

Experimental Investigation on Sustainable Concrete using Coconut Shell and Fly Ash

Mrs. Athira Suresh
Assistant Professor
Department of Civil Engineering
Ilahia College of Engineering & Technology
Muvattupuzha, Kerala, India

Ashitha Sasidharan, Chithra P.V,
Sandhya Mohan, Soumya K.G
Btech Students, Department of Civil Engineering
Ilahia College of Engineering & Technology
Muvattupuzha, Kerala, India

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Abstract—Rapid urbanization has increased the demand for concrete, leading to depletion of natural resources and environmental concerns. This study investigates the use of coconut shell as a partial replacement for coarse aggregate and fly ash as a partial replacement for cement in M20 grade concrete. Coconut shells, an agricultural waste, were processed and used in varying proportions (10–30%), while fly ash was used at 5–10% replacement levels. Concrete cubes were cast and tested for workability and compressive strength at 7 and 28 days. Results indicate that partial replacement improves sustainability while maintaining acceptable strength. The study concludes that coconut shell and fly ash can be effectively utilized to produce lightweight, eco-friendly, and cost-effective concrete.

Keywords— Coconut shell, Fly ash, Sustainable concrete, Lightweight concrete, Compressive strength

I. INTRODUCTION

Concrete is widely used in construction due to its strength and durability. However, excessive use of natural resources such as sand and aggregates leads to environmental degradation. To address this issue, alternative materials like coconut shell and fly ash are being explored. Coconut shell is an agricultural waste available aggregate. Fly ash, a byproduct of thermal power plants, improves workability and long-term strength due to its pozzolanic properties in abundance and can be used as a lightweight.

This study aims to combine these materials to develop sustainable concrete and evaluate its performance in terms of strength and workability.

II. LITERATURE REVIEW

Previous studies show that:

- Coconut shell can replace 10–20% of coarse aggregate without major strength loss.
- Fly ash improves durability, reduces permeability, and enhances long-term strength.
- Combined use of coconut shell and fly ash improves sustainability.

However, limited studies focus on simultaneous use of coconut shell (fine & coarse) and fly ash, which forms the research gap of this study.

A. OBJECTIVES

- To investigate the use of coconut shell waste as a partial replacement of coarse aggregate in concrete of grade M20.
- To study the effect of fly ash as a partial replacement of cement on the mechanical and durability properties of CS concrete.
- To determine the optimum replacement percentage of coconut shell and fly ash for achieving acceptable strength and durability.
- To evaluate the mechanical properties (compressive strength, Split tensile strength) of concrete containing CS and FA.
- To assess the durability characteristics of CS concrete, including water absorption, sorptivity, permeability, and resistance to environmental effects.
- To prepare cubes and conduct relevant tests to validate the feasibility of CS concrete for sustainable and lightweight construction.

.III. METHODOLOGY

- Materials were tested as per IS codes
- M20 mix design was prepared (IS 10262:2009)
- Coconut shell replaced aggregate (10–30%)
- Fly ash replaced cement (5–10%)
- Cubes of size 150×150×150 mm were cast
- Curing done for 7 and 28 days
- Compressive strength tested using CTM

IV. MATERIALS

- Cement: OPC 53 Grade
- Fly Ash: Class F fly ash

- Fine Aggregate: M-sand
- Coarse Aggregate: 20 mm crushed stone
- Coconut Shell: Used as fine and coarse aggregate
- Water: Potable water

A. MATERIAL TESTING

4.1 Cement

Material testing of cement is carried out to determine its physical properties and ensure it meets the requirements specified by Indian Standards (IS 4031 and IS 269:2015). The main tests conducted on cement include specific gravity, fineness, consistency, setting times, and compressive strength. The results obtained are as follows.

TABLE 4.1 TEST RESULT FOR CEMENT

Test	Result	IS code recommendations (IS 4031,IS 269:2015)
Specific Gravity	3.16	3.1-3.16
Fineness	2%	≤ 10%
Consistency of standard cement paste	30%	26 -33%
Initial setting time	142 min	Not less than 30 minutes
Final setting time	256 min	Not more than 600 minutes
Compressive strength in 3 days	28.40 Mpa	Not less than 27 Mpa
7 days	41.33 Mpa	Not less than 37 Mpa

4.2 Fly ash

The use of fly ash as a partial replacement for hydraulic cement will usually reduce water demand. Usually strength development is extremely slow due to pozzolanic reaction of ash. Later age strength is higher. Class F ash reduces alkali - silica reactivity due to the dense structure and hence expansion is reduced which increases durability. The pozzolanic reaction between ash and lime generates less heat, leading to reduced thermal cracking when ash is employed to exchange a percentage of hydraulic cement. The results obtained are as follows.

TABLE 4.2 TEST RESULT FOR FLY ASH

Test	Result
Specific Gravity	2.5
Fineness	20%

4.3 M. sand

Material testing of manufactured sand (M-sand) is carried out to ensure that it meets the required standards for use in concrete and construction works. The tests are conducted as per IS 383:2016 and IS 2386:1963 to determine its physical properties. The results obtained are as follows.

TABLE 4.3 TEST RESULT FOR M. SAND

Test	Result	IS code recommendations (IS 383:2016,IS 2386:1963)
Specific Gravity	2.68	2.50- 2.80
Bulk density		1.45- 1.65g/cm ³
a) Loose	1.55 g/cm ³	
b) compacted	1.82 g/cm ³	
Fineness modulus	3.18	2.20-3.20
Water absorption	1%	≤ 3%

4.4 Coconut shell as Fine Aggregate

The fine aggregate supplied were of crushed coconut shell of below 4.75mm. Tests were conducted for determining the following properties of specific gravity, Bulk density , Fineness modulus and Water absorption . The results obtained are as follows.

TABLE 4.4 TEST RESULT FOR CSA AS FINE AGGREGATE

Test	Result
Specific Gravity	1.3
Bulk density	
a) Loose	0.68 g/cm ³
b) compacted	0.76g/cm ³
Fineness modulus	5.46
Water absorption	6.30 %

4.5 Coconut shell as Coarse Aggregate

The coarse aggregate supplied were of crushed coconut shell of 12 mm. Tests were conducted for determining the following properties of specific gravity, Bulk density , Fineness modulus, Water absorption , aggregate crushing value and aggregate impact value. The results obtained are as follows.

TABLE 4.5 TEST RESULT FOR CSA AS COARSE AGGREGATE

Test	Result
Specific Gravity	1.43
Bulk density	
a) Loose	0.60 g/cm ³
b) compacted	0.68 g/cm ³
Fineness modulus	2.41
Water absorption	6.30 %
Aggregate crushing value	2.02
Aggregate impact value	2.7

4.5.1 Water Soaking Treatment

Water soaking is the simplest and most commonly used method for treating coconut shell aggregates. In this method, crushed coconut shells are immersed in clean water for approximately 24 hours. This process allows the pores of the shells to absorb water and reach a saturated surface dry (SSD) condition. The SSD condition ensures that the coconut shells do not absorb additional water during the concrete mixing process, which could otherwise affect the water-cement ratio and workability of the concrete. Since coconut shells exhibit relatively high water absorption due to their porous structure, pre-soaking is essential for maintaining proper hydration of cement during concrete mixing. In this project, water soaking treatment was carried out to treat the crushed coconut shell aggregates before using them in concrete. The collected coconut shells were first cleaned to remove dust, fibers, and other impurities. After cleaning, the crushed coconut shell aggregates were immersed in clean water for approximately 24 hours. During this soaking period, the pores of the coconut shells absorbed water and the aggregates reached the Saturated Surface Dry (SSD) condition. In this condition, the internal pores of the aggregates were completely filled with water while the surface remained dry. This treatment prevented the coconut shell aggregates from absorbing additional water during the concrete mixing process. Since coconut shells have relatively high water absorption due to their porous structure, soaking the aggregates helped maintain the designed water-cement ratio, improve the workability of the concrete mix, and ensure proper cement hydration.

4.6 Coarse Aggregate-20 mm metal

The coarse aggregate supplied were of crushed stone of 20mm. Tests were conducted as per IS 2386-1963 part IV to determine the following properties specific gravity, elongation index, flakiness index, bulk density, aggregate crushing value, aggregate impact value, particle size distribution and water absorption. The results obtained are as follows.

TABLE 4.6 TEST RESULT FOR COARSE AGGREGATE

Test	Result	IS code recommendations (IS 383:2016,IS 2386:1963)
Specific Gravity	2.74	2.62-2.90
Bulk density		>1.40g/cm ³
a) Loose	1.38 g/cm ³	
b) compacted	1.54 g/cm ³	
Fineness modulus	7.47	6-8
Water absorption	0.2%	≤ 2%
Flakiness index	8.26%	≤ 25%
Elongation index	17.27%	≤ 25%

Aggregate crushing value	29	≤ 30%
Aggregate impact value	30	≤ 30%

B. MIX DESIGN

As per IS 456:2000 (Concrete Mix Proportioning Guidelines), a design mix of M20 grade concrete was prepared to achieve the desired strength, workability, and durability for structural applications. The mix was proportioned using standard procedures, considering the properties of materials such as cement, fine aggregate (M-sand), coarse aggregate, water, and supplementary materials like fly ash and coconut shell aggregates. The target mean strength was determined by adding a suitable margin to the characteristic strength of 20 MPa, and the water-cement ratio was fixed to ensure adequate workability and durability. Proper batching, mixing, and compaction were carried out to maintain uniformity in the concrete. The prepared mix aimed to meet the performance requirements specified by IS 456:2000 while incorporating sustainable materials to reduce the environmental impact of construction.

Mix Proportion of trial mix 1:2:3.3

Cement - 349 kg
 Water - 192 kg
 Fine aggregate - 719kg
 Coarse aggregate - 1150kg

C. M20 MIX PROPORTION

The mix proportion table represents the detailed composition of different concrete mixes prepared to study the combined effect of fly ash and coconut shell as partial replacement materials in M20 grade concrete. In this experimental program, fly ash is used as a supplementary cementitious material to partially replace cement, thereby improving sustainability and reducing the carbon footprint of concrete production. Similarly, crushed coconut shells are introduced as a lightweight and eco-friendly substitute for conventional coarse aggregates.

The objective of these mixes is to evaluate how varying replacement levels of fly ash (5–10%) and coconut shell (10–30%) influence the concrete's workability, strength, and overall performance. Each mix maintains a fixed water-to-cement ratio and consistent slump range (75–100 mm) to ensure uniformity in testing conditions. The inclusion of fly ash enhances the pozzolanic activity and contributes to long-term strength development, while the use of coconut shell helps in reducing the density of concrete, making it a more sustainable and economical construction material. Overall, this study aims to promote the use of agricultural and industrial by-products in concrete to achieve eco-friendly and cost-effective construction practices.

V. RESULT AND DISCUSSION

A. FRESH PROPERTIES

Workability-Slump Cone Test

This was done for concrete mixes containing varying percentages of Fly ash as cement (0%, 5%, 10%), and Coconut shell granules as fine aggregate and Coconut shell aggregate as coarse aggregate replacement (0%, 5%, 10%, 15%, 20%). The values obtained for slump for various percentage mixes are given in fig 5.1

The slump test results indicated that the incorporation of fly ash and coconut shell aggregates did not adversely affect the workability of the concrete. The slump values decreased gradually from 62 mm to 38 mm as the percentage of fly ash and coconut shell content increased. This reduction in slump was smooth and consistent, indicating good mix control during the preparation of concrete. Despite the gradual decrease, all the mixes maintained acceptable workability levels suitable for practical applications. These results demonstrate that the proposed sustainable materials can be effectively incorporated into concrete without significantly affecting its fresh properties, thereby supporting the quality and reliability of the experimental work.

Sample S1- S6 – Workability gradually decreases. At the same time the workability is within the range of lightly reinforced section in slabs, beams, walls, columns and floors. The S4 sample have moderate replacement level still provide highest workability and slump.

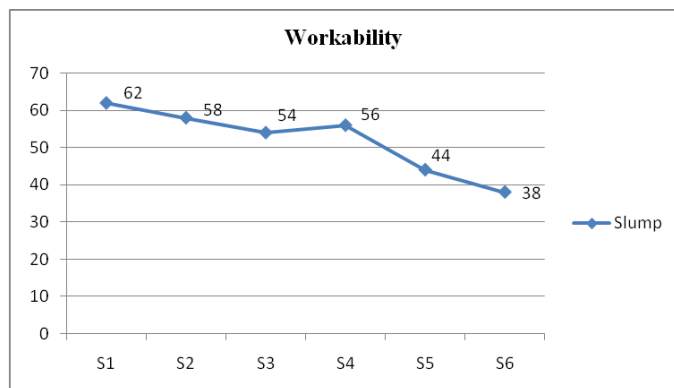


Fig 5.1 Slump value of various mixes

B. HARDENED PROPERTIES

Compressive strength

Compressive strength is the most important property of concrete. The cube strength was evaluated according to IS 516-1959 (Reaffirmed 2004). The tests were conducted on a 2000kN compression testing machine and values were analysed. Cubes of standard size were prepared for conducting this test. The compressive strength for 7 and 28 days were

determined. For each percentage mix, 3 samples were prepared and the average of the three values was taken as the compressive strength for the particular mix.

The compressive strength of different concrete mixes (S1–S6) incorporating Fly Ash and Coconut Shell Aggregate (CSA) was evaluated at curing ages of 7 days and 28 days. The results obtained from the compressive strength test are presented in the table. These values indicate the variation in strength development of concrete when natural coarse aggregate is partially replaced with coconut shell aggregate and when fly ash is used as a supplementary cementitious material.

The compressive strength test was conducted on concrete cubes of size 150 mm × 150 mm × 150 mm with a cross-sectional area of 22500 mm². Different mixes were prepared by partially replacing conventional materials with fly ash and coconut shell aggregates. The strength was measured at 7 days and 28 days for each mix.

- From the results, the control mix S1 (0% replacement) showed the highest strength with an average 7-day compressive strength of 17.60 N/mm² and 28-day compressive strength of 25.79 N/mm².
- When the percentage of fly ash and coconut shell aggregate increased, the compressive strength gradually decreased. Mix S2 (5% replacement) showed 14.45 N/mm² at 7 days and 23.49 N/mm² at 28 days, which is close to the control mix.
- Further increase in replacement levels (S3, S4, S5 and S6) resulted in lower strength values. The lowest strength was observed in S6 (10% fly ash, 15% CS aggregate) with 9.86 N/mm² at 7 days and 16.15 N/mm² at 28 days.
- Overall, the results indicate that a small percentage of fly ash and coconut shell aggregate can be used without significant reduction in strength, but higher replacement levels reduce the compressive strength of concrete.

The concrete mixes shown in the table are based on M20 grade concrete with partial replacement using fly ash and coconut shell aggregate. M20 concrete is commonly used for general construction works where moderate strength is required.

The hardened properties of concrete were evaluated by conducting compressive strength tests at 7 days and 28 days. The results showed that the 7-day compressive strength ranged from 17.6 N/mm² to 9.8 N/mm², while the 28-day compressive strength varied from 25.79 N/mm² to 16.15 N/mm² depending on the percentage of fly ash and coconut shell aggregate replacement. It was observed that the compressive strength gradually decreased with an increase in coconut shell replacement, which is scientifically expected due to the lightweight and porous nature of coconut shell aggregates. However, the presence of fly ash contributed to improved long-term strength development because of its pozzolanic reaction with cement. Overall, the results indicate that although there is a reduction in strength at higher replacement levels, the concrete still maintains reasonable strength characteristics, demonstrating the feasibility of using

fly ash and coconut shell aggregates as sustainable materials in concrete production.

Concrete incorporating fly ash and coconut shell aggregate showed satisfactory performance in both fresh and hardened states. The mixes exhibited stable and predictable behaviour, indicating good quality of the experimental work. The study also shows that these materials can be used as eco-friendly alternatives in concrete, especially for non-critical structural applications. Therefore, sustainable concrete can be produced using these materials without significantly affecting essential performance.

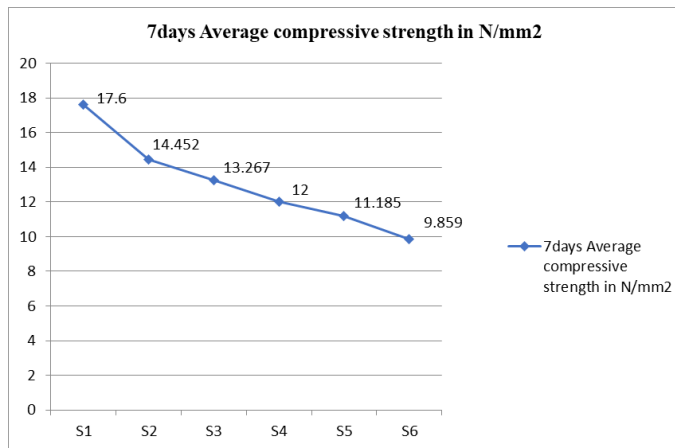


Fig 5.2 7 days Average compressive strength value of various mixes

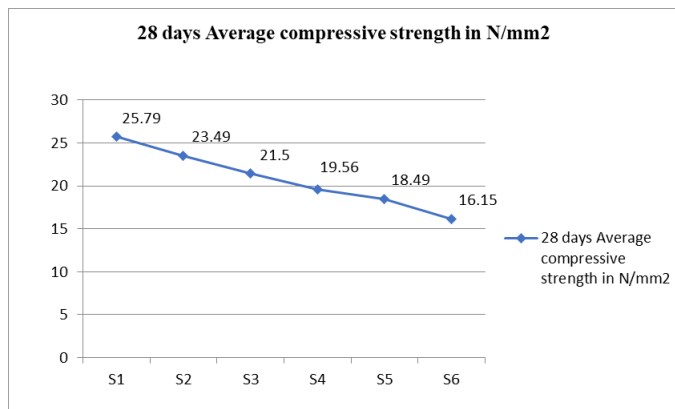


Fig 5.3 28 days Average compressive strength value of various mixes

C. PURPOSE OF THE PROJECT

- The main purpose of this project is to explore the use of fly ash and coconut shell aggregates as sustainable alternatives in concrete.
- The study aims to understand how these materials affect the workability and compressive strength of concrete.
- It also checks whether these materials can partially replace conventional materials without reducing

concrete quality.

- The project focuses on making concrete more eco-friendly, cost-effective, and lightweight.
- The use of coconut shell waste helps in reducing solid waste problems and promotes recycling.
- The utilization of fly ash, an industrial by-product, reduces landfill disposal.
- Coconut shell aggregates can produce lightweight concrete, which reduces the dead load of structures.
- Such concrete can be used in small-span structures, non-load-bearing walls, precast blocks, and pavements.
- The use of these materials can reduce the overall cost of concrete production, making it suitable for low-cost and rural construction.
- The study also provides useful baseline data for future research and helps students understand sustainable engineering practices.

VI. CONCLUSIONS

In this project titled “*Experimental Investigation of Utilizing Coconut Shell and Fly Ash Derivatives in Concrete,*” the work focused primarily on the preliminary study and preparation of the M20 grade concrete mix design as per IS 456:2000 and IS 10262:2019 guidelines. The materials—cement, fly ash, M-sand, crushed stone, and coconut shell aggregates—were tested for their physical properties to ensure suitability for concrete production. Based on these material properties, different mix proportions were designed by partially replacing cement with fly ash (5% and 10%) and coarse aggregate with coconut shell (5%, 10%, 15%, 20% and 30%).

The present study investigated the feasibility of utilizing coconut shell and fly ash as partial replacement materials in M20 grade concrete in order to promote sustainable and eco-friendly construction practices. The experimental results showed that the incorporation of fly ash and coconut shell aggregates can produce lightweight concrete while reducing the consumption of conventional natural resources. From the compressive strength results, it was observed that the control mix exhibited the highest strength; however, mixes with small replacement levels of fly ash and coconut shell still achieved satisfactory strength suitable for many structural and non-structural applications. The workability of concrete slightly decreased with increasing replacement levels of coconut shells. Overall, the study demonstrates that limited replacement of conventional materials with coconut shell and fly ash can produce environmental friendly concrete without significantly compromising its performance. The optimum mix is S2 as it provides the best balance between compressive

strength and workability. It achieves adequate strength (23.49 N/mm² at 28 days), shows good slump, and requires only a small amount of replacement while remaining environmentally friendly. Therefore, this mix is suitable for pavements, blocks, partition walls, low-cost housing, and lightweight structural elements. Therefore, the use of these agricultural and industrial waste materials not only contributes.

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