

Structural Performance and Sustainability Assessment of RCC Beams Incorporating Coconut Shell Powder And Recycled Aggregates

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ABSTRACT - Concrete remains one of the most essential materials in modern construction; however, its production poses serious environmental concerns due to high carbon emissions from cement manufacturing and the extensive use of natural resources. Simultaneously, construction and demolition (C&D) activities generate significant waste, creating disposal and sustainability challenges.

The experimental investigation focuses on evaluating key properties such as workability, compressive strength, flexural strength, load-deflection response, and failure behavior of RCC beams. The results indicate that beams with controlled material replacement, particularly in low-stress regions such as the neutral axis, demonstrate comparable structural performance to conventional beams without significant loss of strength. Among the tested mixes, 4% replacement of cement with CSP showed optimal performance with minimal reduction in mechanical properties.

Overall, the study demonstrates that the combined use of agricultural and construction waste materials can provide a sustainable and cost-effective alternative for concrete production, contributing to resource conservation and environmentally responsible construction practices.

KEY WORDS: Coconut Shell Powder, Recycled Aggregates, Sustainable Concrete, RCC Beams, Compressive Strength, Eco-friendly Materials

1. INTRODUCTION

In recent years, the demand for concrete has increased rapidly due to continuous growth in construction and infrastructure development. Concrete is one of the most preferred construction materials due to its high strength and long-term durability & use in different types of structures such as buildings, roads, and bridges. However, the production of concrete, especially cement, has a negative impact on the environment as it releases a large amount of carbon dioxide. In addition, excessive use of natural aggregates is leading to depletion of natural resources.

At the same time, construction and demolition (C&D) activities are generating a huge amount of waste materials. Most of this waste is not properly reused and ends up causing environmental problems such as land pollution. Because of this, there is a need to find alternative materials that are both sustainable and economical. Coconut Shell Powder (CSP), which is an agricultural waste, can be used as a partial replacement for cement. Similarly, recycled aggregates obtained from construction waste can be used instead of natural aggregates. This not only helps in reducing waste but also decreases the demand for natural resources.

In this study, an attempt is made to use these materials in reinforced cement concrete (RCC) beams and study their behavior. Special attention is given to the neutral axis region of the beam, where the stress is relatively low. By replacing materials in this zone, it is possible to reduce material usage without affecting the overall strength significantly.

This study focuses on evaluating the structural performance of reinforced cement concrete (RCC) beams incorporating CSP and recycled aggregates. A key aspect of the investigation is the strategic use of these materials in regions of the beam that experience relatively low stress, particularly near the neutral axis. Since concrete in this zone contributes less to load resistance, selective material replacement can optimize resource utilization without significantly affecting structural behavior.

2. METHODOLOGY

In this study, an experimental approach was used to understand the behavior of RCC beams made with Coconut Shell Powder (CSP) and recycled aggregates. The work was carried out in a step-by-step manner, starting from material preparation to final testing and analysis. The experimental program consists of different mix combinations, as summarized in Table 1.

Table 1: Mix Proportions for Different Cases

Case	Cement (CSP)	Fine Aggregate (DWS)	Coarse Aggregate (RCA)
Nominal Mix	0%	0%	0%
Case A	4%	10%	25%
Case B	8%	20%	40%



Fig 2.1.B Processed C&D Waste Aggregates

The entire process was divided into stages such as material collection, mix design, casting, curing, testing, and result evaluation.

2.1 MATERIAL COLLECTION AND PREPARATION

a) Coconut Shell Powder (CSP)

Waste coconut shells were collected from local sources, cleaned, and dried. The shells were then crushed and ground to obtain Coconut Shell Powder (CSP), which was sieved through a 90-micron sieve to achieve uniform fineness. FTIR analysis was carried out to confirm the presence of silica and pozzolanic properties.

b) Construction and Demolition (C&D) Waste

Demolition waste was collected from nearby construction sites and processed to obtain usable aggregates. The waste materials were crushed manually and mechanically to produce coarse and fine aggregates, which were then sieved into required sizes (10 mm and 20 mm). Due to the higher water absorption capacity of recycled aggregates, they were pre-soaked prior to mixing to maintain proper workability and water balance. Basic tests such as aggregate impact value were conducted in accordance with relevant IS standards to evaluate their suitability for concrete applications.

2.2 MIX DESIGN

A control mix of M20 grade concrete was designed in accordance with IS 10262:2019 guidelines. Coconut Shell Powder (CSP) was used as a partial replacement of cement at levels of 4% and 8%, while construction and demolition (C&D) waste aggregates were used as partial replacement of natural aggregates.

RCC beam specimens were prepared with different combinations of CSP and recycled aggregates. Special emphasis was given to the region below the neutral axis, where concrete primarily acts as a stress transfer medium rather than a load-resisting component. This approach helps in optimizing material usage without significantly affecting structural performance. A constant water-cement ratio of 0.45–0.50 was maintained for all mixes to ensure uniformity and reliable comparison of results. Proper control of water content also helped in maintaining consistent workability and strength characteristics across different mixes.

2.3 CASTING AND CURING



Collection



Cleaning And Drying



Grinding



CSP

Fig 2.1A Coconut Shell Powder (CSP) Collection and Preparation

Concrete specimens were cast in the form of cubes (150×150×150mm) for compressive strength testing and beams (150×150×700mm) for flexural testing.

The freshly prepared concrete was placed into oiled Moulds in three equal layers, with each layer compacted using a table vibrator to eliminate entrapped air and achieve proper densification. After casting, the specimens were kept undisturbed for 24 hours to allow initial setting. Subsequently, the specimens were Demoulded and cured in a water tank for 7, 14, and 28 days to ensure adequate hydration and strength development.

2.4 TESTING PROCEDURES

2.4.1 Fresh Concrete Tests

Workability of fresh concrete was evaluated using the slump test to study the effect of CSP and recycled aggregates on consistency. The variation in slump values was used to assess the ease of mixing, placing, and compaction of different concrete mixes.

2.4.2 Mechanical Properties

Compressive strength tests were conducted on cube specimens at 7, 14, and 28 days as per IS 516:2014 to evaluate the strength development of concrete with replacement materials.

Flexural strength of RCC beams was determined under two-point loading using a Universal Testing Machine (UTM) to evaluate load-carrying capacity and crack behavior. The test also helped in understanding the structural performance and failure characteristics of the beams.

2.4.3 Structural Performance of Beams

The structural behavior of beams was assessed through load-deflection analysis, where mid-span deflection was measured using a dial gauge under incremental loading. The position of the neutral axis was observed and compared with conventional beams. Crack patterns and failure modes, including flexural and shear failure, were carefully recorded.

2.5 Data Analysis and Interpretation

The experimental results were compared with conventional RCC beams to evaluate performance variations. The optimum replacement levels of CSP and C&D waste aggregates were determined based on the following criteria:

- Compressive strength retention of at least 90% of the control mix
- Comparable flexural performance
- Reduction in density and self-weight

Further analysis was carried out in terms of cost efficiency, resource conservation, and overall sustainability benefits.

3. EXPERIMENTAL WORK

3.1 Fourier Transform Infrared Spectroscopy (FTIR) Test

Fourier Transform Infrared Spectroscopy (FTIR) analysis was carried out on the collected Coconut Shell Powder (CSP) sample at National Chemical Laboratory (NCL), Pune to identify the chemical functional groups and pozzolanic characteristics of the ash. The FTIR spectrum shows a strong absorption peak around 1000–1050 cm^{-1} , confirming the presence of silicate and aluminate groups.

These groups are responsible for pozzolanic reactions in concrete. The additional presence of hydroxyl and carbonyl groups indicates partially burnt biomass components.

The results clearly show that Coconut Shell Powder possesses pozzolanic characteristics and can be effectively used as a partial cement replacement in concrete. The selected replacement levels of 4% and 8% used in this project are justified based on FTIR analysis.

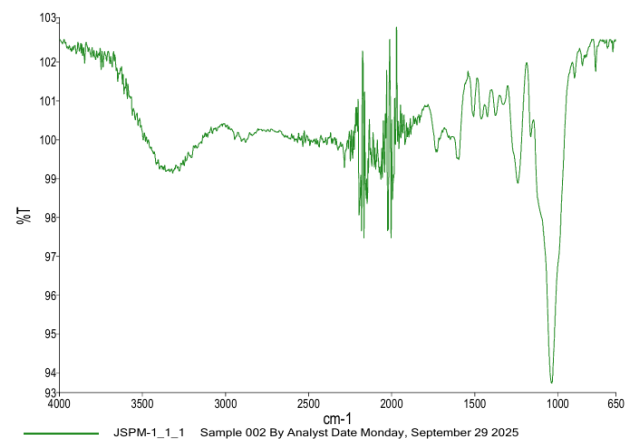


Fig.3.1 FTIR GRAPH

The FTIR test conducted at NCL Pune confirms that Coconut Shell Powder contains silicate and aluminate functional groups, indicating potential for pozzolanic activity.

3.2 AGGREGATE IMPACT VALUE (AIV) FOR RECYCLED AGGREGATES

To determine the impact resistance of Recycled Aggregates (RA) and to evaluate their suitability for partial or full replacement of natural aggregates in concrete and pavement works.

Recycled aggregates are obtained from demolished concrete and generally consist of natural aggregate particles covered with old adhered mortar. Due to this

mortar layer, RA shows lower strength, higher porosity, higher water absorption, and higher impact value. The RA tested show an AIV of 13.58% suitable for use as 20-40% replacement of natural fine and coarse aggregates

Table2: Determination of Aggregate Impact Value (AIV) of Recycled Aggregates

Weight of oven-dry RA sample	501 gm
Weight passing 2.36 mm sieve	68 gm
AIV Result	13.58 %

Table 3: Workability Comparison of Nominal and Replacement Mixes

Sr. No.	Concrete Mix Type	Measured Slump
1	Nominal Mix	160
2	4% Replacement Mix	140
3	8% Replacement Mix	100



Fig.3.3 SLUMP TEST

3.3 SLUMP CONE TEST

To determine the workability of freshly prepared concrete using the Slump Cone Test.

Workability refers to the ease with which concrete can be mixed, placed, compacted, and finished. The slump cone test is the most widely used field test to measure workability. The slump values of the nominal mix and replacement mixes were recorded.



Fig.3.2 AIV TEST

3.4 CONCRETE MIX DESIGN

A) CUBE CASTING

To cast cubes for Nominal, 4%, and 8% replacement of cement, aggregate and evaluate compressive strength. The concrete mix was designed for M20 grade and the mix design was done as per IS 10262:2019 and IS 456:2000.

Concrete is the most widely used construction material due to its strength, durability, and availability of raw materials. However, the extraction of natural aggregates and cement production causes environmental stress. To reduce this, sustainable replacements such as agricultural waste, demolition waste, and recycled aggregates are being used. The objective is to evaluate the effects of these eco-friendly replacements on workability and compressive strength of concrete.

This study focuses on partial replacement of-

- ✓ Cement with coconut shell powder- 4% and 8%
- ✓ Fine aggregate with demolition waste sand- 10-20%
- ✓ Coarse aggregate with recycled coarse aggregate- 25-40%



FIG.3.4. A.1 CONCRETE MIX



FIG.3.4. A.2 CUBE CASTING



FIG.3.4. A.3 CUBE DEMOULDING

B) BEAM CASTING

To cast reinforced concrete beams using modified concrete containing 4% Coconut Shell Powder (CSP) as cement replacement, 10% Demolition Waste Sand (DWS) as fine aggregate replacement, and 25% Recycled Coarse Aggregate (RCA) as coarse aggregate replacement, and evaluate the fresh &

hardened properties. Beam casting for Case B was not performed as the mix exhibited lower compressive strength and poor cohesiveness. The higher replacement levels adversely affected workability and structural integrity; therefore, it was not considered suitable for flexural beam testing.

In this case study, three types of reinforced concrete beams were cast to evaluate the effect of sustainable material replacement on structural performance.

Beam-1 (Control Beam) The control beam was cast using the conventional M20 concrete mix without any replacement of cement or aggregates. This beam served as a reference to compare the structural performance, flexural strength, and crack behavior with the beams incorporating partial replacement of Coconut Shell Powder (CSP) and recycled aggregates.

Beam-2 (Partial Replacement Beam) was prepared with 4% Coconut Shell Powder (CSP) as cement replacement, 10% Demolition Waste Sand (DWS) as fine aggregate replacement, and 25% Recycled Coarse Aggregate (RCA) as coarse aggregate replacement. The Beam-2 was to investigate the flexural behavior of beams with partial replacement of conventional materials.

Beam-3 (Neutral Axis Beam) was cast such that only the neutral axis region, which experiences low tensile stresses, used the replacement mix (4% CSP + 10% DWS + 25% RCA), while the remaining portion of the beam was made with normal concrete. The purpose of Beam-2 was to study the impact of selective material replacement in the zero-stress region on the overall flexural performance of the beam.



FIG.3.4.B. BEAM DEMOULDING

4. RESULTS AND DISCUSSION

4.1 Compressive Strength Results

Compressive strength tests were carried out on cube specimens at 7, 14, and 28 days in accordance with IS 516:2014 to evaluate the effect of partial replacement of cement and aggregates.

Discussion

The early-age strength of the replacement mixes was slightly lower than that of conventional concrete due to the slower pozzolanic reaction of Coconut Shell Powder (CSP). However, at later stages (28 days), strength development improved as CSP contributed to secondary hydration, leading to the formation of additional C-S-H gel. The inclusion of Recycled Coarse Aggregate (RCA) resulted in a marginal reduction in strength due to higher water absorption and a weaker interfacial transition zone (ITZ). Despite this, Case A retained a significant portion of the strength (around 85–90% of control), indicating its suitability for M20 grade structural applications.

Key Observations

- CSP enhances micro-filling and contributes to long-term strength gain.
- RCA increases porosity, but proper curing helps in minimizing strength loss.

Overall compressive strength remains within acceptable structural limits.

Table 4 Compressive Comparison of Nominal and Replacement Mixes

Mix Type	7 Days (N/mm ²)	14 Days (N/mm ²)	28 Days (N/mm ²)
Normal Mix	11.26	13.42	22.71
Case A (4%)	9.8	11.46	19.5
Case B (8%)	7.9	10.4	16.1

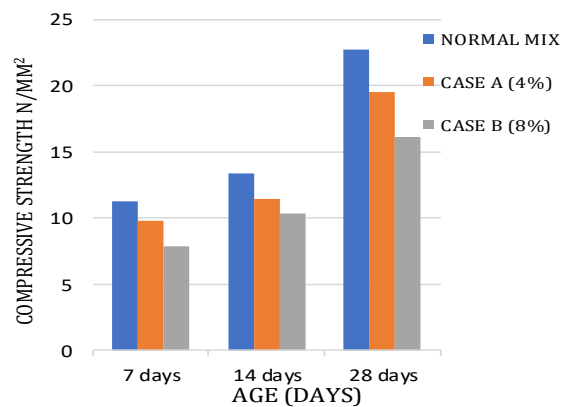


FIG 4.1.1 COMPRESSIVE RESULT



FIG 4.1.2 COMPRESSIVE TESTING MACHINE

4.2 FLEXURAL STRENGTH RESULTS (BEAM TEST)

Flexural strength testing was carried out using a Universal Testing Machine under two-point loading to evaluate the bending performance of RCC beams. Beam-1 (Control Beam), cast with conventional concrete, was used as a reference for comparison. Beam-2 (Partial Replacement Beam) exhibited comparable load-carrying capacity with slight variation due to the inclusion of recycled aggregates. Beam-3 (Neutral Axis Replacement Beam) showed nearly similar flexural strength, as the replacement was limited to the zero-stress region. The mid-span deflection values of all beams were found to be within permissible serviceability limits.

Crack Pattern & Failure Mode

- Initial cracks appeared at the tension zone (bottom).
- Cracks propagated vertically indicating flexural failure.
- No sudden brittle failure was observed.
- Neutral axis position remained within expected depth range.

Structural Interpretation

- Since replacement in Beam-2 was done only at Neutral Axis (zero-stress zone), it did not significantly affect bending resistance.
- This proves that selective material replacement in low-stress zones can maintain structural performance.

Sustainability & Cost Analysis

- Utilization of demolition waste reduces landfill burden.
- Coconut Shell Powder is an agricultural by-product, reducing cement consumption.
- Reduction in natural aggregate extraction conserves resources.
- Estimated material cost reduction: 5-6 % (based on local rates).

Environmental Benefits:

- Lower carbon footprint due to reduced cement usage.
- Promotes circular economy in construction industry.
- Sustainable waste management approach.

Table 6 Flexural Comparison of Beam

Beam ID	Flexural Strength of Concrete Beam
Control Beam	3.51 N/Sq Mm
Beam-1 (Partial Replacement)	3.66 N/Sq Mm
Beam-2 (Neutral Axis Replacement)	3.47 N/Sq Mm



FIG 4.2.1 FLEXURAL TESTING MACHINE

5. CONCLUSION

From the experimental study carried out on RCC beams using Coconut Shell Powder (CSP) and recycled aggregates, a few important observations were made. It was found that partial replacement of cement with CSP can be used without causing a major reduction in strength. In this study, 4% replacement gave better results compared to higher percentages. Similarly, replacing a portion of fine and coarse aggregates with demolition waste materials produced acceptable results in terms of strength and workability.

Overall, the study shows that using CSP and recycled aggregates can help in reducing waste, saving natural resources, and making concrete more sustainable, without major loss in performance when used in proper proportions.

- Partial replacement of cement with 4% Coconut Shell Powder (CSP) resulted in satisfactory compressive strength and maintained structural integrity of concrete.
- Replacement of fine aggregate with 10% Demolition Waste Sand (DWS) and coarse aggregate with 25% Recycled Coarse Aggregate (RCA) produced concrete with acceptable mechanical properties.
- The compressive strength of the modified mix remained within permissible limits for M20 grade concrete, confirming its suitability for structural applications.
- Flexural strength of RCC beams with partial replacement was found to be comparable to conventional beams, with similar load-deflection behavior.

- E. Crack patterns observed were typical flexural cracks, and all beams exhibited ductile failure without brittle behavior.
- F. The beam with replacement only at the neutral axis (zero-stress zone) showed no significant reduction in flexural strength, proving that selective replacement in low-stress regions is structurally feasible.
- G. Higher replacement levels (Case B) resulted in reduced compressive strength and poor workability, making them unsuitable for structural applications.
- H. The use of CSP and recycled aggregates contributes to reduction in cement consumption, conservation of natural resources, and effective waste utilization.

Waste to Replace Conventional Aggregates in Concrete

- 10) Recycled Aggregate From C&D Waste & Its Use In Concrete – A Breakthrough Towards Sustainability In Construction Sector: A Review
- 11) IS 10262:2019 – Concrete Mix Proportioning – Guidelines
- 12) IS 516:2014 – Methods of Tests for Strength of Concrete

6. REFERENCES

The following references were consulted to understand the properties of concrete, behavior of recycled aggregates, and the application of Coconut Shell Powder as a sustainable construction material.

These studies provide a strong foundation for evaluating mechanical performance, durability aspects, and environmental benefits of modified concrete. Relevant IS codes were also referred to for mix design, testing procedures, and standard specifications. The selected literature supports the feasibility of using waste materials in RCC structures for sustainable development.

- 1) Experimental Study on Partial Replacement of Concrete Below Neutral Axis of Beam. (Volume 3, Issue 29 Special Issue – 2024)
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