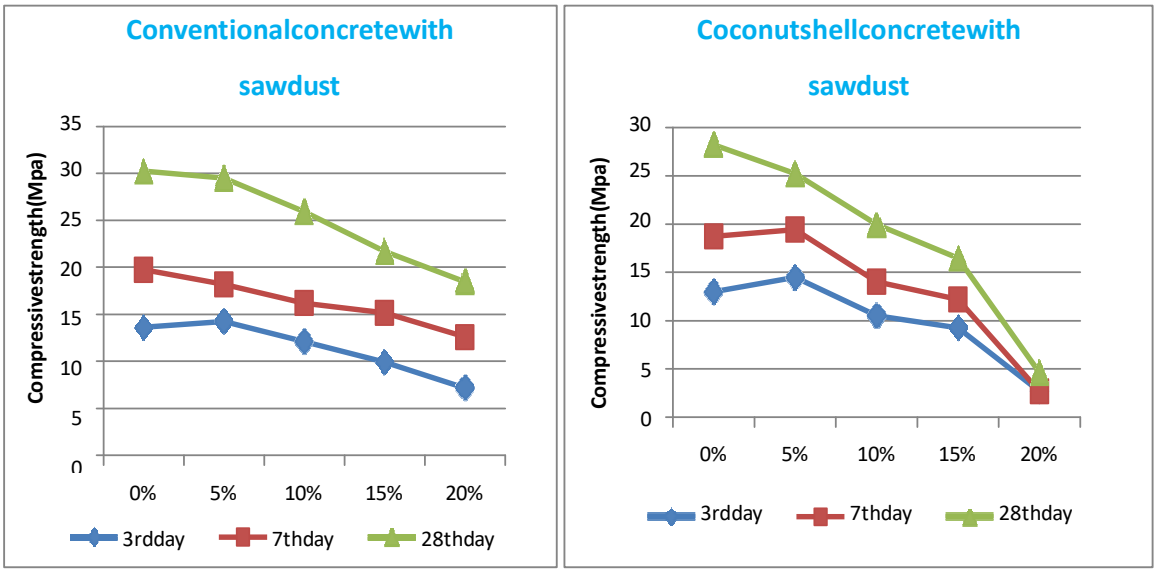

Fig 3 Line charts of CC and CSC with sawdust

As shown in table 6 and figure 1, it is evident that the 5% replacement of sawdust in conventional as well as in coconut shell composites gives the greatest strength at 29.47Mpa and 25.23Mpa. In this regard, fiber was incorporated into the 5% replacement of sawdust in CC and CSC in the quantities ranging from 1% to 5%, and the results tests were as depicted in table 7.

Table 7 Compressive strength test results for partial replacement of sawdust in CC and CSC with addition Fiber

Compressivestrength(Mpa)				
Mix	**Fiber %**	**3rd day**	**7th day**	**28th day**
Conventionalconcretewith5% saw dust and addition of fiber	0	14.23	18.17	29.47
	1%	12.76	15.73	29.1
	2%	15.23	17	30.96
	3%	14.3	19.73	34.43
	4%	16.2	19.96	29.47
	5%	9.83	11.93	13.23
Coconutshellconcretewith5% sawdust and addition of fiber	0	14.23	18.17	25.23
	1%	14	16.83	22
	2%	21.33	26.13	33.22
	3%	22.7	27.53	29.89
	4%	17	20.12	26.033
	5%	15.65	18.36	24.26

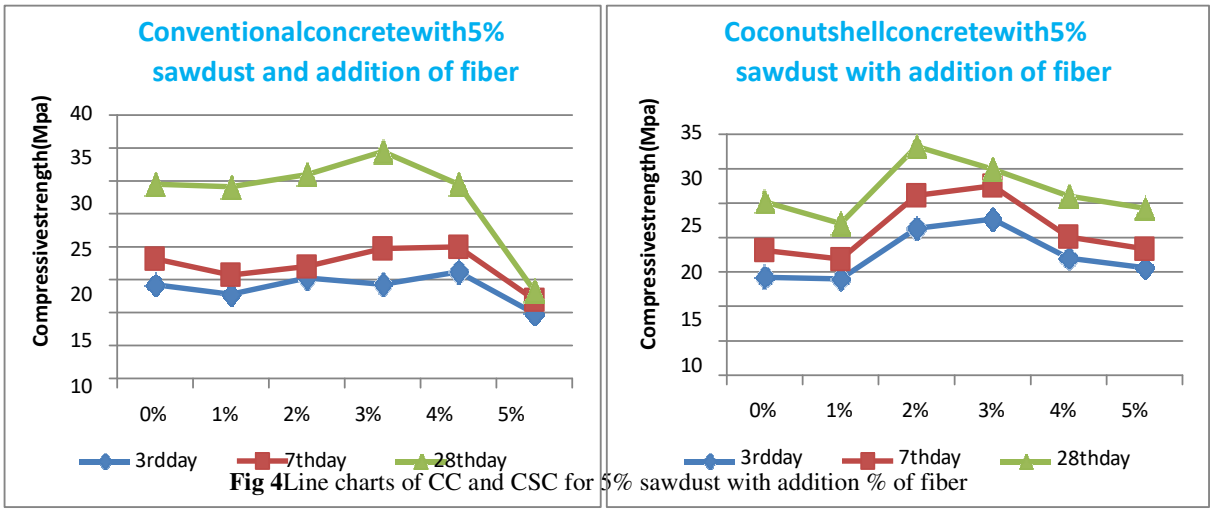

Fig 4 Line charts of CC and CSC for 5% sawdust with addition % of fiber

The test results in the table above indicate that the compressive strength of concrete is maximum at the addition of 3% fiber in CCSC and 2% fiber in CSSC. The values are 34.33Mpa and 33.22Mpa respectively, which helps ascertain the optimum percentage of fiber to be used for the remaining tests.

3.2 Split Tensile Test

The concrete cylindrical specimens measuring 100×200mm prepared in the steel moulds undergo this test. The test is conducted by placing the cylinder horizontally in the compression testing machine. A vertical crack through the diameter should appear at the point of removal. The figure is somewhere around 0.05 - 0.12 times above the direct tensile strength. As described earlier, the mix is prepared for the split tensile test with 5% sawdust addition and 3% fiber incorporation in CCSC, Same percentages of sawdust replacement with 2% fiber addition in CSSC and the results are as stated in table 8.

Fig5 Split Tensile Testing

Table 8 Split tensile strength for beams with 5% sawdust and addition of fiber in CC and CSC

Splittensilestrength(Mpa)				
M25	**Fiber %**	**3rd day**	**7th day**	**28th day**
CC	0	2.35	3.82	4.02
CCSC	3	2.95	4.23	4.86
CSC	0	1.09	2.12	2.82
CSSC	2	1.89	2.97	3.19

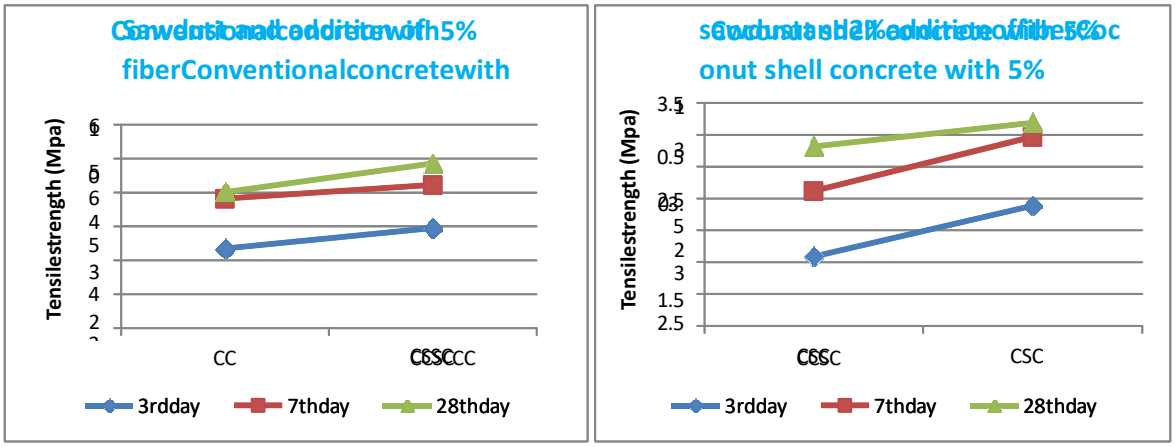

Fig 6 Line chart for CC, CCSC, CSC and CSSC with addition of fiber

3.3 Flexural test

The test is done Beams of size 100×100×500mm; it does not contain any additional reinforcement. It is a three-point loading method, continues load is applied until the specimen breaks. This makes the load to divide equally between the rollers such that it gets failure the test values are given in the following table 9.

Fig 7 Flexural Testing

Table 9 Flexural test on CC, CCSC, CSC and CSSC with addition of fiber

Flexurestrength(Mpa)				
M25	**Fiber %**	**3rd day**	**7th day**	**28th day**
CC	0	2.08	3.45	4.23
CCSC	3	2.85	4.53	5.33
CSC	0	1.93	2.42	3.81
CSSC	2	2.09	2.89	4.12

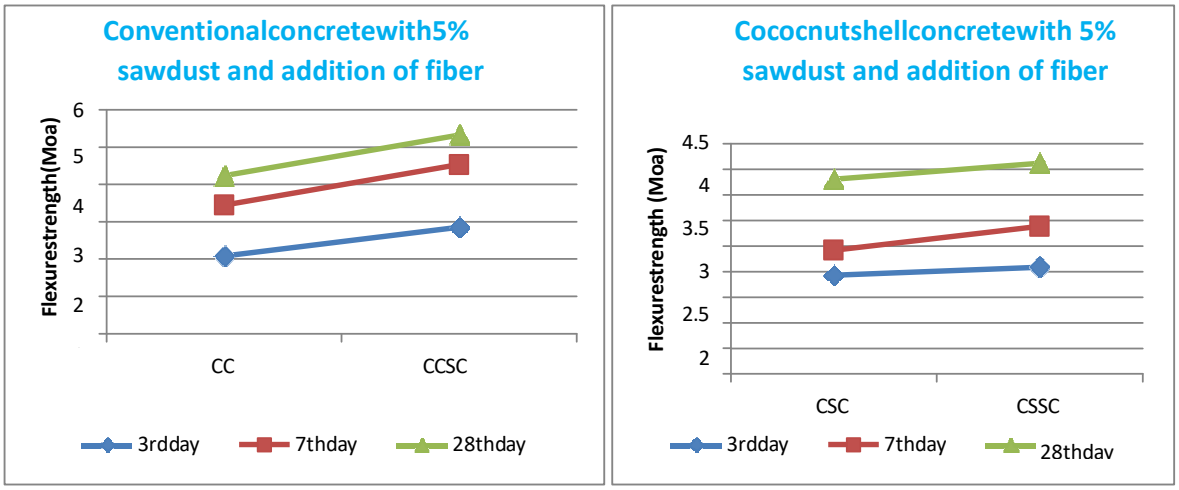

Fig 8 Line chart for CC, CCSC, CSC and CSSC with addition of fiber

3.4 Impact Testing

It measures the strength of concrete specimen with respect to sudden load application. This done on the specimen size 65×150mm where it also serves as an impact disk. Until a certain number of blows is delivered the specimen does not fail which means producing an initial crack and goes to break, after which the specimen is said to have broken. The test results are listed below in table 10.

Fig 9 Impact Disk

Table 10 Impact test on CC, CCSC, CSC and CSSC with addition of fiber

Impact strength (Mpa)			
Mix	**Fiber %**	**No.ofblowsin28days**	
		Initialcrack	**Finalcrack**
CCSC	3	266	268
CSSC	2	110	128

As demonstrated in table 10, impact test results have been improved with the use of fiber. This suggests that the concrete containing fibers can bear sudden loads which means it is suitable for use in construction where impact and static (roller) loads are encountered.

4. CONCLUSION

This study tentatively explored the possible effectivity of sawdust employed as partial replacements of fine aggregate and coconut coir fiber as reinforcing

materials for concrete for more sustainable construction. The experimental results showed that concrete sawdust addition up to 5% with coconut fiber offered a significant enhancement to the mechanical properties of the concrete.

In compression, sawdust concrete of 5% sawdust and 3% fiber attained a 16.8% increase over normal concrete, while CSC concrete with 5% sawdust and 2% fiber improved 30% over normal CSC concrete. Similarly, split tensile strength was enhanced by up to 4.86 MPa with the addition of 3% fiber in sawdust-modified concrete. Flexural strength improvement was also established with an increase rate of 26% in sawdust and fiber-modified concrete compared to control specimens.

Furthermore, impact strength showed a marked improvement in toughness and crack resistance, especially with the incorporation of fibers, under dynamic loading conditions.

To conclude, it can be inferred that sawdust at 5% replacement level with 2–3% coconut coir fiber could be used as a viable and green alternative for concrete construction with enhanced mechanical performance and utilization of wastes for sustainable development in construction.

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