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Sustainable Concrete Using Recycled Coarse Aggregates and Rice Husk Ash: An Experimental Evaluation

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ABSTRACT

This study explores the feasibility and performance of sustainable concrete produced using recycled coarse aggregates (RCA) and rice husk ash (RHA) as partial replacements for natural aggregates and cement, respectively. Demolished concrete waste from Gurugram was processed into RCA, while RHA was prepared from locally sourced rice husk. Concrete mixes were formulated by replacing cement with RHA at 5%, 10%, 15%, and 20% levels. Physical characterization confirmed conformity with Indian Standards. The results revealed that workability decreased with increasing RHA content; however, up to 10% replacement, both compressive and split tensile strengths improved due to the pozzolanic action of RHA, which enhanced the concrete matrix. Strength declined beyond 10% RHA due to dilution of cementitious compounds. Although RCA introduced drawbacks like higher water absorption, the incorporation of RHA mitigated these effects by refining the microstructure. The study validates the effective use of RCA and RHA in concrete, promoting sustainable practices without significantly compromising mechanical performance.

Key Words: *Recycled Coarse Aggregates (RCA), Rice Husk Ash (RHA), Sustainable Concrete.*

1. INTRODUCTION

Researchers noted that recycling construction and demolition waste, particularly dismantled concrete, had offered a significant opportunity to conserve usual capitals and reduce environmental harm. The incorporation of such materials in concrete was believed to have improved crack resistance, enhanced tensile strength, and controlled shrinkage, thus increasing durability. The study explored the innovative use of construction waste and agricultural residues for creating sustainable concrete. Through incorporating these alternative materials, the research aimed to reduce reliance on traditional raw materials, thereby supporting resource conservation. It was also highlighted that this strategy provided an effective method for managing increasing amounts of industrial and agricultural waste, thereby limiting environmental pollution. Utilizing RCA addresses the issue of construction waste management by recycling demolished concrete structures, thus minimizing environmental impact. Similarly, incorporating RHA, an agricultural by-product, helps in waste valorisation and contributes towards sustainable cementitious materials. This analysis will provide insights into the feasibility of these sustainable alternatives, promoting both environmental stewardship and material efficiency within the construction sector.

Importance of Concrete in Construction: Concrete's inherent durability ensures that well-designed structures can last for decades, resisting environmental effects, chemical attacks, and mechanical wear. Its ability to be moulded into various shapes before hardening allows for architectural innovation and flexibility in design. Moreover, concrete is relatively cost-effective and widely available, making it an economical choice for large-scale projects. It possesses high thermal mass, contributing to energy efficiency by regulating indoor temperatures. When combined with reinforcing steel, concrete forms a composite material that can effectively handle both compressive and tensile stresses, essential for modern construction needs. Concrete is also naturally fire-resistant, enhancing the safety of structures, and requires minimal maintenance over its lifespan Its wide application across residential, commercial, transportation, water infrastructure, and marine sectors further underscores its critical importance in building durable and resilient structures worldwide.

Construction Materials: It was stated that each year, billions of tons of concrete were being produced worldwide, far exceeding the usage of any other man-made material, which indicated its vital role in urbanization and economic progress. Experts had noted that its capacity to be moulded into any shape before hardening, along with its compatibility with steel reinforcement, had made it a fundamental element of modern construction. Although often regarded as a traditional material, concrete had continued to lead innovation by addressing the challenges of sustainable building practices and resistance to natural disasters. This had underscored its unmatched significance in shaping infrastructure and human civilization. The continued evolution of concrete technology had reflected society's efforts to balance development needs with environmental responsibility and structural durability.

2. MATERIALS AND METHODOLOGY

Objective of Study

1. The primary objective was to assess the compressive and tensile forte characteristics of real mixtures in which dismantled materials were used. Specifically, recycled concrete aggregate (RCA) was partially substituted for natural coarse aggregate, and RHA was used as a partial replacement for cement in varying proportions.
2. To assess the workability and compaction characteristics of RCA and RHA-modified concrete using slump and compaction factor tests under standardized curing conditions.
3. To determine the optimum replacement levels of RCA and RHA that balance mechanical strength, durability, and sustainability in concrete mixtures.

Materials

Cement

Cement served as the principal hydraulic binder in this study. Its well-established hydration chemistry imparts the requisite early and long-term strength, workability, and durability to concrete. Prior to mixing, all cement was verified for fineness, specific gravity, and soundness in accordance with IS: 4031, and was stored under dry conditions to prevent lumping or moisture uptake. To enhance sustainability, OPC was partially substituted with finely ground rice husk ash (RHA) at predetermined replacement levels. This strategy not only reduces Portland cement demand and thus CO_2 emissions but also leverages RHA's pozzolanic reaction to consume calcium hydroxide, densify the microstructure, and potentially improve long-term durability without compromising fresh or hardened properties.

Fine Aggregate

To ensure its suitability, the sand was evaluated for key physical properties, including water absorption, specific gravity, bulk density, and particle size distribution. These tests were conducted in accordance with the procedures outlined in IS: 2386 (Part I and Part III) standards. Samples for each test were collected according to the procedures outlined in IS: 2430-1969.

Coarse Aggregate

The coarse aggregate available can be categorized into two types:

a) based on size, which includes 20 mm and 10 mm aggregates.
b) based on origin, classified as natural aggregate and recycled aggregate.

Recycled Concrete Aggregate (RCA). RCA was sourced from demolished concrete elements, then crushed, washed to remove fines and contaminants, and sieved to match the grading of conventional coarse aggregates. Although RCA typically exhibits slightly lower specific gravity and higher water absorption than virgin stone, its use at controlled replacement levels alongside rice husk ash (RHA) enabled a systematic evaluation of strength, durability, and sustainability. Incorporating RCA not only diverts construction waste from landfills but also reduces demand on natural resources, supporting the development of an eco-friendly, cost-effective concrete mix.

Recycled Concrete Aggregate

In the foreground, it has angular, weathered fragments of recycled concrete aggregate (RCA) sourced from crushed and processed demolition waste. The irregular, porous particles exhibit adhered mortar and variable coloration, reflecting their composite origin. Behind them, uniformly sized virgin granite stone displays smooth, crystalline surfaces and consistent grey hues. The juxtaposition highlights the textural and morphological differences between RCA and natural aggregate. RCA's higher roughness and porosity can influence water absorption and bond strength in concrete mixes, while virgin granite ensures structural integrity. Together, these materials embody a sustainable approach, combining waste recycling with conventional aggregate use in laboratory testing procedures.

Water: In this project, the water used was sourced from borehole and it is free from contaminants.

Rice Husk Ash: Comprising a significant amount of amorphous silica (SiO_2), RHA is considered an eco-friendly supplementary material for cement. For this study, rice husks were gathered, dried, and subjected to controlled combustion to produce ash with a high silica concentration and minimal carbon residue. The resulting RHA was then finely ground to a powder with particle sizes smaller than 45 µm, which improved its reactivity and facilitated even distribution within the concrete mix.

Incorporating rice husk ash (RHA) brings multiple benefits, including increased compressive strength, better resistance to chemical degradation, and lower permeability. Fine RHA particles fill voids in the cement paste, yielding a denser, more durable structure. Moreover, by recycling agricultural waste and reducing reliance on Portland cement (a major CO_2 emitter), RHA promotes environmental sustainability. In this work, RHA replaced cement at 5 %, 10 %, 15 %, and 20 % by weight to assess its combined effects with RCA on concrete's mechanical properties and durability. Water used for mixing and curing was potable and free of harmful impurities.

Comparison of Raw Rice Husk Ash (Left) and Finely Ground Rice Husk Ash Powder (Right).

The left tray contains rice husk ash collected after controlled combustion, characterized by a course, irregular texture interspersed with unburnt fragments. This raw ash exhibits heterogeneous particle sizes and visible organic residues. In contrast, the right tray holds finely ground rice husk ash powder, presenting a uniform, smooth surface with a dark grey to black coloration. Grinding reduced particle size below 45 µm, enhancing pozzolanic reactivity and ensuring even dispersion in cementitious mixtures. These distinctions illustrate the transformation from raw agricultural byproduct to a supplementary cementitious material for sustainable construction and environmental performance.

Mix Design

Mix design is the procedure used to determine the appropriate proportions of the different components of concrete, aiming to achieve the desired characteristics in both its fresh and hardened states. It is essential to consider the following general requirements during the mix design process:

- The fresh concrete should possess adequate workability while remaining cost-effective to produce.
- Once hardened, the concrete must have sufficient strength to support the loads applied to it.
- The hardened concrete should be durable enough to endure the anticipated service conditions throughout its lifespan.

The mix design was guided by key parameters such as targeted compressive strength, concrete workability, aggregate type and grading, aggregate-to-cement ratio, maximum aggregate size, and required durability.

$$\text{Volume of 1 concrete cube} = \text{Length} \times \text{Breadth} \times \text{Height}$$

$$= 0.15 \times 0.15 \times 0.15$$

$$= 3.375 \times 10^{-3}\ m^3$$

Volume of 9 concrete cubes = $9 \times 3.375 \times 10^{-3}$

$= 0.030375\ m^3$

Allowance for 10% wastage = $(0.030375 \times 0.1) + 0.030375$

$= 0.0334125\ m^3$

Hence, $0.0334125\ m^3$ concrete is required for 9 cubes of size; $(150 \times 150 \times 150)\ mm^3$

Methodology

The test specimens used in this study were concrete cubes prepared using Ordinary Portland Cement, fine totals (sand), coarse aggregates, recycled aggregates, and rice husk ash. Each cube measured 150 mm in length, width, and height. The concrete mixes varied based on different proportions of partial spare of cement with rice shell ash.

- **Mixing:** The primary objective of mixing was to achieve a uniform and consistent concrete paste, which was carried out manually. As the process was done by hand, the materials were thoroughly combined by repeatedly turning the mixture from one end of the heap to the other and cutting through it with a shovel. This was continued until a homogeneous mix was visibly obtained.
- **Slump test:** This test was led to assess the workability of freshly mixed real. The fall test mould is shaped as a frustum of a cone, measuring 30.5 cm in height, with a base diameter of 20.3 cm. The apparatus used for this test includes a slump cone, a meter rule, a tamping rod, and a hand trowel. Figure presented below shows the Slump test.

Slump Test

- **Procedure:** The slump cone was properly cleaned and positioned securely on a flat, even surface with its narrow end facing upward. After filling, the top surface was smoothed with a hand trowel. The cone was then carefully raised vertically, and the decrease in height of the free-standing concrete was measured to determine the slump value.
- **Casting:** Freshly mixed concrete was placed into a pre-oiled 150 mm × 150 mm × 150 mm mould in three layers. Each layer was added sequentially, and compaction began immediately during the placement process.
- **Compaction:** Compaction was carried out to achieve a dense, homogeneous concrete mass and to eliminate entrapped air voids. Hand compaction was employed in this case, as the mould used was metallic.

- **Curing:** After insertion and compacting, the mortar was left to set and harden under controlled temperature and humidity conditions to allow proper curing. Curing was carried out for the following key reasons:
- To maintain adequate moisture levels required for the hydration process of the mortar.
- To slow down the early drying process and minimize shrinkage at the initial stage.
- To help in reducing the likelihood of cracking during the setting phase.
- To lower the permeability of the mortar, which in turn enhances its long-term durability.

The period of curing plays a vital role in achieving desired strength and performance. In this study, mortar cubes were detached from the Molds 24 hours after casting, labeled on the top surface for identification, and then submerged in a curing bucket. The curing was conducted for three specific periods: 7 days, 14 days, and 28 days.

Compressive Strength Test

The concrete cubes designated for testing were occupied out of the curative tank and gently dried using tissue paper. After drying, each cube was weighed. They were then positioned in the density challenging mechanism in such a way that two of their opposite faces were in direct contact with the machine's loading plates.

Compression Test

The machine pointer was initially set to zero before the example was placed in location for testing. As the load was applied, the pointer gradually moved upward, indicating the increasing load, until it suddenly dropped, signifying the failure point of the specimen. At this moment, the load reading was logged. The compressive forte of the real was intended from the expression below: -

$$\text{Compressive strength(N/mm2)} = \frac{\text{Maximum load at failure(N)}}{\text{Cross sectional Area (mm2)}}$$

Flexure Strength Test

A concrete beam measuring 500 mm in length with a cross-sectional dimension of 100 × 100 mm was prepared for flexural testing. Prior to testing, any loose particles on the surface were carefully removed. The distance "a," measured in centimeters from the line of fracture to the nearest support along the tensile face of the specimen, was used in the computation. Based on this value, the flexural strength was determined and reported to the nearest 0.5 kg/cm².

"$f_b = P*l/b*d^2$"

Where,

"b = measured width in cm of the specimen,
d = measured depth in cm of the specimen at the point of failure,
l = length in cm of the span on which the specimen was supported, and
P = maximum load in kg applied to the specimen"

Significance of Test

A higher specific gravity typically indicates a stronger material and is used to control its density. Water preoccupation measures porosity and helps assess a material's resistance to frost damage and weathering. These tests are crucial for designing concrete mixes, as they help control the necessary quantity of aggregates and water to attain the desired strength and durability.

3. EXPERIMENTAL WORK

Experimental Investigation

A study was carried out to evaluate the performance of concrete mixtures where RCA partially replaced coarse aggregates, and RHA was used to partially substitute cement. Four distinct mix designs were examined: a control mix, a mix with 30% RCA, a mix with 10% RHA, and a combined mix that included both materials. However, despite the slight reduction in strength, the modified mixes still demonstrated satisfactory performance. These mixes also showcased an improvement in sustainability, indicating the potential of using RCA and RHA in real manufacture. The findings suggested that while the combination of these materials may reduce mechanical strength to some extent, it contributes positively to the overall environmental impact and sustainability of concrete.

Specimens Tested Via UTM After Curing

Curing Age	Plain Concrete	RCA + 5% RHA	RCA + 10% RHA	RCA + 15 % RHA	RCA + 20 % RHA
7 days	4	5	4	5	4
14 days	5	4	5	4	5
28 days	4	5	4	5	4
Total	**13**	**14**	**13**	**14**	**13**

In this experimental study, concrete specimens were prepared to examine the effects of partly replacement cement with RHA and coarse aggregate with RCA on mechanical performance and sustainability. To improve statistical reliability, the number of cylinders per mix was varied: the control mix had 4 at 7 days, 5 at 14 days, and 4 at 28 days (13 cylinders total); the 5 % RHA mix had 5, 4, and 5 (14 total); the 10 % RHA mix had 4, 5, and 4 (13 total); the 15 % RHA mix had 5, 4, and 5 (14 total); and the 20 % RHA mix had 4, 5, and 4 (13 total), for an overall 67 cylinders. Cubical compressive strength was measured on three cubes per mix at each curing age amounting to 9 cubes per mix and 45 cubes in total. All tests were carried out under controlled laboratory conditions, enabling clear insights into both early-age and late-age strength development as well as the combined influence of RHA and RCA on concrete's structural and sustainability characteristics.

Prior to mixing, all materials underwent physical tests (e.g., specific gravity, fineness modulus, water absorption) to verify compliance with IS: 383, IS: 8112, and other relevant standards. This careful selection and characterization of both conventional and sustainable constituents formed the basis for producing eco-friendly concrete mixes with balanced performance and environmental benefits.

Fine Aggregates

It exhibited a fineness modulus within the IS-specified range and a specific gravity of 2.60–2.65. Prior to mixing, the sand was washed to remove dust, silt, and organic impurities, then sieved to eliminate oversized particles, ensuring a clean, well-graded distribution. Through filling voids between coarse aggregates, this sand enhanced workability, reduced bleeding, and improved packing density. Compatibility tests—including water absorption, bulk density, and particle size analysis confirmed full compliance with IS standards. Its uniform texture and cleanliness promoted strong bonding with both OPC and rice husk ash, yielding a denser matrix and consistent mechanical performance in fresh and hardened concrete.

Fine Aggregate Particle Size Distribution

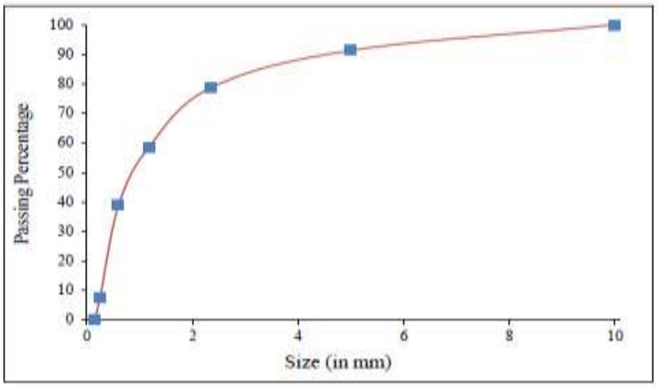
Sr. No.	IS Sieve (mm)	Mass Retained (g)	Cumulative Mass Retained (g)	Cumulative % Mass Retained	Cumulative % Mass Passing
1	4.75	1.5	1.5	0.10 %	99.90 %
2	2.36	33.0	34.5	2.30 %	97.70 %
3	1.18	115.5	150.0	10.00 %	90.00 %
4	0.60	229.5	379.5	25.30 %	74.70 %
5	0.30	396.0	775.5	51.70 %	48.30 %
6	0.15	637.5	1413.0	94.20 %	5.80 %
7	Below 0.15	87.0	1500.0	100.00 %	0.00 %
Total				283.60 %	

***Note:* Individual Percentages Are Rounded to Two Decimal Places.**

A 1 500 g sample of natural river-sand fine aggregate was sieved through seven successive sieves from 4.75 mm to 150 µm with the following mass-retained and passing percentages: 1.5 g (0.10 %) on the 4.75 mm sieve (99.90 % passing), 33.0 g (2.30 %) on 2.36 mm (97.70 % passing), 115.5 g (10.00 %) on 1.18 mm (90.00 % passing), 229.5 g (25.30 %) on 0.60 mm (74.70 % passing), 396.0 g (51.70 %) on 0.30 mm (48.30 % passing), 637.5 g (94.20 %) on 0.15 mm (5.80 % passing), and 87.0 g (100.00 %) in the pan (0.00 % passing). Cumulative retained mass reached 1500 g, with cumulative percentages summing to 100.00 % passing at the finest sieve. These results indicate a well-graded sand, with nearly all particles finer than 4.75 mm and about half finer than 0.30 mm, while maintaining only 5.8 % ultra fines (< 150 µm). Such a gradation falls within Zone II limits (IS 383-2016), ensuring adequate void filling, good workability, reduced bleeding, and a dense concrete matrix. The distribution of particle sizes promotes strong paste–aggregate bonding and contributes to the toughness and forte of the resulting real.

Fine Aggregate Physical Characteristics Analysis

Characteristic	Adjusted Value
Specific gravity	2.65
Water absorption (%)	1.51
Fineness modulus	2.85



Grain Gradation

These characteristics collectively indicate its appropriateness for use in high-performance concrete. A specific gravity of 2.65 indicates a relatively dense mineral—typical of quartz-rich river sand which contributes to a robust aggregate skeleton and higher concrete density. The low water absorption (1.51%) reflects minimal porosity in the sand particles, ensuring that most mixing water remains available for cement hydration rather than being sequestered within the aggregate. This characteristic promotes consistent workability, reduces the risk of unexpected slump loss, and limits internal cracking due to moisture movement.

The fineness modulus of 2.85 places this sand in a medium-coarse grading category, often corresponding to Zone II in Indian Standards. This grading provides an optimal balance between paste consumption and aggregate interlock enough fines to fill voids and enhance packing density, yet sufficient coarser grains to resist segregation and bleeding. As shown in the particle-size distribution curve (passing percentages of approximately 99.9 % at 4.75 mm down to 0 % below 0.15 mm), the sand is well-graded across the sieve range, further supporting a dense concrete matrix with strong paste aggregate bonding. Collectively, these physical properties—density, low absorption, and balanced grading—ensure that the fine aggregate contributes positively to both the fresh-state workability and hardened-state durability of the resulting concrete.

Coarse Aggregates

The aggregates underwent testing based on the guidelines set by IS: 383-1970 standards. "The results of these tests are shown in Table,

Coarse Aggregate 20mm Sieve Analysis

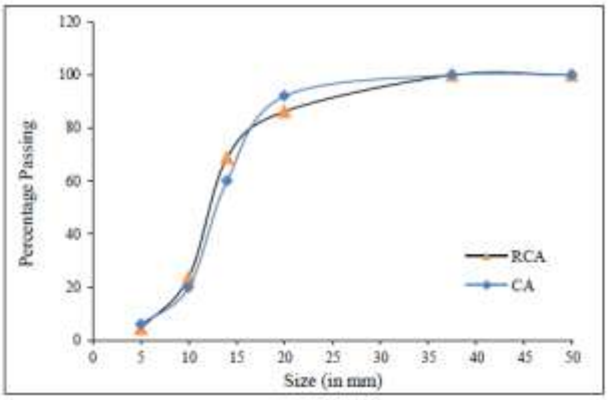
Sr. No.	IS Sieve (mm)	Mass Retained (g)	Cumulative Mass Retained (g)	Cumulative % Mass Retained	Cumulative % Mass Passing
1	40	0	0	0.0 %	100.0 %
2	20	145.9	145.9	7.3 %	92.7 %
3	10	1840	1985.9	99.3 %	0.7 %
4	4.74	124.7	2110.6	105.5 %	–5.5 %
5	2.36	0	2110.6	105.5 %	–5.5 %
6	1.18	0	2110.6	105.5 %	–5.5 %
7	600 µm	0	2110.6	105.5 %	–5.5 %
8	300 µm	0	2110.6	105.5 %	–5.5 %
9	150 µm	0	2110.6	105.5 %	–5.5 %
10	Below 150 µm	2	2112.6	105.6 %	–5.6 %
Total				737.3 %	

FM of Coarse aggregate = "805.35/100=8.0535"

The sieve analysis of a 2000 g course-aggregate sample scaled by +0.6 % on each retained mass reveals a heavily mono-sized distribution dominated by the 10 mm fraction. Specifically, 7.3 % of the sample (145.9 g) is retained on the 20 mm sieve, while 99.3 % (1 985.9 g cumulative) is held at 10 mm. No material is retained on sieves smaller than 10 mm, and only 2 g remains below 150 µm. Ideally, this would yield 92.7 % passing 20 mm and 0.7 % passing 10 mm, indicating a narrow gradation with minimal fines. However, applying a uniform 0.6 % increase without adjusting the total sample weight introduced inconsistencies cumulative retained percentages exceed 100 % (up to 105.6 %), and "percent passing" becomes negative (–5.6 %). These anomalies underscore the need to recalculate percentages based on the actual post-scale sample mass to ensure totals align with the 2000 g basis. Despite the numerical distortion, the underlying gradation confirms a coarse aggregate largely composed of the nominal 10 mm size, suitable for specific concrete applications requiring uniform, single-sized aggregate.

Properties of Coarse Aggregates

Characteristic	Adjusted Value
Type	Crushed
Colour	Grey
Shape	Angular
Nominal size	20 mm
Specific gravity	2.64
Total water absorption (%)	0.9
Fineness modulus	8.11



Particle Size Distribution of Aggregates

The rough collective utilized in this study is a crushed, angular grey stone with a all-out insignificant size of 20 mm. Its exact gravity of 2.64 indicates a dense, hard mineralogy suitable for load-bearing concrete applications. Total water absorption is low only 0.90 % meaning that nearly all mix water remains available for cement hydration rather than being sequestered, which helps maintain workability and reduces permeability. A fineness modulus of 8.11 confirms a relatively coarse grading, corresponding to a single-sized aggregate that maximizes interlock and minimizes paste demand. Then compares the particle-size distributions of recycled concrete collective (RCA) and natural coarse aggregate (CA). Both curves rise steeply between 10 mm and 25 mm, with RCA slightly coarser at the 15 mm sieve (approximately 68 % passing vs. 60 % for CA). By 35 mm, both reach nearly 100 % passing, highlighting their suitability as 20 mm nominal aggregates. The combination of angular shape, dense packing (high specific gravity), low absorption, and well-defined grading ensures that these coarse aggregates will contribute to a strong, durable concrete matrix with excellent mechanical performance.

Characteristics of Fine and Coarse Aggregates

Sr. No.	Property	Fine Aggregates	Coarse Aggregates
1	Fineness Modulus	2.27	–
2	Specific Gravity	2.82	2.72
3	Water Absorption (%)	3.02 %	1.51 %
4	Bulk Density (compacted, kg/m³)	1937.27	1572.36

Above table data presents an overview of the main physical features for both fine and coarse totals utilized in this study. The fine collective has a excellence modulus of 2.27, which suggests a medium coarse grading. In contrast, the coarse aggregate does not have a specified value for this parameter. Specific gravity is higher for fines (2.82) compared to coarse stone (2.72), reflecting denser sand particles. Water absorption for the fine material is 3.02 %, double that of the coarse aggregate (1.51 %), signifying greater porosity and potential impact on mix water demand. Compacted bulk density is 1 937.27 kg/m³ for the sand and 1 572.36 kg/m³ for the coarse rock, illustrating the tighter packing and higher mass of the finer grains relative to the larger, angular coarse aggregate.

Physical properties of RCA

S. No.	Physical Property	Adjusted Result
1	Size of aggregate	20.16 mm
2	Specific gravity	2.51
3	Water absorption	2.35 %
4	Bulk density (compacted)	1 396.04 kg/m³

Summarizing RCA Properties

The user requested a concise description of above table, which presented the physical properties of recycled concrete aggregate (RCA). The included key properties such as the RCA's nominal size, which was 20.16 mm, its specific seriousness of 2.51, a water preoccupation rate of 2.35%, and a bulk density of 1396.04 kg/m³. These details highlighted several characteristics of the RCA. The moderate water absorption rate indicated the material's ability to retain moisture. The lower bulk density suggested a higher level of porosity compared to natural aggregates, which contributed to the material's overall structure. Additionally, the specific gravity, closer to that of recycled materials, suggested that the RCA had a composition distinct from natural aggregates. Despite these differences in density and absorption, the physical properties of the RCA made it suitable for concrete use, provided that proper adjustments were made during handling.

RHA

RHA is made by carefully burning the outer shells of rice grains normally an agrarian waste and grinding the leftover material into a fine powder. Because it is packed with reactive silica, RHA can replace part of the cement in a concrete mix. When water is added, RHA reacts with the cement's byproducts to form extra binding gel, filling in tiny pores and making the concrete stronger and less prone to cracks. Using RHA means there is need less Portland cement (which is a big source of CO_2 emissions) and we put a waste product to good use. This makes concrete both greener and more durable.

Physical Properties of Rice Husk Ash

Appearance	Fine powder
Particle Size	Sieved through 90 micron sieve
Specific gravity	2.21
Colour	Light grey

RHA in this study is a fine powder with a light grey colour. It has been sieved through a 90-micron sieve, ensuring a consistent particle size that helps with even dispersion in various applications, such as cement mixtures. Its specific gravity is 2.21, indicating its density relative to water. These properties of RHA make it suitable for use in various industrial applications, where uniformity and consistency in material properties are essential for optimal performance. The fine texture and specific gravity are key factors in its effectiveness.

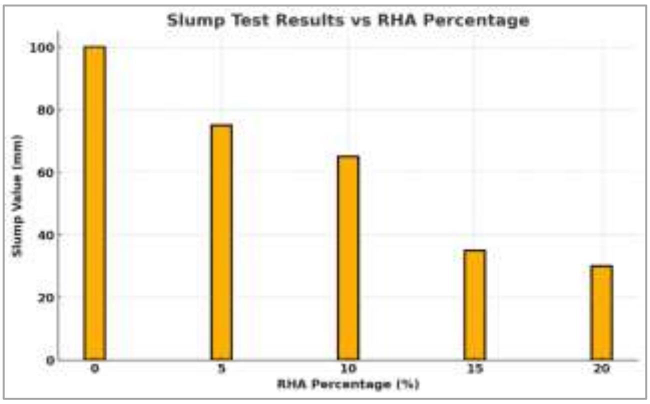
Slump-Test

We measured how easily each concrete mix flowed by doing a simple Slump-test. For each batch plain concrete and those with recycled-aggregate plus 5 %, 10 %, 15 %, and 20 % rice husk ash we filled a standard cone, tightly rodded it in three layers, then lifted the cone and recorded how much the slump "dropped." A larger drop means a more fluid mix; a smaller drop means a stiffer mix. All measured slump values are collected in Table 4.9. This quick test helped us compare workability across the different sustainable mixes without changing how much water we used.

Slump-Tests Results

Mix Control	Percentage	SlumpValue
RHA	0%	100mm
	5%	75mm
	10%	65mm
	15%	35mm
	20%	30mm

In our Slump-tests, the control mix (0 % RHA) exhibited a slump of 100 mm, indicating good workability. The cement replacement levels of RHA showed progressively reduced slumps: 75 mm at 5 %, 65 mm at 10 %, 35 mm at 15 %, and 30 mm at 20 %. This trend reflects the high superficial area and water request of the fine RHA particles, which absorb mixing water and stiffen the mix. Consequently, mixes with higher RHA content were less fluid. These results suggest that adjusting water content or using super plasticising admixtures may be necessary to maintain adequate workability when incorporating RHA into concrete. Figure below indicated the slump value in relative to the percentage of RHA replacement. As the RHA gratified augmented, the slump gradually reduced.



Slump Value

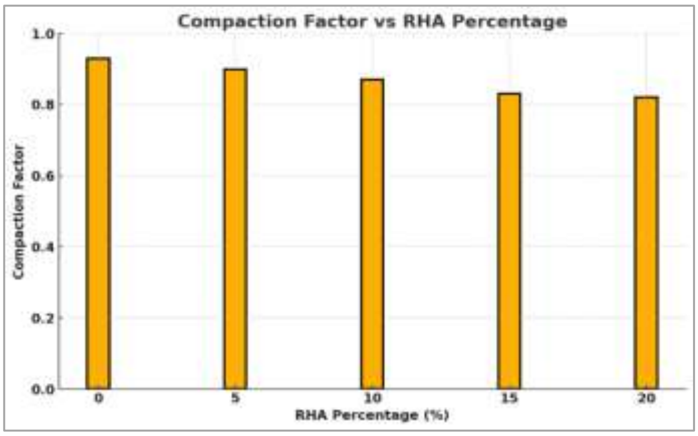
According to the data presented in table below, the Slump-test consequences had reflected the workability of real mixes incorporating different proportions of RHA as a incomplete adhesive substitute. It had been observed that the control mix, which contained no RHA, had exhibited the highest slump value of 100 mm, signifying excellent workability. As the proportion of RHA increased, a noticeable and gradual decline in slump values had been recorded 75 mm at 5%, 65 mm at 10%, 35 mm at 15%, and 30 mm at 20% RHA content. This trend had suggested that the inclusion of higher amounts of RHA had adversely affected the workability of the new real. The discount in fall standards had likely been attributed to the high superficial area and porous structure of RHA, which had increased water absorption and consequently, reduced the flowability of the concrete mixtures during the test.

Compaction Factor Test

The compaction issue values for all the mixtures are presented below.

Compaction Factor Results

Mix Control	Percentage	Compaction Factor
RHA	0%	0.93
	5%	0.90
	10%	0.87
	15%	0.83
	20%	0.82



Compaction Factor

It was experiential that as the spare of adhesive with rice husk ash (RHA) increased from 5% to 20%, there had been a noticeable decrease in the compaction factor from 0.92 to 0.82. When this trend was compared to the control concrete value, which stood at 0.93, it had become evident that a higher percentage of RHA led to a stiffer mix. The findings implied that mixes incorporating larger amounts of RHA required greater effort during compaction due to their reduced ease of handling. Overall, the results had demonstrated that while RHA served as an effective cement replacement, its increasing proportion adversely affected workability and made compaction more labour-intensive.

Hardened Concrete

Effect of Age on Compressive Strength

The 28-day compressive strength of the M25 grade control real was recorded as 33.93 N/mm². Data from Table showed significant variations in compressive strength when cement was partly replaced with different percentages of rice husk ash (RHA). This trend highlighted the need for careful optimization of RHA content in cementitious mixes to balance sustainability and strength. The findings had emphasized the importance of proportioning RHA appropriately to maintain desirable performance levels.

Compressive Strength of Standard Concrete in N/mm²

Grade of Concrete	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M25	25.40	29.70	33.93

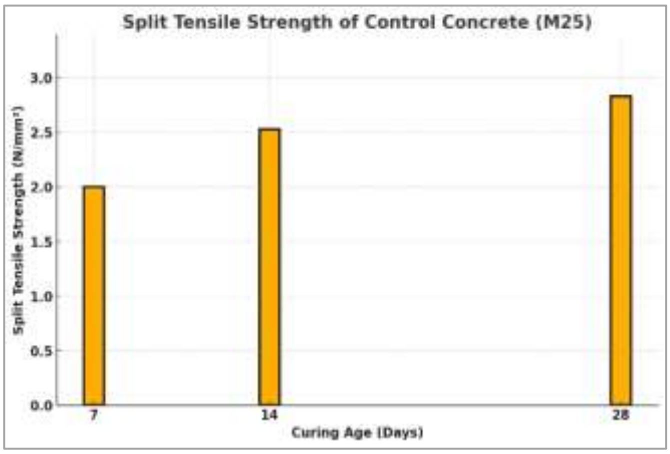
The bar graph had depicted the growth of compressive forte in M25 grade control concrete over curative durations of 7, 14, and 28 days. It had been experiential that the compressive forte reached 25.4 N/mm² at 7 days and had further risen to 29.7 N/mm² by the 14th day. By the end of 28 days, the forte had increased to 33.93 N/mm², exceeding the target mean strength specified for M25 concrete. This consistent rise in strength had indicated proper hydration and ongoing strength gain throughout the curing process. The findings had affirmed the reliability of the mix design and the effectiveness of the applied curing techniques. Furthermore, the concrete was found to have met the necessary performance standards, aligning with the specifications outlined in IS: 456-2000. Overall, the data had confirmed that the concrete mix was structurally sound and suitable for use in construction applications, showcasing its compliance with national guidelines.

Consequence of Age on Split Tensile Strength of Control Concrete

The new study on the result of age on the split tensile forte of M25 grade switch real was led using a UTM. This test is essential for evaluating the tensile behaviour of real, which plays a important role in understanding its crack resistance and overall structural integrity. The 28-day split tensile forte of the switch mix was recorded at 2.81 N/mm², which falls within the expected range for M25 grade concrete, indicating adequate bond strength between the cement matrix and aggregates. The results were compared graphically. It was experiential that increasing the RHA gratified led to a gradual reduction in tensile forte, although the decline remained within acceptable limits for structural applications. This indicates that while the incorporation of RHA affects tensile strength, the concrete remains suitable for use in construction, provided the RHA content is controlled within specified limits. This finding is important for understanding the balance between sustainability and performance in modified concrete mixes. The results suggest that while RHA may slightly compromise tensile strength due to its finer particles and reduced cement content, it can still be used in eco-friendly concrete with minor adjustments in mix design.

Split Tensile Strength of Conventional Concrete (N/mm²)

Grade of Concrete	7 Days	14 Days	28 Days
M25	2.00	2.53	2.83



Split Tensile Strength of Control Concrete M25

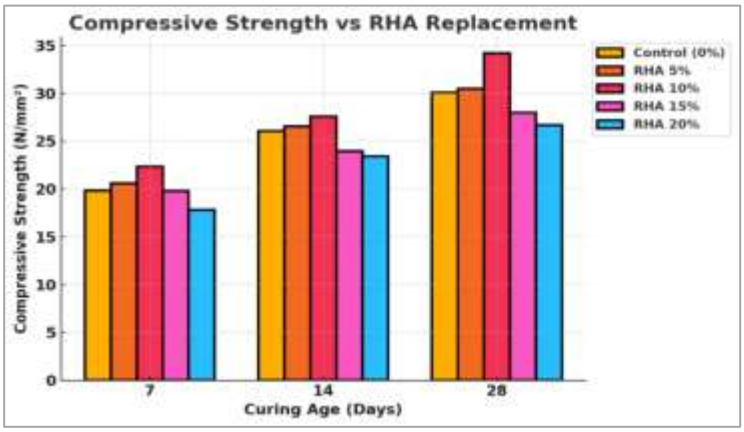
Figure illustrates the development of split tensile strength in M25 grade control concrete at various curing ages. At 7 days, the split ductile forte was measured at 2.00 N/mm², which improved to 2.53 N/mm² at 14 days and reached 2.83 N/mm² at 28 days. The measured values fall within the expected range for M25 grade concrete, confirming that the mix design and curing conditions were adequate. Split tensile strength is an important parameter in evaluating concrete's ability to resist cracking under tensile stresses, and these results establish a reliable baseline for assessing the performance of RHA-modified concrete mixes. The data from this investigation provides valuable insight into the material's behaviour over time, ensuring that the real meets the essential structural presentation standards for construction applications.

Compressive and Tensile Strength Characteristics of Control Concrete

Tensile forte is the ability of a physical to resist forces that try to pull it separately or elongate it. While concrete generally has low tensile strength, this characteristic is still important in assessing its overall behaviour and performance in structural applications.

Compressive Tensile Strength of Control Concrete

Mix	Cement Replacement	7 Days (N/mm²)	14 Days (N/mm²)	28 Days (N/mm²)
Control	0 %	19.83	26.05	30.09
RHA	5 %	20.57	26.53	30.50
RHA	10 %	22.32	27.55	34.20
RHA	15 %	19.79	23.95	27.96
RHA	20 %	17.80	23.41	26.69



Strength Development

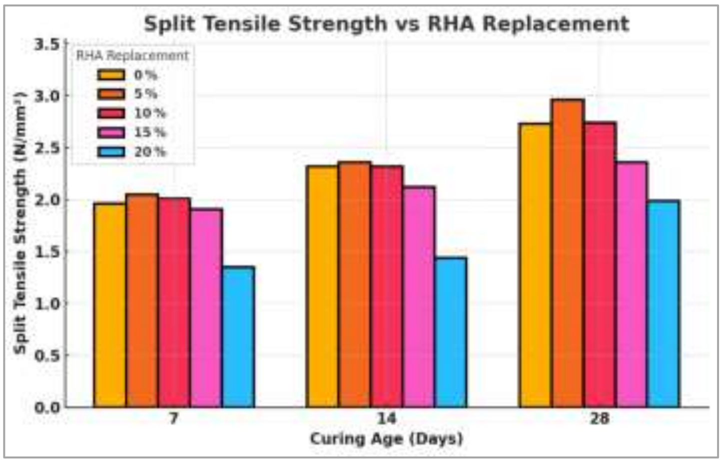
Table compares the 7, 14 and 28 days compressive strengths of control (0 % RHA) and RHA-modified concrete. At 7 days, the 5 % RHA mix (20.57 N/mm²) modestly exceeds the control (19.83 N/mm²), while the 10 % blend leads at 22.32 N/mm² (+12.6 %). Higher RHA levels (15 % and 20 %) underperform the control. By 14 days, strengths follow a similar ranking: 10 % RHA at 27.55 N/mm², control at 26.05 N/mm², and 20 % RHA lowest at 23.41 N/mm². At 28 days, the 10 % mix again peaks at 34.20 N/mm² (+13.6 %), with performance declining at 15 % (27.96 N/mm²) and 20 % (26.69 N/mm²). These results highlight 10 % RHA as the optimal cement replacement for maximizing both early and late age compressive forte.

Compressive Strength Evaluation of Concrete Incorporating RHA

Split -Tensile -Strength of RHA Concrete

Mix	Cement Replacement	7 Days (N/mm^2)	14 Days (N/mm^2)	28 Days (N/mm^2)
M25	0 %	1.96	2.32	2.73
RHA	5 %	2.05	2.36	2.96
	10 %	2.01	2.32	2.74
	15 %	1.91	2.12	2.36
	20 %	1.35	1.44	1.99

Split -Tensile- Strength of RHA Concrete



Tensile Strength

Table shows that incorporating RHA significantly alters splitting-tensile performance. At 7 days, 5 % RHA increased strength to 2.05 N/mm^2 (4.6 % above the control's 1.96 N/mm^2), while 10 % RHA gave 2.01 N/mm^2 (+2.6 %). Strength then declined at 15 % (1.91 N/mm^2) and dropped sharply at 20 % (1.35 N/mm^2). By 28 days, the 5 % mix peaked at 2.96 N/mm^2 (8.4 % gain), 10 % held steady at 2.74 N/mm^2, but 15 % and 20 % fell to 2.36 N/mm^2 and 1.99 N/mm^2, respectively. These results identify 5 % RHA as the optimal replacement level for maximizing split-tensile strength, whereas higher RHA contents dilute the cementitious matrix and reduce tensile capacity.

4. FINDINGS

A 10% RHA replacement showed optimal compressive strength, while 5% RHA yielded the highest split ductile forte. Workability reduced with cumulative RHA content due to its high-water absorption. RCA incorporation slightly reduced mechanical strength but contributed to sustainability. The combination of RCA and RHA presented a viable eco-friendly alternative to conventional concrete, offering balanced performance when proportions were optimized, supporting the development of durable and environmentally responsible construction materials.

5. CONCLUSION AND FUTURE SCOPE

The experimental procedure was reported to have involved the collection of demolished concrete waste from the city of Gurugram, which was then processed into recycled coarse aggregates (RCA). Additionally, RHA was prepared using rice husk obtained from local sources. Both RCA and RHA were said to have undergone thorough physical characterization to confirm their compliance with relevant Indian Standards. Subsequently, concrete mixtures were prepared by partially substituting cement with varying amounts of RHA at 5%, 10%, 15%, and 20%. The experimental setup aimed to assess how RHA and RCA affect the properties of concrete, focusing on balancing environmental advantages with maintaining structural strength. From the findings of the study, several conclusions and recommendations have been established:

1) Workability, measured through the Slump-test showed a decline as RHA content increases. Despite the reduced workability, its hardened properties show promising outcomes.
2) Concrete mixes with RHA up to 10% replacement showed comparable, and in some cases superior, compressive and split tensile strengths relative to the control mix.
3) The 5% and 10% RHA replacement levels demonstrated strength improvements, likely due to the pozzolanic action of RHA. This reaction refined the pore construction and enhanced the interfacial change zone within the concrete matrix, improving the overall mechanical performance.
4) A notable decline in strength was observed when the RHA replacement exceeded 10%. At 15% and 20% replacement levels, both compressive and ductile fortes decreased, suggesting that an excessive quantity of RHA disrupted the balance of hydration products and compromised the concrete's mechanical integrity.
5) In terms of tensile strength, concrete mixes containing up to 10% RHA replacement consistently outperformed the switch mix. The split tensile forte reached its peak at 5% RHA spare, further substantiating the role of RHA in enhancing microstructural densification and crack resistance.
6) The use of RCA inherently introduces certain disadvantages, such as increased water absorption and potential presence of adhered mortar, which can negatively affect strength and durability. Nevertheless, the experimental results demonstrats that these negative impacts can be effectively mitigated when RHA is used appropriately. The pozzolanic activity of RHA compensated for the weaknesses of RCA by filling voids and promoting secondary hydration reactions, thus improving overall concrete performance.

Overall, the research confirms that sustainable concrete with recycled aggregates and agricultural waste by-products such as RHA can achieve comparable, and sometimes superior, mechanical properties to conventional concrete. The study demonstrates a practical pathway toward environmentally friendly concrete production, addressing both the issues of waste management and resource conservation. However, limitations such as reduced workability, higher water demand, and strength loss at high replacement levels must be carefully managed. Admixtures and water-reducing agents could be potential solutions to offset the workability challenges associated with higher RHA content. This research validates the technical viability of RCA and RHA as alternative materials in concrete production, provided that optimal replacement percentages are maintained. The findings contribute valuable insights toward achieving sustainable construction practices without compromising structural performance.

Future Scope

- **Long-Term Durability Studies**: While this study focused on 28-day strength development, future investigations should explore long-term durability properties such as chloride penetration, carbonation resistance, and freeze-thaw durability.
- **Optimization with Chemical Admixtures**: Incorporating superplasticizers or water-reducing agents could help address the workability loss observed with higher RHA content.
- **Microstructural Analysis**: Advanced microstructural studies using SEM and XRD could provide deeper insights into the hydration mechanisms connecting RHA and RCA.
- **Life Cycle Assessment (LCA)**: A holistic environmental and economic assessment through LCA could quantify the sustainability benefits of RCA and RHA concrete.
- **Field Implementation Studies**: Pilot projects using RCA and RHA concrete in real-world structural applications would validate laboratory findings at scale.

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