Cumulative Effects of Rice Husk Ash and Coconut Coir Fibers on M25 Grade Concrete's Mechanical Properties

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Abstract: ***The increasing demand for environmentally responsible construction practices has accelerated the exploration of agricultural by-products as sustainable alternatives to conventional concrete constituents. This study presents a performance-based investigation of M25 grade concrete modified with Rice Husk Ash (RHA) as a partial cement replacement and Coconut Coir Fiber (CCF) as natural reinforcement. Concrete mixes incorporating varying levels of RHA (5%, 10%, and 15% by weight of cement) and CCF (0.5%, 0.75%, and 1% by volume of concrete) were evaluated alongside a control mix. A total of ten mix designs were prepared and tested in accordance with IS 10262:2019. Experimental evaluations included workability (slump), compressive strength, split tensile strength, and flexural strength at 7 and 28 days. The results indicate that the incorporation of RHA and CCF significantly improves certain mechanical properties while promoting material sustainability. The optimal combination—10% RHA with 0.75% CCF—demonstrated superior overall performance, making it a viable option for sustainable rural construction. This study validates the potential of agro-waste utilization in developing durable, cost-effective, and eco-friendly concrete.***

Keywords: Sustainable Concrete, Rice Husk Ash, Coconut Coir Fiber, M25 Grade, Eco-Friendly Construction

1. Introduction

1.1 Background

Concrete is the most widely used construction material globally due to its exceptional compressive strength, durability, and adaptability across a wide range of applications. However, the production of Ordinary Portland Cement (OPC), a key component of concrete, is energy-intensive and contributes significantly to global CO_2 emissions. With the construction industry under increasing scrutiny for its environmental footprint, the integration of sustainable materials into concrete formulations has gained considerable momentum.

Among various eco-friendly alternatives, Rice Husk Ash (RHA) has emerged as a promising supplementary cementitious material (SCM) due to its high silica content and pozzolanic activity. On the other hand, Coconut Coir Fiber (CCF), a natural agricultural by product, presents a biodegradable, low-cost solution for improving concrete's post-cracking behavior and ductility. The combined use of RHA and CCF in concrete not only reduces dependence on OPC and synthetic fibers but also promotes agricultural waste utilization, thereby contributing to sustainable development goals.

1.2 Problem Statement

The M25 grade concrete is widely used in rural and medium-scale infrastructure projects. However, it suffers from moderate durability and lacks resistance to tensile stresses and crack propagation. While previous studies have independently explored the role of pozzolanic materials or natural fibers in concrete, limited research exists on the synergistic effect of RHA and CCF, particularly in M25 grade concrete. Moreover, the optimization of their combined proportions to achieve improved mechanical properties and sustainability remains an underexplored area. Addressing this gap is essential to develop cost-effective, durable, and environmentally responsible concrete suitable for rural applications.

1.3 Objectives of the Study

The primary objective of this study is to evaluate the influence of Rice Husk Ash and Coconut Coir Fiber on the mechanical and workability characteristics of M25 grade concrete. The specific objectives include:

1) To investigate the effect of replacing OPC with RHA at 5%, 10%, and 15% by weight of cement on the performance of M25 concrete.
2) To examine the impact of incorporating Coconut Coir Fiber at 0.5%, 0.75%, and 1.0% by volume of concrete on tensile and flexural performance.
3) To analyze the combined influence of RHA and CCF on the workability, compressive strength, split tensile strength, and flexural strength.
4) To determine the optimal RHA–CCF combination that offers enhanced mechanical properties while maintaining workability and sustainability.

1.4 Scope of the Study

This research is limited to M25 grade concrete, with RHA serving as a partial cement replacement and CCF as a

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secondary reinforcement. A total of ten trial mixes are designed, tested, and analyzed in accordance with IS 10262:2019 and IS 456:2000 standards. The scope includes slump tests for workability and compressive, split tensile, and flexural strength tests at 7 and 28 days. The study contributes to the development of sustainable concrete solutions for rural and low-cost construction applications.

2. Literature Review

2.1 Introduction

Recent advancements in sustainable concrete have focused on using agro-waste like Rice Husk Ash (RHA) and natural fibers such as Coconut Coir Fiber (CCF) to enhance performance and reduce environmental impact. RHA acts as a pozzolanic material improving strength and durability, while CCF enhances ductility and crack resistance. Several studies from 2021 to 2024 have investigated their combined influence, particularly in medium-strength concretes like M25. This review presents key findings supporting their application in eco-efficient concrete design.

1) **Harnawansyah et al. (2025):** Investigated combinations of 1% Coconut Fiber Ash (CFA) and varying RHA (7.5%, 10%, 12.5%, 15%) in concrete targeting ~M20 strength. The mix with 1% CFA + 7.5% RHA achieved the highest 28-day compressive strength (23.11 MPa), outperforming control mixes and meeting design requirements. Demonstrated that CFA + RHA is a viable sustainable cement substitute.
2) **De Silva et al. (2024):** Evaluated cement mortar modified with RHA and coconut coir fiber. Optimum results were at 5–10% RHA and 0.3–0.5% fiber, yielding notable improvements in compressive, tensile, and flexural strength with enhanced sustainability. Emphasized the necessity of superplasticizer to ensure acceptable workability.
3) **Morato et al. (2023):** Explored concrete blends with 0.25–0.75% coconut fiber waste (CFW) and 2–10% RHA. The combination of 5% RHA + 0.5% CFW delivered the best performance in compressive strength and sulfate resistance, along with reduced CO_2 emissions and capillary absorption.
4) **Fapohunda et al. (2023):** Fapohunda and colleagues reviewed structural performance of ternary concrete blends incorporating Rice Husk Ash and other agro-waste pozzolans. Their study emphasized the sustainability benefits and the potential of these materials to partially replace cement due to their pozzolanic activity. They highlighted the need for coordinated research and development of practical guidelines for integrating such ternary blends in structural concrete applications.
5) **Bebhe and Daton (2021):** investigated the effect of incorporating rice husk ash (RHA) and coconut fiber into white soil bricks commonly used in Timor Island, Indonesia. The study aimed to improve the compressive strength of bricks made without sand due to the naturally high sand content of the white soil. Using an experimental approach, the bricks were dried for 28 days before testing. The results showed that a mix ratio of 1:1 (coconut fiber to cement) achieved a compressive strength of 147 kg/cm², and 1.5:1 (RHA to cement) achieved 114.3 kg/cm². Both mixes performed significantly better than the control mix of 1:7 (cement to soil), which only achieved 51.9 kg/cm². The findings demonstrate that both RHA and coconut fiber are effective additives for enhancing the strength of white bricks, exceeding the minimum strength requirements of quality bricks as per SNI 03-0349-1989 standards.
6) **Rana and Verma (2020):** carried out an experimental investigation on the performance of concrete incorporating Rice Husk Ash (RHA) and coconut coir fiber. The cement was partially replaced with RHA at 10% and 15%, while coir fibers were added at 0.5% and 1% by weight of cement. Tests for compressive, split tensile and flexural strength were conducted at 7 and 28 days. The results indicated that the combination of 10% RHA with 0.5% fiber provided the best overall improvement in mechanical properties. Higher dosages resulted in reduced workability and marginal decreases in compressive strength. The study highlighted that the synergy between RHA's pozzolanic reaction and fiber bridging mechanism can be effectively utilized in sustainable concrete applications.
7) **Malik et al. (2020):** carried out an experimental study to evaluate the effect of lime, rice husk ash (RHA), and coconut coir fiber (CCF) on the strength properties of subgrade soil. The research focused on improving weak subgrade soils through partial stabilization using varying percentages of these materials. The mix containing 4% lime, 10% RHA, and 1% CCF exhibited optimum performance in terms of unconfined compressive strength (UCS) and California bearing ratio (CBR) values. Results indicated that the addition of RHA and CCF alongside lime significantly improved load-bearing capacity and ductility while reducing plasticity and swelling behavior. The study concluded that this ternary blend can be effectively used in road and foundation subgrade improvement, offering a sustainable alternative to conventional methods.
8) **Satish & Bharatkumar (2020):** Satish and Bharatkumar studied slump retention and rheological behavior in self-compacting and fiber-reinforced concrete. They found that when RHA is used as a partial cement replacement, slump retention issues arise due to its high surface area. However, they demonstrated that the use of polycarboxylate-based superplasticizers effectively counteracts this issue. Their findings validate the importance of chemical admixtures in hybrid mixes and directly support your use of 0.5% superplasticizer for maintaining slump at 100 mm.
9) **Jan et al. (2020):** conducted an experimental investigation into the stabilization of clayey subgrade soil using a combination of lime, rice husk ash (RHA), and coconut fibre (CF). The study aimed to replace conventional cementitious stabilizers with agricultural by-products for enhanced sustainability. Soil samples were treated with varying proportions of these materials, and tests were conducted to evaluate consistency limits, compaction behavior, and strength characteristics. The results showed that adding lime, RHA, and coconut fibre reduced maximum dry density and increased optimum moisture content. The combination of 6% lime, 8% RHA, and 1% coconut fibre was identified as the optimum mix, providing

improved strength performance while offering a cost-effective and eco-friendly alternative for subgrade soil stabilization in road construction.

10) **Thomas and Gupta (2019):** presented a detailed review on the mechanical properties of concrete reinforced with natural coconut fibers. The paper summarized findings from several experimental studies focusing on compressive strength, tensile strength, flexural strength, and durability of coconut fiber–reinforced concrete. It was observed that the addition of 0.5% to 1.5% untreated coir fiber significantly improved the post-cracking behavior and flexural strength of concrete due to the bridging effect of fibers. However, challenges related to fiber dispersion and increased water demand were also reported. The authors recommended surface treatment of fibers and controlled dosages to maximize performance while maintaining workability. The review emphasized the potential of coconut fiber as a renewable and eco-friendly reinforcement in cementitious composites.
11) **Tutur and Noor (2018):** investigated the use of natural waste materials—Rice Husk Ash (RHA) and Coconut Coir Fibers (CCF)—as partial cement replacements to enhance the flexural and split tensile strength of concrete intended for pavement construction. The study utilized controlled proportions of RHA and coir fibers as additives in conventional concrete mixtures. RHA, being a highly pozzolanic by-product of the paddy industry, was added due to its silica content and known durability benefits, while CCF was incorporated for its excellent mechanical and crack-bridging properties. Their experimental results demonstrated that the optimal enhancement in tensile and flexural strength was achieved at 16.5% RHA and 4% CCF, respectively. The authors concluded that the integration of RHA and CCF could be effectively used to produce strong, durable, and sustainable concrete pavements, contributing to both waste management and improved pavement performance.
12) **Tushar Baviskar et al. (2018):** investigated the use of natural waste materials—Rice Husk Ash (RHA) and Coconut Coir Fibers (CCF)—as partial cement replacements to enhance the flexural and split tensile strength of concrete intended for pavement construction. The study utilized controlled proportions of RHA and coir fibers as additives in conventional concrete mixtures. RHA, being a highly pozzolanic by-product of the paddy industry, was added due to its silica content and known durability benefits, while CCF was incorporated for its excellent mechanical and crack-bridging properties. Their experimental results demonstrated that the optimal enhancement in tensile and flexural strength was achieved at 16.5% RHA and 4% CCF, respectively. The authors concluded that the integration of RHA and CCF could be effectively used to produce strong, durable, and sustainable concrete pavements, contributing to both waste management and improved pavement performance.
13) **Mohamed Barveen and Gunasekaran (2018):** studied the influence of rice husk ash (RHA) as a partial cement replacement in concrete where coconut shell (CS) was used as a coarse aggregate. The study evaluated varying percentages of RHA replacement (0% to 12%) for ordinary Portland cement in both conventional concrete and coconut shell concrete (CSC). Key properties assessed included workability, density, compressive strength, split tensile strength, flexural strength, impact resistance, and modulus of elasticity. Results showed that the compressive strength and other mechanical properties improved with increasing RHA content up to an optimal level of 10%. Beyond this point, the strength gains declined. The research concluded that replacing cement with 10% RHA in CSC not only enhances mechanical performance but also improves workability, demonstrating the material's suitability for sustainable concrete applications.
14) **Habeeb and Mahmud (2018):** investigated the potential of Rice Husk Ash (RHA) as a partial replacement for cement in high-strength concrete. The study focused on analyzing the physical and chemical properties of RHA produced under controlled conditions and its effect on concrete performance when used at 10% and 20% replacement levels. Test results showed that RHA contributed to improved compressive strength, reduced permeability, and enhanced durability due to its high silica content and fine particle size, which facilitated pozzolanic activity. The study also noted that proper grinding and controlled burning of rice husk were essential for obtaining reactive ash. The authors concluded that RHA can effectively enhance both strength and long-term performance of high-strength concrete when used under optimized conditions.
15) **Abarajithan et al. (2017):** conducted a study to evaluate the feasibility of soil stabilization using Rice Husk Ash (RHA) and coconut coir fiber. The research tested various proportions—such as 6% RHA + 2% coir, 7% RHA + 1.5% coir, and 8% RHA + 1% coir—on expansive clay subgrade soils. Results showed that optimal improvement in bearing capacity and unconfined compressive strength was achieved with 8% RHA and 1% coir fiber. The study concludes that combining RHA and coir enhances soil index properties (OMC, MDD, CBR, UCS), offering an economical and eco-friendly solution for pavement subgrade stabilization.
16) **Zhang et al. (2017):** Zhang and co-authors conducted rheological assessments of fiber-reinforced concrete using advanced tools like concrete rheometers. Their study revealed that fiber inclusion, especially natural fibers like coconut coir, significantly increases the yield stress and plastic viscosity of the mix, thereby reducing flowability. However, with proper use of superplasticizers, the negative effects on workability can be mitigated. These findings support your thesis's design consideration of incorporating 0.5% superplasticizer to maintain desired slump and flow in coir-blended concrete.
17) **Swathika et al. (2017):** conducted an experimental study on the use of rice husk ash (RHA) as a partial replacement for cement and coconut coir fiber as reinforcement in concrete to improve its mechanical properties. The research aimed to utilize locally available, sustainable materials to reduce concrete production costs and manage agricultural waste. Various concrete mixes were prepared with RHA

replacing cement at different levels and coir added as fiber. The hardened concrete was tested for compressive strength, split tensile strength, and flexural strength. The results showed a significant improvement in all strength parameters, indicating that RHA and coir can together enhance the performance of concrete while promoting sustainable construction practices.

18) **Hameed et al. (2017):** investigated the mechanical properties of natural fiber-reinforced polyester composites using coconut fiber, rice husk, and rice husk ash. The study aimed to develop low-cost, eco-friendly composites with improved strength characteristics. Experimental analysis revealed that the composite containing polyester resin and rice husk ash provided the highest flexural strength, while coconut fiber contributed to overall improvement in mechanical behavior. The results confirmed the potential of using coconut fiber and rice husk derivatives as effective reinforcements in structural and non-structural composite applications. The study suggests future exploration into fiber orientation, treatment, and fiber-to-resin ratios for enhanced performance.
19) **Sadhu Prasanth and T. Suseela (2016):** investigated the use of natural waste materials—Rice Husk Ash (RHA) and Coconut Coir Fibers (CCF)—as partial cement replacements to enhance the flexural and split tensile strength of concrete intended for pavement construction. The study utilized controlled proportions of RHA and coir fibers as additives in conventional concrete mixtures. RHA, being a highly pozzolanic by-product of the paddy industry, was added due to its silica content and known durability benefits, while CCF was incorporated for its excellent mechanical and crack-bridging properties. Their experimental results demonstrated that the optimal enhancement in tensile and flexural strength was achieved at 16.5% RHA and 4% CCF, respectively. The authors concluded that the integration of RHA and CCF could be effectively used to produce strong, durable, and sustainable concrete pavements, contributing to both waste management and improved pavement performance.
20) **Mehta & Monteiro (2014):** Mehta and Monteiro, in their foundational textbook on concrete microstructure and properties, discussed the importance of controlled mix proportioning when combining fibers and pozzolanic materials. They emphasized that both materials alter the rheology of fresh concrete and demand careful balancing using superplasticizers and water reducers. Their comprehensive research supports the methodological framework of your thesis, particularly in managing slump and cohesiveness in hybrid RHA–fiber mixes.
21) **Jagannatha & Ramaswamy (2013):** In this study, Jagannatha and Ramaswamy examined the ductility and cracking behavior of concrete incorporating varying levels of coir fiber. They observed that 0.75% CCF provided the best balance between enhanced tensile strength and manageable workability. Their load–deflection curves clearly showed increased energy dissipation capacity, crucial for structures exposed to dynamic loads. This study further validates your selection of 0.75% CCF as a key fiber dosage level in your experimental matrix.
22) **Ali et al. (2012):** Ali and his team conducted experimental investigations on the split tensile behavior of concrete reinforced with natural fibers, including Coconut Coir Fiber (CCF). Their study found that the inclusion of 1% CCF enhanced split tensile strength by nearly 20% compared to conventional concrete. They attributed this improvement to the excellent bonding between coir fibers and the cementitious matrix, which helped bridge cracks and resist tensile failure. This research strongly supports your study's focus on split tensile testing and confirms the structural contribution of fiber reinforcement at higher percentages.
23) **Domke et al. (2011):** conducted an experimental investigation to assess the mechanical behavior of concrete using rice husk ash (RHA) as a partial replacement for cement and coir (coconut fiber) as natural reinforcement. RHA, a reactive pozzolanic by-product from the rice milling industry, was used to enhance concrete strength and reduce environmental impact. The study examined concrete mixes with various RHA contents and coir additions, observing that compressive strength began to decline beyond 12.5% RHA. However, the mix containing 15% RHA and coir fiber demonstrated the highest strength results. This optimal blend also showed potential for application in non-structural construction elements like wall panels and paving blocks, highlighting the effectiveness of combining agricultural waste materials for sustainable concrete production.
24) **Arulraj et al. (2011):** Arulraj and co-authors explored the impact resistance and crack propagation behavior of concrete containing CCF. They reported that the presence of coir fiber significantly improved the ability of concrete to absorb impact energy and delay the formation of surface cracks. The fibers effectively arrested crack growth, leading to longer fatigue life under cyclic loading conditions. This study is particularly relevant to your research on the flexural behavior of RHA–fiber concrete and its application in dynamic or impact-prone environments.

2.2 Gaps in Existing Literature

A review of the existing literature reveals a significant research gap concerning the combined use of Rice Husk Ash (RHA) and Coconut Coir Fiber (CCF) in M25 grade concrete. Although several studies have independently validated the pozzolanic activity of RHA and the reinforcing capability of CCF, limited research has investigated their synergistic influence on the mechanical and workability characteristics of medium-strength concrete such as M25. Most existing investigations tend to focus on either high-performance or low-strength concrete, often overlooking the practical mix proportioning and codal compliance requirements specific to M25-grade concrete. Additionally, detailed assessments of compressive, split tensile, and flexural strengths at both 7 and 28 days using standardized design procedures (IS 10262:2019 and IS 456:2000) are notably absent in prior research. Furthermore, the role of superplasticizers in improving the workability of fiber-reinforced RHA-modified mixes remains underexplored. Therefore, this study seeks to systematically evaluate the mediating effect of RHA on the performance of CCF-incorporated M25 concrete, with a focus on workability optimization and mechanical property enhancement under codal provisions. This investigation aims to contribute meaningful insights for sustainable rural and mid-scale construction practices.

3. Materials, Mix Design And Experimental Methodology

3.1 Introduction

This chapter outlines the materials used, the mix design methodology, and the step-by-step experimental procedures adopted for M25 grade concrete incorporating Rice Husk Ash (RHA) and Coconut Coir Fiber (CCF). The objective is to ensure consistency and repeatability in assessing mechanical and workability properties of modified concrete mixes for sustainable rural construction applications.

3.2 Materials Used

3.2.1 Cement

Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112:2013 was used. The cement was fresh and free from lumps with a specific gravity of 3.15.

3.2.2 Fine Aggregate

Locally available river sand passing through a 4.75 mm IS sieve and conforming to Zone II of IS 383:2016 was used. The specific gravity of the sand was 2.62.

3.2.3 Coarse Aggregate

Crushed angular coarse aggregates of 20 mm nominal size conforming to IS 383:2016 were used with a specific gravity of 2.88.

3.2.4 Water

Potable tap water, free from impurities and suitable for mixing and curing as per IS 456:2000, was used.

3.2.5 Rice Husk Ash (RHA)

RHA obtained from controlled burning of rice husk was sieved through a 90-micron sieve. The RHA used conformed to the physical requirements for pozzolanic materials and had a specific gravity of 2.10.

3.2.6 Coconut Coir Fiber (CCF)

Natural Coconut Coir Fibers with lengths of 10–30 mm were used. The fibers were pre-soaked and surface-dried before mixing. Specific gravity was 1.15.

3.2.7 Superplasticizer

A Polycarboxylate-based superplasticizer conforming to IS 9103:2021 was used at 0.5% by weight of binder to achieve desired workability.

3.3 Mix Design Methodology (IS 10262:2019)

The concrete mix for M25 grade was designed following IS 10262:2019, incorporating RHA as a partial replacement for cement (5%, 10%, and 15% by weight) and Coconut Coir Fiber at 0.5%, 0.75%, and 1.0% by volume of concrete. A control mix (Trial A1) without RHA and CCF was also prepared.

The target slump was 100 ± 25 mm with 2% entrapped air volume considered in volume batching. Mix design included 0.5% superplasticizer.

3.4 Experimental Trials and Specimen Casting

Ten mix combinations (A1 to A10) were prepared for M25 grade concrete with varying RHA and CCF levels. For each trial, 9 cubes of size 150 mm × 150 mm × 150 mm were cast.

Table 3.4A: Mix Design Variation – M25 Grade

Trial No.	*Description*	*RHA (%)*	*CCF (%)*
A1	M25 Control Mix	0	0
A2	M25 With RHA 5% + CCF 0.5%	5	0.5
A3	M25 With RHA 5% + CCF 0.75%	5	0.75
A4	M25 With RHA 5% + CCF 1.0%	5	1
A5	M25 With RHA 10% + CCF 0.5%	10	0.5
A6	M25 With RHA 10% + CCF 0.75%	10	0.75
A7	M25 With RHA 10% + CCF 1.0%	10	1
A8	M25 With RHA 15% + CCF 0.5%	15	0.5
A9	M25 With RHA 15% + CCF 0.75%	15	0.75
A10	M25 With RHA 15% + CCF 1.0%	15	1

Specimens were tested for:
Compressive Strength (7 and 28 days) as per IS 516:2021
Split Tensile Strength (7 & 28 days) as per IS 5816:1999
Flexural Strength (7 & 28 days) as per IS 516:2021
Workability (Slump) as per IS 1199:2018
Cubes were demoulded after 24 hours and cured in water at 27 ± 2°C.

3.5 The experimental program included the following tests

Compressive strength test was conducted on 150 mm × 150 mm × 150 mm cube specimens as per IS 516:2021 at 7 and 28 days of curing.

Split tensile strength test was performed on 150 mm diameter × 300 mm height cylindrical specimens following IS 5816:1999, tested at 7 & 28 days.

Flexural strength test was carried out on 100 mm × 100 mm × 500 mm prism specimens in accordance with IS 516:2021, at 7 & 28 days of curing.

Workability was assessed using the slump test on fresh concrete, following IS 1199:2018.

3.6 Summary Table

Table 3.6: Mix Design Parameter

Sr. No.	*Parameter*	*Value*
1	Grade of Concrete	M25
2	Type of Cement	OPC 53 Grade
3	Cement Content (kg/m³)	M25: 330
4	Maximum Nominal Aggregate Size	20 mm
5	Coarse Aggregate Fraction	20 mm (57%), 10 mm (43%)
6	Fine to Total Aggregate Ratio (FA:CA)	43:57:00
7	Specific Gravity of Cement	3.15
8	Specific Gravity of RHA	2.1
9	Specific Gravity of Fine Aggregate	2.62
10	Specific Gravity of Coarse Aggregate	2.88
11	Specific Gravity of Water	1
12	Specific Gravity of CCF	1.15
13	Specific Gravity of Superplasticizer	1.1

4. Results and Discussion

4.1 Introduction

This chapter presents and discusses the experimental results obtained from various concrete mixes developed using Rice Husk Ash (RHA) and Coconut Coir Fiber (CCF) in M25 grade concrete. A total of ten mix trials (A1 to A10) were prepared with varying proportions of RHA (0%, 5%, 10% & 15%) and CCF (0%, 0.5%, 0.75%, 1%). The results discussed include workability (slump), compressive strength, split tensile strength, and flexural strength. Comparisons are made between control and modified mixes to evaluate the effectiveness of RHA and CCF as sustainable cement replacement and reinforcement materials.

4.2 Mix Design Trial Basis Results & Observation

Given That: Refer to Table No. 3.4A

Trial No.	*Description*	*RHA (%)*	*CCF (%)*
A1	M25 Control Mix	0	0
A2	M25 With RHA 5% + CCF 0.5%	5	0.5
A3	M25 With RHA 5% + CCF 0.75%	5	0.75
A4	M25 With RHA 5% + CCF 1.0%	5	1
A5	M25 With RHA 10% + CCF 0.5%	10	0.5
A6	M25 With RHA 10% + CCF 0.75%	10	0.75
A7	M25 With RHA 10% + CCF 1.0%	10	1
A8	M25 With RHA 15% + CCF 0.5%	15	0.5
A9	M25 With RHA 15% + CCF 0.75%	15	0.75
A10	M25 With RHA 15% + CCF 1.0%	15	1

Trial A1: M25 With 0% RHA & 0% CCF

Table A1: Final Mix Design for M25 With 0% RHA & 0% CCF

Material	*Supplier*	Batch WT (1m³)/ kg	RHA %	CCF %	Water Adj.	*Batch WT (0.0334 m³)/ kg (Adj.)*
Cement OPC 53	Ultratech Cement Pvt. Ltd.	330	0%	0%	186+6% & After 20 % Reduce	11.02
RHA	Rice Mill Pvt. Ltd.	0				0
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	0				0
Fine Agge.	River Sand (Zone II	806.44				26.93
CA-20mm	Crusher Plant	669.96				22.37
CA - 10mm	Crusher Plant	505.41				16.88
Total		2471.19				82.53

Trial A2: M25 With 5% RHA & 0.5% CCF

Table A2: Final Mix Design for M25 With 5% RHA & 1.0% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	313.5	5%	0.5%	186+6% & After 20 % Reduce	10.48
RHA	Rice Mill Pvt. Ltd.	16.5				0.55
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	5.75				0.19
Fine Agge.	River Sand (Zone II	798.05				26.63
CA-20mm	Crusher Plant	662.88				22.11
CA - 10mm	Crusher Plant	500.06				16.7
Total		2456.64				81.96

Trial A3: M25 With 5% RHA & 0.75% CCF

Table A3: Final Mix Design for M25 With 5% RHA & 0.75% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	313.5	5%	0.75%	186+6% & After 20 % Reduce	10.47
RHA	Rice Mill Pvt. Ltd.	16.5				0.55
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	8.63				0.29
Fine Agge.	River Sand (Zone II	794.99				26.54
CA-20mm	Crusher Plant	660.58				22.06
CA - 10mm	Crusher Plant	498.33				16.63
Total		2451.91				81.80 kg

Trial A4: M25 With 5% RHA &1% CCF

Table A4: Final Mix Design for M25 With 5% RHA & 1.0% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	313.5	5%	1.0%	186+6% & After 20 % Reduce	10.47
RHA	Rice Mill Pvt. Ltd.	16.5				0.55
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	11.5				0.38
Fine Agge.	River Sand (Zone II	792.55				26.45
CA-20mm	Crusher Plant	658.12				21.98
CA - 10mm	Crusher Plant	496.47				16.57
Total		2447.02				81.73 kg

Trial A5: M25 With 10% RHA &0.5% CCF

Table A5: Final Mix Design for M25 With 10% RHA &0.5% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	297	10%	0.5%	186+6% & After 20 % Reduce	9.91
RHA	Rice Mill Pvt. Ltd.	33				1.1
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	5.75				0.19
Fine Agge.	River Sand (Zone II	794.96				26.54
CA-20mm	Crusher Plant	660.41				22.06
CA - 10mm	Crusher Plant	498.2				16.63
Total		2448.7				81.76 kg

Trial A6: M25 With 10% RHA &0.75% CCF

Table A6: Final Mix Design for M25 With 10% RHA & 0.75% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	297	10%	0.75%	186+6% & After 20 % Reduce	9.91
RHA	Rice Mill Pvt. Ltd.	33				1.1
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	8.625				0.29
Fine Agge.	River Sand (Zone II	792.29				26.46
CA-20mm	Crusher Plant	658.12				21.98
CA - 10mm	Crusher Plant	496.47				16.58
Total		2444.81				81.74 kg

Trial A7: M25 With 10% RHA &1.0% CCF

Table A7: Final Mix Design for M25 With 10% RHA & 1.0% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	297	10%	1.0%	186+6% & After 20 % Reduce	9.91
RHA	Rice Mill Pvt. Ltd.	33				1.1
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	11.5				0.38
Fine Agge.	River Sand (Zone II	789.41				26.36
CA-20mm	Crusher Plant	656.82				21.93
CA - 10mm	Crusher Plant	493.74				16.48
Total		2440.85				81.59 kg

Trial A8: M25 With 15% RHA &0.5% CCF

Table A8: Final Mix Design for M25 With 15% RHA & 0.5% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	280.5	15%	0.5%	186+6% & After 20 % Reduce	9.36
RHA	Rice Mill Pvt. Ltd.	49.5				1.65
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	5.75				0.19
Fine Agge.	River Sand (Zone II	792.29				26.46
CA-20mm	Crusher Plant	658.95				22.01
CA - 10mm	Crusher Plant	495.35				16.54
Total		2441.72				81.74 kg

Trial A9: M25 With 15% RHA &0.75% CCF

Table A9: Final Mix Design for M25 With 15% RHA & 0.75% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	280.5	15%	0.75%	186+6% & After 20 % Reduce	9.36
RHA	Rice Mill Pvt. Ltd.	49.5				1.65
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	8.625				0.29
Fine Agge.	River Sand (Zone II	789.41				26.37
CA-20mm	Crusher Plant	655.37				21.89
CA - 10mm	Crusher Plant	494.4				16.51
Total		2437.78				81.56 kg

Trial A10: M25 With 15% RHA & 1% CCF

Table A10: Final Mix Design for M25 With 15% RHA & 1.0% CCF

Material	Supplier	Batch WT (1m³)	RHA %	CCF %	Water Adj.	Batch WT (0.0334 m³/ kg) (Adj.)
Cement OPC 53	Ultratech Cement Pvt. Ltd.	280.5	15%	1.0%	186+6% & After 20 % Reduce	9.36
RHA	Rice Mill Pvt. Ltd.	49.5				1.65
Water	Water (tested)	157.73				5.27
Dosage (SP)	Supplier	1.65				0.055
CCF	Nigam ULB	11.5				0.38
Fine Agge.	River Sand (Zone II	786.52				26.27
CA-20mm	Crusher Plant	653.36				21.83
CA - 10mm	Crusher Plant	492.88				16.47
Total		2433.64				81.52 kg

Note: Refer to Appendix – (A1-A10) for Details Mix Design calculations.

4.2.1 Workability Test Results & Observation:

Table 4.2.1: – Slump Test Results (M25 Grade, Trials A1–A10)

Trial No.	*RHA (%)*	*CCF (%)*	*Measured Slump (mm)*	*Workability*
A1	0	0	102	Medium
A2	5	0.5	98	Medium
A3	5	0.75	95	Medium
A4	5	1	95	Medium
A5	10	0.5	94	Medium
A6	10	0.75	91	Medium
A7	10	1	88	Medium
A8	15	0.5	90	Medium
A9	15	0.75	87	Medium
A10	15	1	85	Medium

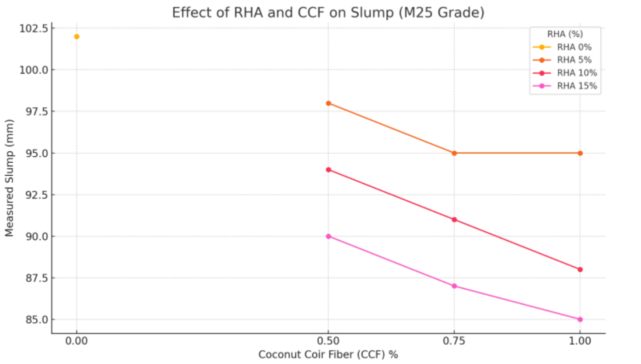

Figure 4.1: Effect of RHA & CCF on Slump – M25 Grade

Slump Observation

The line graph shows a consistent decrease in slump values with increasing Coconut Coir Fiber (CCF) content across all Rice Husk Ash (RHA) levels for M25 grade concrete. For the control mix (0% RHA), the slump reduced from 102 mm (at 0% CCF) to 95 mm (at 1% CCF). Similar downward trends are seen at 5%, 10%, and 15% RHA levels. This reduction is primarily due to the fibrous nature and high water absorption capacity of CCF, which impedes flow. Additionally, RHA's fine pozzolanic particles increase water demand, further reducing workability. Therefore, the combined use of RHA and CCF requires workability-enhancing measures such as superplasticizers.

4.2.2 Compressive Strength Results & Observation:

Table 4.2.2: Compressive Test Results (M25 Grade, Trials A1–A10)

Trial No.	RHA (%)	CCF (%)	7-Day Strength (MPa)	28-Day Strength (MPa)	Workability Class
A1	0	0	23.5	34.2	Medium
A2	5	0.5	24.2	36.5	Medium
A3	5	0.75	25.4	35.2	Medium
A4	5	1	23.8	32.0	Medium
A5	10	0.5	23.2	34.2	Medium
A6	10	0.75	22.5	32.9	Medium
A7	10	1	21.9	31.0	Medium
A8	15	0.5	21.5	30.4	Medium
A9	15	0.75	20.9	29.3	Medium
A10	15	1	20.2	28.6	Medium

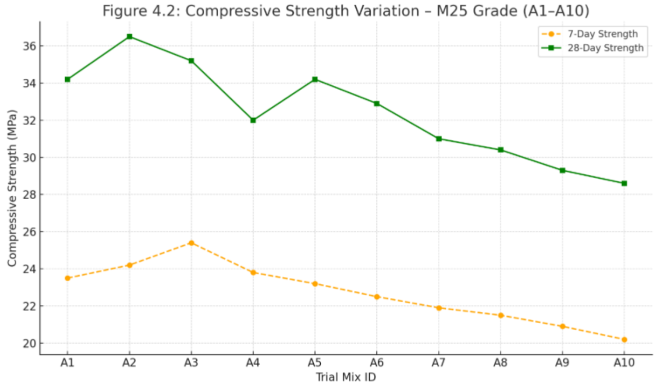

Figure 4.2: Compressive Strength – M25 Grade

Compressive Strength Observation

The compressive strength of M25 concrete shows noticeable variation across mixes incorporating RHA and CCF. The highest 28-day strength (36.5 MPa) was achieved in Trial A2 (5% RHA + 0.5% CCF), outperforming the control mix (34.2 MPa). This improvement is attributed to the pozzolanic reaction of RHA and micro-crack arresting by CCF at optimal dosage. Strength gradually declined with higher RHA and CCF content, reaching the lowest value (28.6 MPa) in A10 (15% RHA + 1% CCF). Nonetheless, all mixes surpassed the minimum 25 MPa requirement, confirming their structural adequacy. The findings suggest a need for optimal RHA-CCF combination for sustainable yet high-strength concrete.

4.2.3 Split Tensile Strength Results & Observation:

Table 4.2.3: Split Tensile Strength Results (M25 Grade, Trials A1–A10)

Trial No.	RHA (%)	CCF (%)	7-Day Tensile Strength (MPa)	28-Day Tensile Strength (MPa)
A1	0	0	1.92	2.84
A2	5	0.5	2.01	3.06
A3	5	0.75	2.08	3.14
A4	5	1	2.1	3.02
A5	10	0.5	2.06	3.12
A6	10	0.75	2.13	3.24
A7	10	1	2.09	3.1
A8	15	0.5	2.03	3.06
A9	15	0.75	2.04	3.09
A10	15	1	2.07	3.08

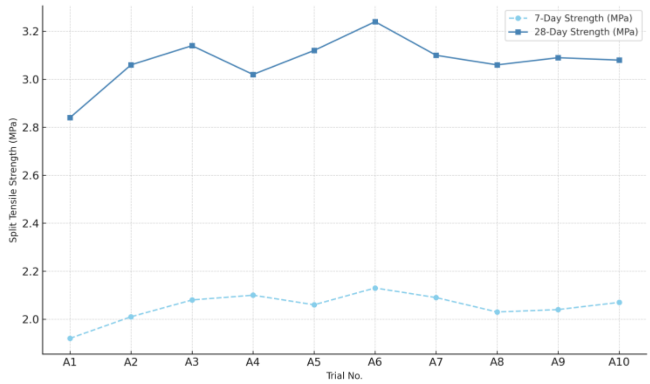

Figure 4.3: Split Tensile Strength – M25 Grade

Split Tensile Strength Observation

Split tensile results show improved tensile capacity with moderate RHA and CCF levels. The highest strength (3.24 MPa) was observed in A6 (10% RHA + 0.75% CCF), followed by A3 and A5. Compared to the control mix (2.84 MPa), moderate dosages enhanced tensile performance, likely due to fiber bridging effects and better particle packing from RHA. However, no significant gains were seen beyond 0.75% CCF or 10% RHA. All mixes met the standard tensile strength for M25, but optimization is essential for maximizing efficiency without overusing materials.

4.2.4 Flexural Strength Results & Observation:

Table 4.2.4: Flexural Strength Results (M25 Grade, Trials A1–A10)

Trial No.	*RHA (%)*	*CCF (%)*	*7-Day Flexural Strength (MPa)*	*28-Day Flexural Strength (MPa)*
A1	0	0	3.1	4.5
A2	5	0.5	3.4	5
A3	5	0.75	3.6	5.2
A4	5	1	3.2	4.8
A5	10	0.5	3.3	4.7
A6	10	0.75	3.1	4.5
A7	10	1	2.9	4.3
A8	15	0.5	2.8	4.1
A9	15	0.75	2.7	3.9
A10	15	1	2.6	3.8

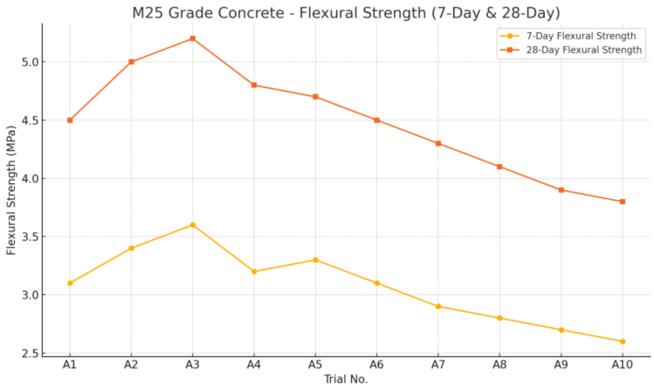

Figure 4.4: Flexural Strength – M25 Grade

Flexural Strength Observation

The highest 28-day flexural strength (5.2 MPa) was achieved in Trial A3 (5% RHA + 0.75% CCF), exceeding the control mix (4.5 MPa). Improvements at this level suggest optimal fiber reinforcement and enhanced matrix bonding due to fine RHA particles. However, strength declined at higher RHA and CCF levels, likely due to excessive porosity and fiber agglomeration, reducing stress distribution. The results confirm that controlled use of RHA and CCF enhances flexural strength, with diminishing returns beyond the optimal point.

Note: Refer to Appendix – Compressive, Split Tensile & Flexural Strength (B, C & D) for Details calculations.

5. Conclusion and Future Scope

5.1 Conclusion

This study aimed to evaluate the mechanical performance of M25 grade concrete incorporating varying proportions of Rice Husk Ash (RHA) as a partial cement replacement and Coconut Coir Fiber (CCF) as a reinforcing agent. The primary objective was to assess the feasibility of utilizing such eco-friendly materials for sustainable rural construction.

Based on experimental investigations, the following key conclusions were drawn:

1) The partial replacement of cement with 10% RHA and inclusion of 0.75% CCF significantly enhanced the compressive, flexural, and split tensile strengths at both 7 and 28 days compared to the control mix.
2) The addition of RHA led to improved matrix densification, contributing to higher strength development, particularly evident beyond 7 days.
3) The incorporation of Coconut Coir Fibers enhanced the post-cracking behavior, improving ductility and crack resistance, especially in flexural and tensile loading conditions.
4) The optimum combination (10% RHA + 0.75% CCF) offered a balanced workability (slump ~95 mm) along with considerable strength improvements, without adversely affecting handling or compaction.

In summary, the findings strongly advocate for the use of agro-waste-based materials like RHA and CCF as effective and sustainable alternatives in concrete. The developed concrete not only satisfies the structural requirements of M25 grade but also supports low-cost, eco-friendly infrastructure development, particularly suited for rural settings. Moreover, it contributes to waste valorization and a circular construction economy.

5.2 Future Scope

Based on the outcomes of the present investigation, the following directions are recommended for future research:

1) Long-term durability assessments such as resistance to sulfate attack, chloride ingress, and carbonation, to establish the suitability of RHA- and CCF-based concrete in aggressive environments.
2) Life cycle cost analysis and embodied carbon studies to evaluate the economic and environmental benefits over the full service life of the structure.
3) Field-scale trials and structural performance evaluations in practical rural applications, including low-rise housing, pavements, and irrigation systems.
4) Investigation of other agro-industrial waste materials (e.g., sugarcane bagasse ash, wheat straw ash, corn husk) to develop multi-blend sustainable concrete systems.
5) Exploration of higher-grade concretes (e.g., M30, M40) and the influence of fiber orientation and distribution under more complex structural loading conditions.

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Appendices

Mix Design Parameter for Appendix: -

Given That:

Table 3.6: Mix Design Parameter

Sr. No.	*Parameter*	*Value*
1.	Grade of Concrete	M25
2.	Type of Cement	OPC 53 Grade
3.	Cement Content (kg/m³)	M25: 330
4.	Maximum Nominal Aggregate Size	20 mm
5.	Coarse Aggregate Fraction	20 mm (57%), 10 mm (43%)
6.	Fine to Total Aggregate Ratio (FA:CA)	43:57:00
7.	Specific Gravity of Cement	3.15
8.	Specific Gravity of RHA	2.1
9.	Specific Gravity of Fine Aggregate	2.62
10	Specific Gravity of Coarse Aggregate	2.88
11	Specific Gravity of Water	1
12	Specific Gravity of CCF	1.15
13	Specific Gravity of Superplasticizer	1.1

Appendix A: Mix Design Calculations – M25 Grade with Table A.

Given That: Refer to Table No. 3.4A

Trial No.	*Description*	*RHA (%)*	*CCF (%)*
A1	M25 Control Mix	0	0
A2	M25 With RHA 5% + CCF 0.5%	5	0.5
A3	M25 With RHA 5% + CCF 0.75%	5	0.75
A4	M25 With RHA 5% + CCF 1.0%	5	1
A5	M25 With RHA 10% + CCF 0.5%	10	0.5
A6	M25 With RHA 10% + CCF 0.75%	10	0.75
A7	M25 With RHA 10% + CCF 1.0%	10	1
A8	M25 With RHA 15% + CCF 0.5%	15	0.5
A9	M25 With RHA 15% + CCF 0.75%	15	0.75
A10	M25 With RHA 15% + CCF 1.0%	15	1

Appendix A1: Mix Design Calculation – M25 Control Mix (0% RHA & 0% CCF):

Trial 1: Mix Design – M25 Control Mix (0% RHA& 0% CCF)

Given That: Refer to Table 3.6: Mix Design Parameters
- Design Basis: IS 10262:2019 (Absolute Volume Method)
- Target Slump: 100 ± 25mm
- Cement Content (Given): 330 kg/m³
- Superplasticizer Dosage: 0.5% by weight of binder
- Water Content: Adjusted for slump and SP as per IS code
- Air Content: 2% (entrapped)
- Aggregate Size: 20 mm (graded)
- Specific Gravities: Cement (3.15), Water (1.00), FA (2.62), CA (2.88), SP (1.10)

Step 1: Cement
- Cement Content: 330 kg/m³
- 0% RHA & 0% CCF

Step 2: Water Content Adjustment
- Base water content for 20 mm aggregate = 186 kg/m³
- Adjustment for 100 mm slump: 6% increase → 186 × 1.06 = 197.16 kg/m³
- After 20% reduction using Superplasticizer → 197.16 × 0.80 = 157.73 kg/m³

Step 3: Cement and Water-Cement Ratio
- Cement Content: 330 kg/m³
- Water-Cement Ratio = 157.73 / 330 = 0.478

Step 4: Admixture Content
- Superplasticizer Dosage = 0.5% of Cement = 330 × 0.005 = 1.65 kg/m³

Step 5: Volume of Each Material

Material	*Mass (kg/m³)*	*Specific Gravity*	*(Mass / SG x 1000) (m³)*	*Volume (m³)*
Cement	330	3.15	330 / 3150	0.1048
Water	157.73	1	157.73 / 1000	0.1577
Superplasticizer	1.65	1.1	1.65 / 1100	0.0015
Total				0.2640

Step 6: Volume Available for Aggregates
- Net Volume = 1.0 - 0.02 = 0.98 m³
- Volume Available for Aggregates = 0.980 - 0.2640 = 0.7160m³

Step 7: Aggregate Calculation
- Aggregate Weight = (Aggregates Volume x SG x 1000)
- Aggregate Proportioning
- Fine Aggregate Volume = (0.7160 x 43%) = 0.3078m³
- Fine Aggregate Weight = (0.3078 x 2.62 x 1000) = 806.44 kg/m³
- Coarse Aggregate Volume = (0.7160 x 57%) = 0.4081m³
- Coarse Aggregate Weight = (0.4081 x 2.88 x 1000) = 1175.38 kg/m³

Step 8: Coarse Aggregate Split (20 mm: 10 mm = 57: 43)
- 20 mm = (1175.38 x 57%) = 669.96 kg/m³
- 10 mm = (1175.38 x 43%) = 505.41 kg/m³

Step 9: Final Mix Design for M25 Control Mix Proportion

Sr. No.	Material	*Quantity (kg/m³)*
1.	Cement	330
2.	Water	157.73
3.	Superplasticizer	1.65
4.	Fine Aggregate	806.44
5.	Coarse Aggregate-20 mm	669.96
6.	Coarse Aggregate-10 mm	505.41
	Total	2471.19

Step 10: Lab Trial Batching (For 9 Cubes of 150 mm)
- Volume of one 150 mm cube = 0.15 × 0.15 × 0.15 = 0.003375 m³
- 9 cubes volume = 9 × 0.003375 = 0.030375 m³
- Add 10% extra for handling losses ⇒Trial batch volume = 0.0334 m³

Table A1: Final Mix Design forM25 Control Mix (Per m³) & Quantity for Lab Trial (0.0334 m³)

Sr. No.	Material	*Quantity (kg/m³)*	*Quantity For Trial Batching (kg/0.0334 m³)*
1.	Cement	330	11.02
2.	Water	157.73	5.27
3.	Superplasticizer	1.65	0.055
4.	Fine Aggregate	806.44	26.93
5.	Coarse Aggregate-20 mm	669.96	22.37
6.	Coarse Aggregate-10 mm	505.41	16.88
	Total	2471.19	82.53

Appendix A2: Mix Design Calculation – M25 With 5% RHA & 0.5% CCF

Trial 2: Mix Design – M25 With 5% RHA & 0.5% CCF

Given That: Refer to Table 3.6: Mix Design Parameters
- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement: 5% by weight of cement
- CCF Dosage: 0.5% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm

- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Step 1: Cementitious Material Composition
- Total Cementitious Material = 330 kg/m³
- Rice Husk Ash (5%) = 5% of 330 = 16.5 kg/m³
- Cement = 330 – 16.5 = 313.5 kg/m³

Step 2: Water Content Adjustment
- Base water content for 20 mm aggregate = 186 kg/m³
- Adjustment for 100 mm slump: 6% increase → 186 × 1.06 = 197.16 kg/m³
- After 20% reduction using Superplasticizer → 197.16 × 0.80 = 157.73 kg/m³

Step 3: Cement and Water-Cement Ratio
- Cement Content: 330 kg/m³
- Water-Cement Ratio = 157.73 / 330 = 0.478

Step 4: Admixture Content
- Superplasticizer Dosage = 0.5% of Cement = 330 × 0.005 = 1.65 kg/m³
- Step 5: Volume of CCF (0.5% by volume)
- Volume of CCF = 0.5% of 1 m³ = 0.005 m³
- Mass of CCF = 0.005 × 1.15 × 1000 = 5.75 kg/m³

Step 6: Volume of Each Material

Material	*Mass (kg/m³)*	*Specific Gravity*	*(Mass / SG x 1000) (m³)*	*Volume (m³)*
Cement	313.5	3.15	313.5 / 3150	0.0995
Water	157.73	1	157.73 / 1000	0.1577
RHA	16.5	2.1	16.5 / 2100	0.0079
Superplasticizer	1.65	1.1	1.65 / 1100	0.0015
CCF	5.75	1.15	5.75 / 1150	0.005
Total				0.2716

Step 7: Volume Available for Aggregates
- Net Volume = 1.0 - 0.02 = 0.98 m³
- Volume Available for Aggregates = 0.980 - 0.2716= 0.7084m³

Step 8: Aggregate Calculation
- Aggregate Weight = (Aggregates Volume x SG x 1000)
- Aggregate Split and Masses
- Fine Aggregate Volume = (0.7084x 43%) = 0.3046m³
- Fine Aggregate Weight = (0.3046x 2.62 x 1000) = 798.05 kg/m³
- Coarse Aggregate Volume = (0.7084x 57%) = 0.4038m³
- Coarse Aggregate Weight = (0.4038x 2.88 x 1000) = 1162.94 kg/m³

Step 9: Coarse Aggregate Split (20 mm: 10 mm = 57: 43)
- 20 mm = (1162.94x 57%) = 662.88 kg/m³
- 10 mm = (1162.94x 43%) = 500.07 kg/m³

Step 10: Final Mix Design for 1m³ of M25 Mix Proportion

Sr. No.	Material	*Quantity (kg/m³)*
1.	Cement	313.5
2.	RHA (5%)	16.5
3.	Water	157.73
4.	Superplasticizer	1.65
5.	CCF (0.5%)	5.75
6.	Fine Aggregate	798.05
7.	Coarse Aggregate – 20mm	662.88
8.	Coarse Aggregate – 10mm	500.06
	Total	2456.64

Step 11: Lab Trial Batching (For 9 Cubes of 150 mm)
- Volume of one 150 mm cube = 0.15 × 0.15 × 0.15 = 0.003375 m³
- 9 cubes volume = 9 × 0.003375 = 0.030375 m³
- Add 10% extra for handling losses ⇒Trial batch volume = 0.0334 m³

Table A2: Final Mix Design for M25 Mix with 5% RHA and 0.5% CCF (Per m³) & Quantity for Lab Trial (0.0334 m³):

Sr. No.	*Material*	*Quantity (kg/m³)*	*Quantity For Trial Batching (kg/0.0334 m³)*
1.	Cement	313.5	10.48
2.	RHA (5%)	16.5	0.55
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (0.5%)	5.75	0.19
6.	Fine Aggregate	798.05	26.63
7.	CA – 20mm	662.88	22.11
8.	CA – 10mm	500.06	16.7
	Total	2456.64	81.96 kg

Appendix A3: Mix Design Calculation – M25 With 5% RHA & 0.75% CCF
Trial 3: Mix Design – M25 With 5% RHA & 0.75% CCF
Given That: Refer to Table 3.6: Mix Design Parameters
- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement: 5% by weight of cement
- CCF Dosage: 0.75% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2.

Table A3: Final Mix Design for M25 With 5% RHA & 0.75% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	313.5	10.47
2.	RHA (5%)	16.5	0.55
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (0.75%)	8.63	0.29
6.	Fine Aggregate	794.99	26.54
7.	Coarse Aggregate – 20 mm	660.58	22.06
8.	Coarse Aggregate – 10 mm	498.33	16.63
	Total	2451.91	81.80 kg

Appendix A4: Mix Design Calculation – M25 With 5% RHA & 1.0% CCF

Trial 4: Mix Design – M25 With 5% RHA & 1.0% CCF

Given That: Refer to Table 3.6: Mix Design Parameters
- Given Mix Design Data: Refer to Table 9: Mix Design Parameters (Common for All Mixes)
- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement: 5% by weight of cement
- CCF Dosage: 1% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A4: Final Mix Design for M25 With 5% RHA & 1.0% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	313.5	10.47
2.	RHA (5%)	16.5	0.55
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (1.0%)	11.5	0.38
6.	Fine Aggregate	792.55	26.45
7.	Coarse Aggregate – 20 mm	658.12	21.98
8.	Coarse Aggregate – 10 mm	496.47	16.57
	Total	2447.02	81.69 kg

Appendix A5: Mix Design Calculation – M25 With 10% RHA & 0.5% CCF

Trial 5: Mix Design – M25 With 10% RHA & 0.5% CCF

Given That: Refer to Table 3.6: Mix Design Parameters
- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement: 10% by weight of cement
- CCF Dosage: 0.5% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A5: Final Mix Design for M25 With 10% RHA & 0.5% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	297	9.91
2.	RHA (10%)	33	1.1
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (0.5%)	5.75	0.19
6.	Fine Aggregate	794.96	26.54
7.	Coarse Aggregate – 20 mm	660.41	22.06
8.	Coarse Aggregate – 10 mm	498.2	16.63
	Total	2448.7	81.76 kg

Appendix A6: Mix Design Calculation – M25 With 10% RHA & 0.75% CCF

Trial 6: Mix Design – M25 With 10% RHA & 0.75% CCF

Given That: Refer to Table 3.6: Mix Design Parameters
- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement:10% by weight of cement
- CCF Dosage:0.75% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A6: Final Mix Design for M25 With 10% RHA & 0.75% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	297	9.91
2.	RHA (10%)	33	1.1
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (0.75%)	8.625	0.29
6.	Fine Aggregate	792.29	26.46
7.	CA – 20 mm	658.12	21.98
8.	CA – 10 mm	496.47	16.58
	Total	2444.81	81.74 kg

Appendix A7: Mix Design Calculation – M25 With 10% RHA & 1.0% CCF
Trial 7: Mix Design – M25 With 10% RHA & 1.0% CCF
Given That: Refer to Table 3.6: Mix Design Parameters
- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement:10% by weight of cement
- CCF Dosage:1.0% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A7: Final Mix Design for M25 With 10% RHA & 1.0% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	297	9.91
2.	RHA (10%)	33	1.1
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (1.0%)	11.5	0.38
6.	Fine Aggregate	789.41	26.36
7.	CA– 20 mm	656.82	21.93
8.	CA– 10 mm	493.74	16.48
	Total	2440.85	81.59 kg

Appendix A8: Mix Design Calculation – M25 With 15% RHA & 0.5% CCF

Trial 8: Mix Design – M25 With 15% RHA & 0.5% CCF

Given That: Refer to Table 3.6: Mix Design Parameters

- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement:15% by weight of cement
- CCF Dosage:0.5% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A8: Final Mix Design for M25 With 15% RHA & 0.5% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	280.5	9.36
2.	RHA (15%)	49.5	1.65
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (0.5%)	5.75	0.19
6.	Fine Aggregate	792.29	26.46
7.	CA – 20 mm	658.95	22.01
8.	CA – 10 mm	495.35	16.54
	Total	2441.72	81.74 kg

Appendix A9: Mix Design Calculation – M25 With 15% RHA & 0.75% CCF

Trial 9: Mix Design – M25 With 15% RHA & 0.75% CCF

Given That: Refer to Table 3.6: Mix Design Parameters

- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement:15% by weight of cement
- CCF Dosage:0.75% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A9: Final Mix Design for M25 With 15% RHA & 0.75% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	280.5	9.36
2.	RHA (15%)	49.5	1.65
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (0.75%)	8.625	0.29
6.	Fine Aggregate	789.41	26.37
7.	CA – 20 mm	655.37	21.89
8.	CA – 10 mm	494.4	16.51
	Total	2437.78	81.56 kg

Appendix A10: Mix Design Calculation – M25 With 15% RHA & 1.0% CCF

Trial 10: Mix Design – M25 With 15% RHA & 1.0% CCF

Given That: Refer to Table 3.6: Mix Design Parameters

- Design Basis: As per IS 10262:2019
- Target Slump: 100 ± 25 mm
- Cementitious Content: 330 kg/m³ (Total)
- RHA Replacement:15% by weight of cement
- CCF Dosage:1.0% by volume of concrete
- Superplasticizer: 0.5% of total cementitious content
- Entrapped Air: 2%
- Aggregate Size: 20 mm
- Specific Gravities: Cement (3.15), RHA (2.10), Water (1.00), FA (2.62), CA (2.88), SP (1.10), CCF (1.15)

Mix Design Calculation: - Same Procedure According to Appendix A2:

Table A10: Final Mix Design for M25 With 15% RHA & 1.0% CCF

Sr. No.	*Material*	*Qty (kg/m³)*	*Trial Qty (kg/0.0334 m³)*
1.	Cement	280.5	9.36
2.	RHA (15%)	49.5	1.65
3.	Water	157.73	5.27
4.	Superplasticizer	1.65	0.055
5.	CCF (1.0%)	11.5	0.38
6.	Fine Aggregate	786.52	26.27
7.	CA – 20 mm	653.36	21.83
8.	CA – 10 mm	492.88	16.47
	Total	2433.64	81.52 kg

Appendix B: Compressive Strength (A1–C10).

Compressive Strength Calculation Formula

- Compressive Strength (MPa) = (Load in kN × 1000) / (Area in mm²)

Where:

- Load in kN = Maximum applied load on the cube at failure (in kilonewtons)
- 1000 = Conversion factor to convert kilonewtons (kN) to newtons (N)
- Area in mm² = Cross-sectional area of the cube (usually 150 mm × 150 mm = 22500 mm²)

Table B: Compressive Strength Results – M25 Grade (A1–A10)

Compressive Strength (MPa) Formula = (Load in kN × 1000) / (Area in mm²)

Trial No.	Age (Days)	Cube 1 Load (kN)	Cube 2 Load (kN)	Cube 3 Load (kN)	Avg. Strength (MPa)
A1	7	526	531	529	23.5
A1	28	769	771	770	34.2
A2	7	543	544	546	24.2
A2	28	821	822	824	36.5
A3	7	571	573	572	25.4
A3	28	789	791	793	35.2
A4	7	535	534	536	23.8
A4	28	720	721	719	32
A5	7	521	523	522	23.2
A5	28	769	770	771	34.2

A6	7	504	507	508	22.5
A6	28	740	741	742	32.9
A7	7	493	491	492	21.9
A7	28	696	694	697	31
A8	7	484	485	482	21.5
A8	28	682	685	684	30.4
A9	7	470	471	470	20.9
A9	28	659	660	661	29.3
A10	7	454	455	454	20.2
A10	28	642	645	646	28.6

Appendix C: Split Tensile Strength (A1–C10) With Table.

Split Tensile Strength (MPa) Formula
- Split Tensile Strength (MPa) = (2 × P) / (π × L × D)

Where:
- P = Maximum applied load (in Newtons)
- L = Length of the cylinder specimen (in mm)
- D = Diameter of the cylinder specimen (in mm)
- π = 3.1416 (constant)

Note: For standard concrete cylinders as per IS 5816:1999 → D = 150 mm, L = 300 mm

So, for standard cylinders:
- Split Tensile Strength (MPa) = (2 × Load in N) / (3.1416 × 150 × 300)
  = Load in N / 70685.75

Or using load in kN directly:
- Split Tensile Strength (MPa) = (Load in kN × 1000) / 70685.75

Table C: Split Tensile Strength Results – M25 Grade (A1–A10)
Formula Split Tensile Strength (MPa) = (2 × P) / (π × L × D)

Or Split Tensile Strength (MPa) Formula = (Load in kN × 1000) / 70685.75

Trial No.	*Age (Days)*	*Load – Cube 1 (kN)*	*Load – Cube 2 (kN)*	*Load – Cube 3 (kN)*	*Avg. Strength (MPa)*
A1	7	138	136	137	1.92
A1	28	200	202	201	2.84
A2	7	145	143	144	2.01
A2	28	216	215	217	3.06
A3	7	150	152	151	2.08
A3	28	221	223	222	3.14
A4	7	152	154	153	2.1
A4	28	213	212	214	3.02
A5	7	149	150	151	2.06
A5	28	219	220	218	3.12
A6	7	154	153	155	2.13
A6	28	227	225	226	3.24
A7	7	151	150	152	2.09
A7	28	217	216	219	3.1
A8	7	147	146	145	2.03
A8	28	215	213	214	3.06
A9	7	148	149	147	2.04
A9	28	216	218	217	3.09
A10	7	150	151	150	2.07
A10	28	215	216	217	3.08

Appendix D: Flexural Strength – M25 Grade (A1–C10) With Table.
- Flexural Strength (MPa) Formula = (P × L) / 4(b × d²)

Where:
- P = Fracture load in NL = Span length (typically 400 mm)
- b = Width of specimen (usually 100 mm)
- d = Depth of specimen (usually 100 mm)

Table D: Flexural Strength Results – M25 Grade (A1–A10)
Flexural Strength (MPa) Formula (Three-Point Loading as per IS 516:2021):

Formula = (P × L) / 4(b × d²)

Trial	*Age (Days)*	*Load – Specimen 1 (kN)*	*Load – Specimen 2 (kN)*	*Load – Specimen 3 (kN)*	*Avg. Load (kN)*	*Flexural Strength (MPa)*
A1	7	30.9	31	31.1	31	3.1
A1	28	44.9	45	45.1	45	4.5
A2	7	33.9	34	34.1	34	3.4
A2	28	49.9	50	50.1	50	5
A3	7	35.9	36	36.1	36	3.6
A3	28	51.9	52	52.1	52	5.2
A4	7	31.9	32	32.1	32	3.2
A4	28	47.9	48	48.1	48	4.8
A5	7	32.9	33	33.1	33	3.3
A5	28	46.9	47	47.1	47	4.7
A6	7	30.9	31	31.1	31	3.1
A6	28	44.9	45	45.1	45	4.5
A7	7	28.9	29	29.1	29	2.9
A7	28	42.9	43	43.1	43	4.3
A8	7	27.9	28	28.1	28	2.8
A8	28	40.9	41	41.1	41	4.1
A9	7	26.9	27	27.1	27	2.7
A9	28	38.9	39	39.1	39	3.9
A10	7	25.9	26	26.1	26	2.6
A10	28	37.9	38	38.1	38	3.8

Equation 1: Target Mean Strength Calculations.

$f_{ck}' = f_{ck} + 1.65 \times S$
Where:
- fck = Characteristic compressive strength (e.g., 25 MPa, 30 MPa, 40 MPa)
- S = Standard deviation as per Table 2 of IS 10262:2019 (for field control “good” → S = 4, “fair” → S = 5, “poor” → S = 5)

Table 1: Target Mean Compressive Strengths as per IS 10262:2019

Grade	fck Mpa	Standard Deviation (S)	Target Mean Strength = (fck + 1.65 x S)
M25	25	4	31.6