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Performance Evaluation Of Coconut Shell As Coarse Aggregate In Concrete Incorporating Silica Fume As An Admixture

[1]Allen Joseph, [2]Anaswara A, [3]Emil Shajan, [4]Sreehari T, [5]Hridya P

[1]Student, [2]Student, [3]Student, [4]Student, [5]Assistant Professor
Department of Civil Engineering,
Vimal Jyothi Engineering College, Chemperi - Kannur, Kerala, India

Abstract: The growing demand for sustainable and eco-friendly construction materials has driven research into alternative aggregates and admixtures for concrete. This study evaluates the performance of M30 concrete incorporating coconut shell (CS) as a partial replacement for coarse aggregate and silica fume (SF) as an admixture. Silica fume was added at 5%, 10%, and 15%, with 10% SF identified as the optimum dosage, achieving a compressive strength of 46.66 N/mm². Further, coarse aggregate was replaced with coconut shell at 10%, 20%, 30%, and 40%, with 10% CS replacement yielding the highest compressive strength making it the optimum replacement level. The mechanical properties were assessed through compressive strength tests. The results indicate that an optimized combination of 10% SF and 10% CS enhances concrete strength and promotes sustainability by utilizing waste materials in construction.

Keywords - Coconut shell, aggregate, Silica fume, M30 concrete, Sustainable concrete, Compressive strength, Partial replacement, Eco-friendly construction, Waste material utilization, Admixtures.

1.INTRODUCTION

The construction industry's rapid expansion has led to a significant increase in the consumption of natural resources, particularly coarse aggregates, contributing to environmental degradation and resource depletion. In response, researchers are actively exploring sustainable alternatives to conventional materials that can reduce the ecological impact of concrete production while maintaining structural integrity. One such promising approach involves the utilization of coconut shell (CS) as a partial replacement for coarse aggregates, supplemented with silica fume (SF) as a pozzolanic admixture to counteract potential strength reductions.

Coconut shell, an abundant agricultural by-product in tropical regions, remains underutilized despite its potential as a sustainable construction material. Its incorporation in concrete presents dual benefits: reducing dependency on natural aggregates and promoting waste management. However, replacing coarse aggregates with coconut shell can lead to a decline in mechanical strength due to its lower density and weaker interfacial bonding with cement paste. To mitigate these drawbacks, silica fume is introduced as a supplementary cementitious material to enhance strength and durability through improved particle packing and pozzolanic reactions.

This study systematically evaluates the performance of M30 concrete incorporating coconut shell and silica fume, where silica fume was added at 5%, 10%, and 15%, with 10% identified as the optimum dosage, yielding a compressive strength of 46.66 N/mm². Subsequently, coarse aggregate was replaced with coconut shell at 10%, 20%, 30%, and 40%, with 10% replacement providing the highest compressive strength, making it the optimal substitution level. To comprehensively assess the effects of these modifications, compressive strength, tensile strength, and flexural strength tests were conducted.

The significance of this research extends beyond material substitution, as it promotes eco-friendly construction practices, aligns with circular economy principles, and reduces the carbon footprint of concrete production. By establishing optimal mix proportions and evaluating the feasibility of coconut shell concrete for structural applications, this study contributes valuable insights into the development of sustainable, high-performance concrete that balances environmental responsibility with engineering requirements.

2. MATERIALS AND PROPERTIES

2.1. Cement

For this study, ACC OPC 43 Grade Cement was used, a high-quality Ordinary Portland Cement (OPC). The 43 Grade designation signifies a compressive strength of 43 MPa after 28 days of curing, making it suitable for a wide range of construction applications. This cement ensures desired performance, durability, and consistency due to its strict quality control standards.

Fig. 1 Cement

Two essential tests were conducted on cement:

- Specific Gravity Test: Determines the density of cement relative to water, influencing mix proportion calculations.
- Fineness Test: Measures the particle size distribution, affecting hydration rate, setting time, and strength development.

The specific gravity of cement typically ranges between 3.1 and 3.16, determined using a Le Chatelier Flask or a Pycnometer. The fineness test, conducted using a 90-micron sieve, ensures that at least 90% of cement particles pass through, promoting early strength gain and optimal workability.

2.2. Fine aggregate

Manufactured Sand (M Sand), sourced from a quarry near Chemperi, Kannur, was used as a fine aggregate. M Sand is a high-quality alternative to natural river sand, offering uniform particle grading and impurity-free composition, ensuring stable and durable concrete mix.

2.2.1Tests Conducted

- Fineness Modulus (FM) Test: Assesses average particle size, impacting workability.
- Specific Gravity Test: Determines density relative to water, crucial for mix design.

Table 1. Tested properties of M sand

No	Material	Properties		Relevant codes
1	Fine aggregate (M Sand)	Fineness modulus	3.2	IS: 2396(Part-1) - 1963
2		Specific gravity	2.63	

2.3. Coarse Aggregate

Coarse aggregate was sourced from a quarry near Chemperi, Kannur. The selected material had a particle size range of 4.75 mm to 20 mm, ensuring proper grading and mix balance for strength and durability.

Fig. 2 Coarse aggregate

2.3.1. Tests Conducted

- Fineness Modulus (FM) Test: Determines particle size distribution.
- Specific Gravity Test: Measures density relative to water, affecting mix stability.

Table 2. Properties of coarse aggregate

No	Material	Properties		Relevant codes
1	Coarse aggregate	Fineness modulus	7.6	IS: 2396(Part-1) - 1963
2		Specific gravity	2.74	
3		Maximum size	20mm	

2.4. Coconut shell

Coconut shells were sourced from a local farm, manually crushed, and sieved to a uniform size (retained on a 20 mm sieve) before being used as a partial replacement for coarse aggregate.

Fig. 3 Coconut shell

2.4.1. Properties of coconut shell

Table 3. Properties of coconut shell

No	Material	Properties		Relevant codes
1	Coarse aggregate (Coconut shell)	Specific gravity	1.15	IS: 2396(Part-1) - 1963
2		Maximum size	20mm	

Coconut shell is added in SSD condition, hence there is no water absorption by coconut shell.

2.5. Silica fume

Silica fume, procured from Bison Shelter System Pvt. Ltd., Edappally, was used to counteract strength loss due to coconut shell replacement. This ultra-fine material enhances packing density, reduces permeability, and improves concrete strength.

Fig. 4 Silica fume

2.5.1. Properties of silica fume

Silica fume reacts with calcium hydroxide in the cement matrix to form additional calcium silicate hydrate (C-S-H), significantly improving compressive strength and durability

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SILICA FUME WHITE

CERTIFICATE OF ANALYSIS

PHYSICAL PROPERTIES	RESULTS
PHYSICAL STATE	MICRONISED
ODOUR	ODOURLESS
COLOUR	WHITE
PACK DENSITY	0.77 GM/CC
PH OF 5% SOLUTION	6.91
SPECIFIC GFRAVITY	2.64
MOISTURE	0.055%
OIL ABSORPTION	54ML/100ML
CHEMICAL PROPERTIES	
SILICA (SIO2)	99.920%
ALUMINA (Al203)	0.031%
FERRIC OXIDE(Fe203)	0.012%
TITNIUM OXIDE(TI02o	0.000%
CALCIUM OXIDE(CaO)	0.000%
Magnesium oxide (MgO)	0.000%
Potassium oxide (K2O)	0.002%
SODIUM OXIDE(Na2O)	0.004%
LOSS ON IGNITION	0.001%
HEAVY METALS: LED (Pb)/ ARSENIC As)	0.000%

Fig. 5 Properties of silica fume (provided by supplier)

3. MIX DESIGN

The mix ratio for M30 concrete with silica fume as a partial replacement for cement is presented in Table 7.1. The silica fume is incorporated at 5%, 10%, and 15% replacement levels, leading to variations in the mix proportions. For each percentage, six concrete cubes are cast and tested for compressive strength at 7 and 28 days. The goal is to determine the optimal silica fume content that provides the highest compressive strength while maintaining good workability and durability. The selected percentage will be used as the most effective mix design for further applications.

Table 4. Mix ratio when silica fume is added as admixture

PERCENTAGE OF SILICA FUME (%)	MIX RATIO (CEMENT: FA: CA: WATER: SF)
5	1: 1.52: 2.7: 0.507: 0.05
10	1: 1.6: 2.85: 0.53: 0.11
15	1: 1.69: 3: 0.567: 0.17

The obtained mix ratio for M30 concrete is 1:1.6:2.85:0.53:0.11 (Cement: Fine Aggregate: Coarse Aggregate: Water: Silica Fume). To determine the optimum percentage of coarse aggregate replacement with coconut shell, six cubes were cast for each replacement level - 10%, 20%, 30%, and 40%. These cubes were cured for 28 days under standard conditions. After the curing period, compressive loading was applied to evaluate their compressive strength. The results from these tests will help identify the most suitable percentage of coconut shell replacement that balances strength and sustainability.

4. TESTS CONDUCTED

A series of tests are conducted to evaluate the properties and performance of the concrete mix. These tests include the Slump Cone Test, which assesses workability and consistency; the Compressive Strength Test, which determines the concrete's ability to withstand compressive loads; the Tensile Strength Test, which evaluates its resistance to tensile forces; and the Flexural Strength Test, which measures its bending resistance. These tests are essential in ensuring the durability, strength, and overall quality of the concrete mix used in this study.

4.1. Slump Cone

The slump cone test is a simple and widely used method to measure the workability or consistency of fresh concrete. The test helps determine the ease with which concrete can be mixed, placed, and compacted.

It is particularly useful for assessing the flowability of the mix. In this test, a standard frustum-shaped cone, known as the slump cone, is placed on a flat, non-absorptive surface. The cone is filled with concrete in three layers, each layer being tamped with a rod to remove air pockets. After the cone is filled, it is carefully lifted vertically, allowing the concrete to slump under its own weight. The slump is measured as the difference between the height of the cone and the height of the slumped concrete. The result is expressed in millimeters (mm). A high slump indicates that the concrete is more fluid and has better workability, while a low slump suggests that the concrete is stiffer and more difficult to work with. Typically, the slump range for normal concrete used in construction is between 25 mm to 75 mm for a stiff mix, while 100 mm to 175 mm is acceptable for more workable mixes, depending on the type of construction.

4.2. Compressive Strength Test

The Compressive Strength Test is a crucial test used to determine the ability of concrete to withstand axial compressive loads and evaluate its overall strength. To conduct this test, freshly mixed concrete is poured into 150 mm × 150 mm × 150 mm cube moulds. The concrete is then compacted to remove air pockets and ensure uniform consistency. The specimens are cured for 28 days under controlled conditions, typically submerged in water at a temperature of 20°C to 25°C.

After curing, the specimens are tested using a compression testing machine, which applies a steadily increasing load until the specimen fails. The maximum applied load before failure is recorded, and the compressive strength is calculated using the formula:

Compressive Strength=Maximum Load/Cross-Section Area

The result is expressed in megapascals (MPa) or newtons per square milli meter (N/mm²). This test is essential for ensuring that the concrete meets the required strength specifications for its intended application.

Fig. 6 Cube Casting

4.3. Split Tensile Strength Test

The Split Tensile Strength Test is conducted to measure the tensile strength of concrete, which is crucial as concrete is inherently strong in compression but weak in tension. This test evaluates the concrete's resistance to cracking under tensile stresses.

In this test, a cylindrical specimen with a diameter of 150 mm and height of 300 mm is placed horizontally in a compression testing machine. A load is applied uniformly along the length of the cylinder until failure occurs, typically by splitting along the vertical axis. The test is based on the principle that concrete, when subjected to compressive loading along its length, will fail due to tensile stresses perpendicular to the applied load.

Fig. 7 Cylinder Casting

5.5 Flexural Strength Test

The Flexural Strength Test, also known as the modulus of rupture, measures the ability of concrete to resist bending or cracking under applied loads. This test is essential for evaluating the tensile strength of concrete when subjected to flexural stresses, which commonly occur in beams, slabs, and other structural elements.

In this test, a concrete beam specimen, typically with dimensions of 100 mm × 100 mm × 500 mm (or as per the specified requirements), is placed on two supports. A central load is then applied at the midpoint of the beam. The beam is subjected to an increasing bending force until failure occurs, and the maximum load at failure is recorded.

This test provides valuable data regarding the flexural performance of concrete and helps ensure the material meets the required strength criteria for structural applications.

Fig. 8 Beam casting

6. RESULTS AND DISCUSSION

6.2 Finding Optimum Percentage of Silica Fume

Table 5. Compressive strength of concrete made with 5%,10% and 15% silica fume as admixture

S NO.	Silica fume percentage	Curing day	Compressive strength (N/mm^2)
1	5%	7 day	26.67
		28 day	41.67
2	10%	7 day	29.33
		28 day	46.67
3	15%	7 day	16.67
		28 day	24.33

The 10% silica fume replacement was selected as the optimum percentage based on compressive strength tests conducted on concrete cubes with 5%, 10%, and 15% silica fume. The cubes were tested at 7 and 28 days, and 10% replacement exhibited the highest compressive strength. The compressive strength of concrete with 5% and 10% silica fume is higher than that of normal concrete, while 15% silica fume results in lower strength, making it unsuitable for consideration. Among the tested percentages, 10% silica fume achieved greater compressive strength than 5%, indicating that the maximum strength is attained at 10% replacement. Based on these findings, the final mix design selected is 1: 1.6: 2.85: 0.53: 0.11(Cement: FA: CA: Water: SF).

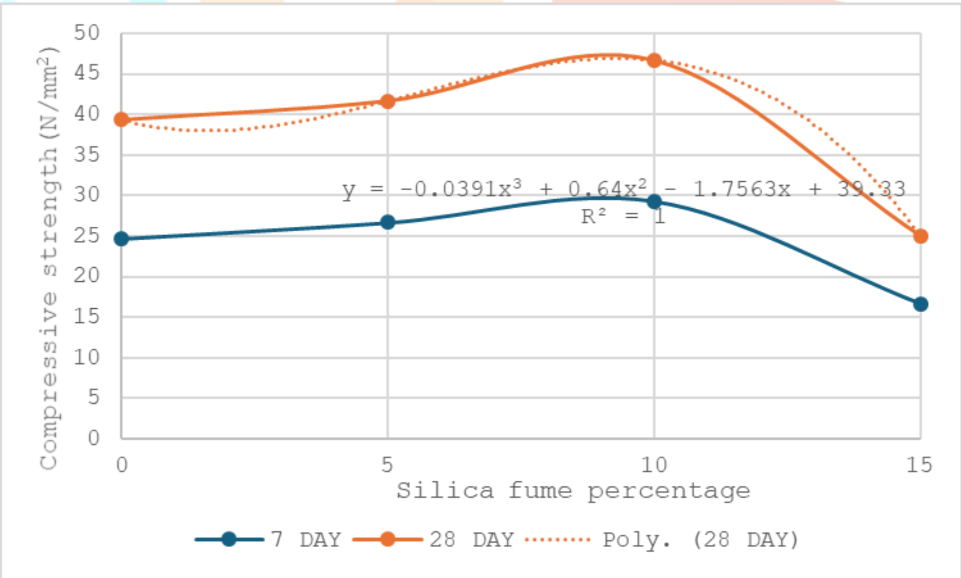

Fig. 9 Result comparison chart of silica fume added concrete with M30 concrete

6.3 Finding Optimum Percentage of Coconut Shell

Table 6. Compressive strength test results for coconut shell replacement

S NO.	% of coconut shell	Curing day	Compressive strength(N/mm^2)
1	10%	7 day	21.62
		28 day	31.25
2	20%	7 day	18.51
		28 day	27.25
3	30%	7 day	17.33
		28 day	25.62
4	40%	7 day	12.59
		28 day	20.73

Based on compressive strength tests conducted on concrete specimens with different replacement levels (10%, 20%, 30%, and 40%) after 28 days of curing, the optimal replacement percentage of coarse aggregate with coconut shell was determined to be 10%. Among all the variations, the 10% replacement achieved the highest strength of 31.25 N/mm^2, making it the most suitable choice for maintaining structural integrity while promoting sustainability. Based on these findings, the final mix design selected is 1: 1.6: 2.56: 0.285: 0.53: 0.11(Cement: FA: CA: Coconut shell: Water: SF).

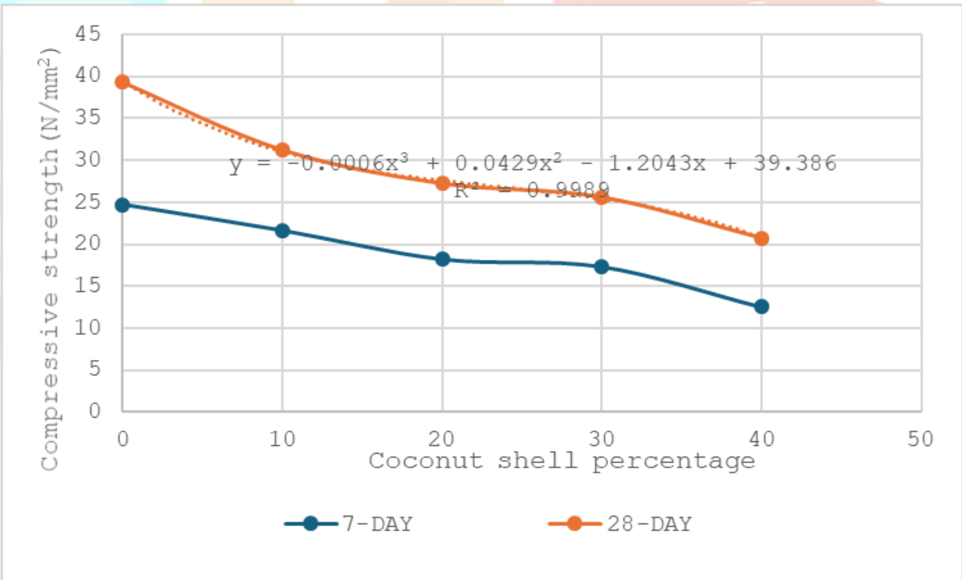

Fig. 10 Result comparison chart of coconut shell added concrete with M30 concrete

8. CONCLUSIONS

- The study demonstrates that concrete incorporating 10% coconut shell as a coarse aggregate replacement and 10% silica fume as an admixture can achieve satisfactory strength characteristics while promoting sustainability.
- The use of coconut shell reduces reliance on natural stone aggregates, minimizing environmental degradation and waste disposal issues. Silica fume, a byproduct of the silicon industry, enhances strength while utilizing industrial waste.
- The modified concrete showed a 14.52% reduction in compressive strength which is expected due to the lower strength of coconut shell compared to conventional coarse aggregates. However, the achieved strength of 31.25 N/mm^2 falls within the typical range of 17–40 N/mm^2 required for structural applications, making it suitable for use in various construction projects while promoting sustainability.

- Overall, the study suggests that this alternative mix can be a viable and eco-friendly option for construction, reducing dependence on conventional materials while utilizing agricultural waste.

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