Experimental Investigation on Rice Husk Ash Blended Concrete Performance in Terms of Compressive Strength

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ABSTRACT: Concrete is the most widely used construction material globally, but its production relies heavily on Portland cement, contributing to significant CO_2 emissions and creating a substantial environmental burden. Rice husk ash (RHA), an abundant agricultural by-product with high silica content and pozzolanic potential, presents a promising opportunity for partial cement replacement, offering environmental and economic benefits. This study investigates the partial replacement of cement with RHA in concrete mixes, evaluating its effect on compressive strength. Concrete specimens were prepared with 0%, 5%, 10%, 15%, and 20% RHA replacement levels by weight, and compressive strength tests were conducted at 7 and 28 days. The gradual decrease in compressive strength with increasing RHA content is evident in the data. For the 28-day strength, the control mix registered 22.73 MPa, while the 5% RHA mix had 19.30 MPa, and the 20% RHA mix reported 13.92 MPa. Strength performance is optimal with a 5% replacement level, which is the closest to the control. This suggests the partial replacement of cement with RHA up to 5% is reasonably attainable, especially considering the marked reduction in cement content, which translates to a reduction in CO2 emissions, the recycling of agricultural waste, and the primary mechanical performance.

KEYWORDS: Compressive Strength, Partial Cement Replacement, Pozzolanic Material, Rice Husk Ash, Sustainable Concrete, Waste Utilization.

1. INTRODUCTION

The worldwide usage of concrete has grown exponentially, even if its production takes a hefty toll on the environment by relying on Portland cement, which accounts for a massive percentage of CO_2 emissions (Vijaya, Jagadeeswari, and Srinivas 2020)(Zareei et al. 2017)(Bixapathi and Saravanan 2022).Concerned about the sustainability of the construction industry, the limited use of cement due to its pozzolanic properties is being actively researched (Vijaya, Jagadeeswari, and Srinivas 2020)(Cavalcante et al. 2018). Incorporating such materials certainly advances the industry in terms of sustainability since it decreases cement usage as well as the cement industry's carbon footprint (Jayaraman et al. 2023)(Zareei et al. 2017). As an agricultural by-product, rice husk ash (RHA) has even more potential use as an admixture to concrete due to its high pozzolanic silica content, availability, and global production (Lo, Lee, and Lo 2021)(Ozturk et al. 2020)(Rajashekhar Reddy, Harihanandh, and Murali 2021). The use of RHA, which is a by-product of the open burning of rice husks, will help in environmental sustainability of concrete production as well as RHA's carbon negative status (Alex, Dhanalakshmi, and Ambedkar 2016)(Zareei et al. 2017). This practice minimizes the use of cement which in turn lowers the emission of CO_2, using agro-waste like RHA, and converting a useless product into a useful one which reduces waste in landfills (Vijaya, Jagadeeswari, and Srinivas 2020)(Mayooran, Ragavan, and Sathiparan 2017) (Alex, Dhanalakshmi, and Ambedkar 2016).

From an environmental perspective, the cement industry's CO_2 emissions and the subsequent production of concrete remains an environmental concern (Zareei et al. 2017)(Ali et al. 2021). This is because the construction industry remains overdependent on cement, which has a high carbon footprint (Mayooran, Ragavan, and Sathiparan 2017) (Zareei et al. 2017)(Tutur et al. 2023). This is of particular importance of developing countries, since RHA can be a low-cost, locally available alternative (Mayooran, Ragavan, and Sathiparan 2017)(Jayaraman et al. 2023)(Igba et al. 2019). For developing countries, this contributes to waste elimination and CO_2 emissions (Wang and Lee 2020) (Tutur et al. 2023). In addition, the concrete's mechanical performance

may be compromised, since little is known regarding RHA's optimal replacement levels (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018). RHA use helps reduce CO_2 cement production and has been said to provide "economic and environmental benefits that encourage the use of high-carbon RHA" (Mayooran, Ragavan, and Sathiparan 2017)(Zareei et al. 2017).

Some prior studies did recognize the characteristics of RHA regarding its chemical, physical, and particle size properties, confirming its pozzolanic reactivity (Vijaya, Jagadeeswari, and Srinivas 2020) (Alex, Dhanalakshmi, and Ambedkar 2016)(Chia et al. 2020).RHA has 8590% amorphous silica, demonstrating its pozzolanic reactivity ability (Zareei et al. 2017) (Bixapathi and Saravanan 2022).An example of RHA having high silica content is 96.44% SiO_2 at calcination of 550°C, with high amorphous silica further enhancing pozzolanic reactions as well as C-S-H gel formation (Lo, Lee, and Lo 2021)(Hussein et al. 2025)(Samad et al. 2022).The pozzolanic activity of RHA enables the formation of C-S-H gel, which enhances strength, durability, and reduces the voids (Chia et al. 2020)(Samad et al. 2022).A number of studies have documented the improvements on compressive strength attributed to RHA and the partial replacement of cement, typically around the 10% replacement mark which resulted in strength enhancements of 19.6% at 28 days (Hussein et al. 2025)(Krishna, Sandeep, and Mini 2016).Moreover, other researches report optimal replacement values to be between 5% and 15% (Zareei et al. 2017)(Fapohunda, Akinbile, and Shittu 2017).As an example, one study confirmed that a 10% RHA replacement increased compressive strength, while replacements beyond 10% led to a reduction due to a porous structure (Ozturk et al. 2020). Research on paver blocks similarly confirms that an optimal RHA content of 10–15% can improve strength while maintaining performance (Kumar and Gopi 2022).Reported benefits include improved compressive strength at optimal partial replacement levels and a reduced heat of hydration (Wang and Lee 2020)(Chia et al. 2020).

Moreover, the current state of the art incorporates contradictions at the empirical level of high replacement and the exploration of the 'ever-lasting' literature at the performance and durability levels in the following studies(Ma et al. 2023)(Syahida Adnan et al. 2021).The prominent gap and limitation of the research done is explaining RHA, in all its forms, above higher replacement levels, as the results are inconsistent starting above 10-20% in the literature (Mayooran, Ragavan, and Sathiparan 2017)(Hussein et al. 2025) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018).The absence of a broader performance range and prolonged durability respectively, in the literature is noticed as most studies have been done with the 7/28 day curing and hence not field-based studies (Vijaya, Jagadeeswari, and Srinivas 2020) (Lo, Lee, and Lo 2021)(Ma et al. 2024) (Tutur et al. 2023).Significant research topics have been insufficiently covered, notably the durability and long-range performance of a concrete or compound, as most research is confined to certain concrete grades and/or relatively brief testing periods(Bixapathi and Saravanan 2022) (Rajashekhar Reddy, Harihanandh, and Murali 2021)(Igba et al. 2019).Furthermore, there is a lack of consensus on sustainable replacement thresholds that do not compromise concrete performance, particularly concerning the trade-off between strength gain and potential permeability reduction at higher replacement levels(Hussein et al. 2025)(Khankhaje et al. 2025). Many studies are limited to specific concrete grades or lack long-term durability data, such as tests for sulfate attack or freeze-thaw cycles, and some research is focused on specialized applications like radiation shielding or evaluating fresh properties for 3D printing concrete without assessing compressive strength, leaving a gap in comprehensive mechanical property analysis for standard structural concrete(Jayaraman et al. 2023)(Alrowaili et al. 2024)(Syahida Adnan et al. 2021)(Samad et al. 2022). A significant research gap identified is the limited data on reinforced concrete behavior, such as the shear or bending responses of RHA beams and slabs, necessitating further research(Fapohunda, Akinbile, and Shittu 2017).

Furthermore, numerous investigations concluded that a key limitation is the lack of clarity on the behavior of RHA at higher replacement levels, with studies showing a linear strength reduction beyond 10-15%(Krishna, Sandeep, and Mini 2016)(Igba et al. 2019). This results in no clear consensus on sustainable replacement thresholds that do not compromise concrete performance(Hussein et al. 2025) (Ma et al. 2023). This study aims to contribute to filling this gap by assessing the effects of various RHA replacement levels on the compressive strength of concrete. The aim of the current study is to assess the effects of RHA replacement levels—specifically 0%, 5%, 10%, 15%, and 20%—on the compressive strength of concrete(Cavalcante et al. 2018). The scope is laboratory-based, focusing on tests for 7-day and 28-day compressive strength only, with durability, shrinkage, and field performance excluded(Bixapathi and Saravanan 2022) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018)(Igba et al. 2019). The ultimate goal is to identify the optimal sustainable replacement level of RHA in cement without compromising strength, thereby contributing to cost savings, waste utilization, and reduced environmental impact(Vijaya, Jagadeeswari, and Srinivas 2020) (Krishna, Sandeep, and Mini 2016).

2. METHODOLOGY

An experimental research design was utilized in this investigation which sought to ascertain the impact of the partial replacement of cement with Rice Husk Ash (RHA) on concrete's compressive strength. Methodologies involved the preparation of the materials, design of the mixes, casting and curing of the specimens, and the testing followed the relevant international standards.

2.1 Materials

The choices for the materials in this study were made with ASTM, IS, and BS standards in mind, and the primary binder used was Ordinary Portland Cement (OPC) from the stallion brand. The Rice Husk Ash (RHA) was obtained from Laghman Province, burnt in an RHA oven, and pure ash was taken to the Khurasan University laboratory. For processing the RHA, a No. 4 sieve (4.75 mm) was used and then the RHA was ground to attain a fine particle size for increased pozzolanic activity. Other studies have also used RHA which was sieved, for example, at <125μm (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018), <20μm (Wang and Lee 2020), or <90μ (Mukilan et al. 2020), and frequently ground to improve reactivity. Fine and coarse aggregates were obtained from Sara Road District, Zangal Bagh. The coarse aggregate size was 20 mm and the Los Angeles abrasion value was 24.36%. The mixing and curing water was potable borewell water obtained from Khurasan University.

2.2 Mix Proportions

The mix design was conducted using the ACI Method 318. A constant water-cement ratio of 0.5 was maintained for all mixes. Cement was partially replaced with RHA at levels of 0% (control), 5%, 10%, 15%, and 20% by weight. One trial mix was conducted for each proportion. For each mix, six cylindrical specimens (150 mm diameter × 300 mm height) were cast: three were designated for testing at 7 days and three at 28 days. The detailed mix proportions and measured slump values are presented in Table 1. The mix designs in other reviewed studies also commonly tested replacement levels up to 20-30%(Wang and Lee 2020) (Tutur et al. 2023).

Table 1:Mix Proportions of Concrete Specimens with Partial Replacement of Cement by Rice Husk Ash (RHA)

Specimen ID	Description	Cement (kg)	RHA as Cement (kg)	Cement Replacement (%)	Water/Cement Ratio (%)	Gravel (kg)	Sand (kg)	Total Batch Mass (kg)
M1	Control (0% RHA)	10.61	0	0	0.5	36.8	29.28	76.69
M2	5% RHA replacement	10.08	0.53	5	0.5	36.8	29.28	76.69
M3	10% RHA replacement	9.55	1.06	10	0.5	36.8	29.28	76.69
M4	15% RHA replacement	9.02	1.59	15	0.5	36.8	29.28	76.69
M5	20% RHA replacement	8.49	2.12	20	0.5	36.8	29.28	76.69

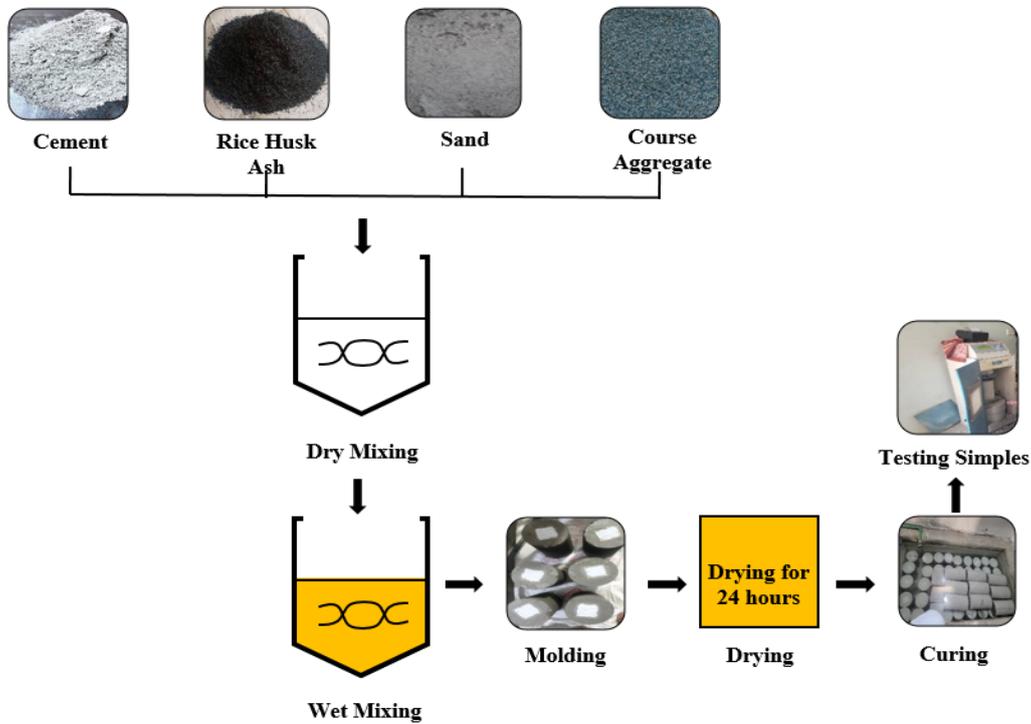## 2.3 Experimental Program and Test Procedures

Figure 1: Schematic Diagram for Rice Husk Ash Mixed Concrete Simples

2.3.1 Batching, Mixing, and Workability Testing

All materials were measured by weight in kilograms. Mixing was performed manually following a specific sequence: coarse aggregate was added first, followed by fine aggregate, then cement, with dry mixing conducted before the addition of water. Mixing continued until a uniform consistency was achieved. The workability of each fresh concrete mix was assessed immediately after mixing using the slump cone test in accordance with ASTM C143. The tests were conducted at an ambient temperature of approximately 25 °C. The results, as shown in Table 1, indicated slump values of 25.4 mm for mixes M1 through M3 and 50.8 mm for mixes M4 and M5.
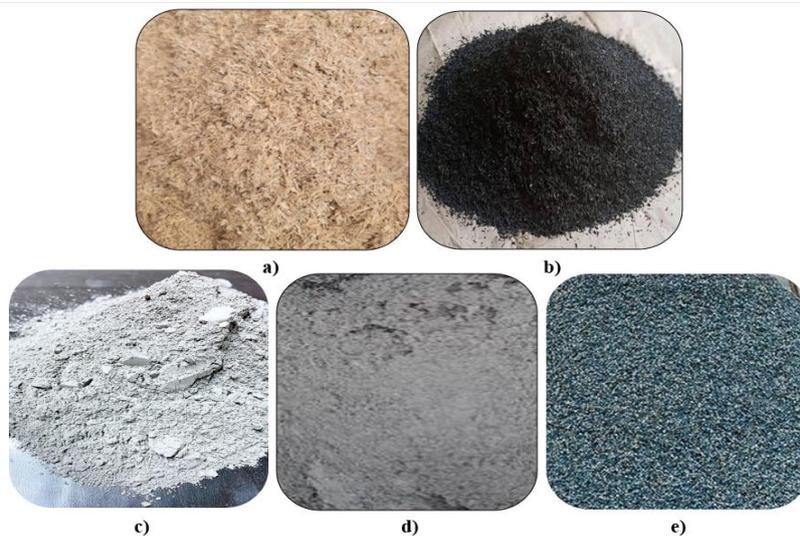

Figure 2:Materials: a) Raw Rice Husk, b) Rice Husk Ash, c) Cement ,d) Sand and e) Coarse Aggregate

2.3.2 Casting, Compaction, and Curing

The concrete was then cast into cylindrical molds (150 mm diameter × 300 mm height) and compacted manually to remove voids. The specimens were kept in their molds for more than 24 hours before demolding. After demolding, the specimens were cured in water tanks at the Khurasan University laboratory. The curing water temperature was maintained at 25 ± 3 °C for the specified durations of 7 and 28 days.

2.3.3 Compressive Strength Testing

The compressive strength was determined using a digital compression testing machine following the procedures outlined in ASTM C39. The loading rate was applied as per the ASTM specifications. Testing was performed on the cylindrical specimens after 7 and 28 days of curing. Three specimens from each mix were tested at each age, and the results were averaged. The compressive strength results are summarized in Table 3.

Figure 3:a) Specimen during compressive Strength testing, b) Specimen after testing and d) Specimen in curing tank.

2.3.4 Additional Observations and Environmental Conditions

No cracks, segregation, or other anomalies were reported during the mixing, casting, curing, or testing phases. There were no deviations from the planned standards or procedures. All laboratory activities were conducted at a stable ambient temperature of approximately 25 °C.

3. RESULTS AND DISCUSSION

3.1 Scope of Tests

Five concrete mixes were tested, corresponding to RHA replacement levels of 0% (control), 5%, 10%, 15%, and 20% by weight of cement. The properties evaluated included workability (slump test) and compressive strength at 7 and 28 days. The mix identification was based on the RHA replacement percentage (M1 for 0% RHA, M2 for 5% RHA, etc.).

3.2 Workability (Slump)

The workability of the fresh concrete mixes, measured by the slump test, showed a notable trend across the replacement levels. The slump value remained consistent at 25.4 mm for the control mix (0% RHA) and mixes with 5% and 10% RHA replacement. However, a significant increase in slump to 50.8 mm was observed for mixes with 15% and 20% RHA. This increase in workability at higher replacement percentages contrasts with the general trend noted in the literature, where RHA's high surface area typically leads to a reduction in workability(Kumar and Gopi 2022) (Rajashekhar Reddy, Harihanandh, and Murali 2021). The observed trend is consistent with a study that noted the use of a superplasticizer to maintain workability in mixes containing blended pozzolans (Vijaya, Jagadeeswari, and Srinivas 2020). Another study also emphasized adjusting water content to maintain a fixed slump when incorporating RHA (Mayooran, Ragavan, and Sathiparan 2017). The anomalous result in this study may be attributed to variations in the water demand, the specific particle morphology, the water-reducing agents used in the mix design, or the specific characteristics of the RHA used(Cavalcante et al. 2018) (Bixapathi and Saravanan 2022).

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Table 2: Slump flow with RHA incorporation

Specimen ID	Description	Slump Flow (mm)
M1	M1(0% RHA)	25.4
M2	M2(5% RHA)	25.4
M3	M3(10% RHA)	25.4
M4	M4(15% RHA)	50.8
M5	M5(20% RHA)	50.8
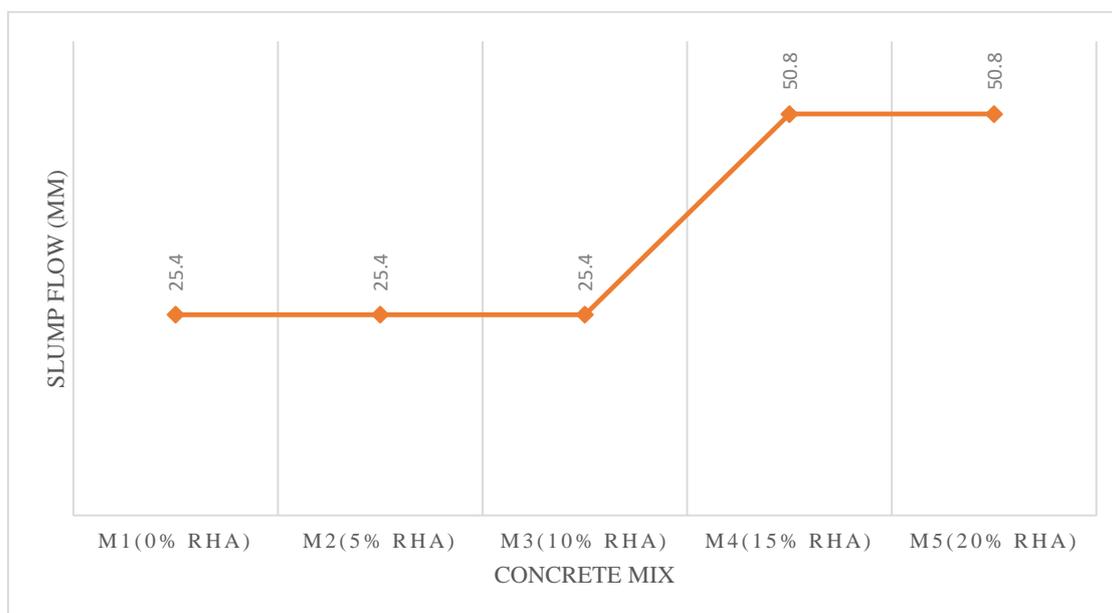
Figure 4: Slump flow of concrete with Different Replacement levels of RHA

3.3 Compressive Strength

3.3.1 Numerical Trends

The compressive strength results for all mixes at 7 and 28 days are summarized in Table 3. A progressive decrease in strength was observed with increasing RHA content at both testing ages. The 7-day compressive strength dropped from 14.10 MPa for the control mix (0% RHA) to 5.98 MPa for the mix with 20% RHA. Similarly, the 28-day strength decreased from 22.73 MPa (0% RHA) to 13.92 MPa (20% RHA). The results indicate that even a 5% replacement (M2) led to a reduction in strength, with values of 10.80 MPa at 7 days and 19.30 MPa at 28 days, though this reduction was minimal compared to higher replacement levels.

Table 3:Compressive Strength Test Results

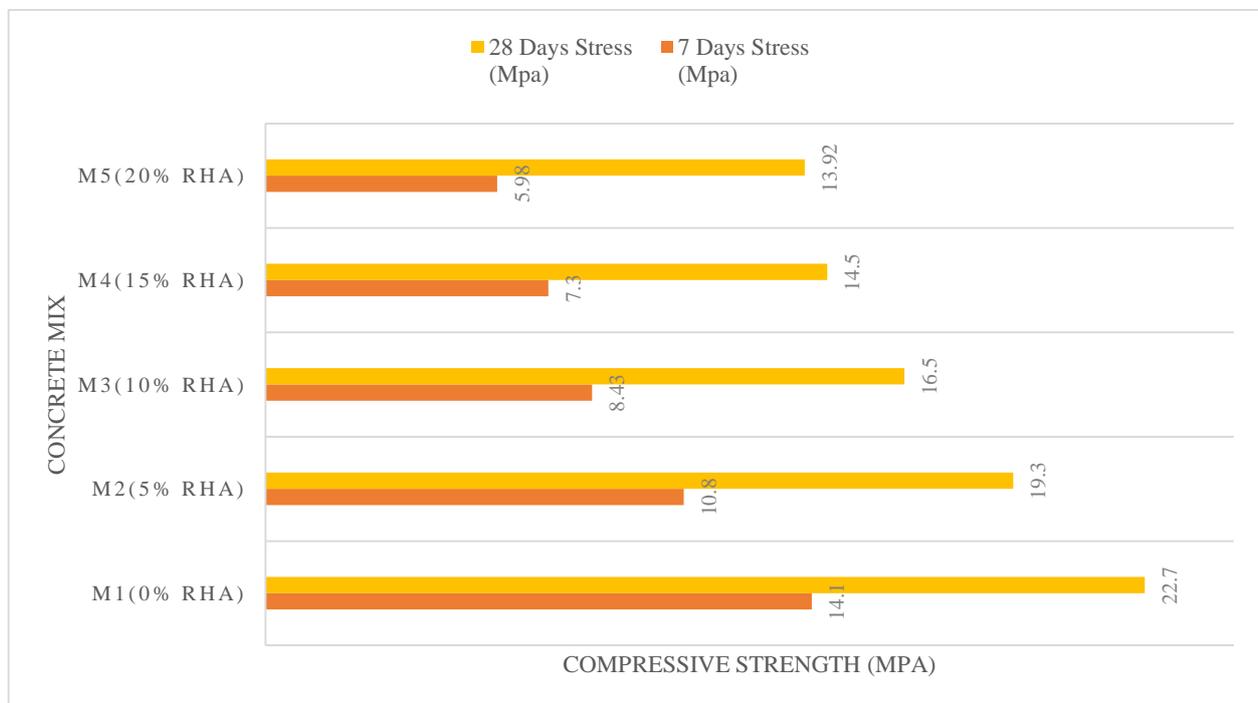| Specimen ID	Replacement Materials by RHA	Days	Stress (Mpa)	Days	Stress (Mpa)
M1	M1(0% RHA)		14.1		22.7
M2	M2(5% RHA)		10.8		19.3
M3	M3(10% RHA)	7	8.43	28	16.5
M4	M4(15% RHA)		7.3		14.5
M5	M5(20% RHA)		5.98		13.92

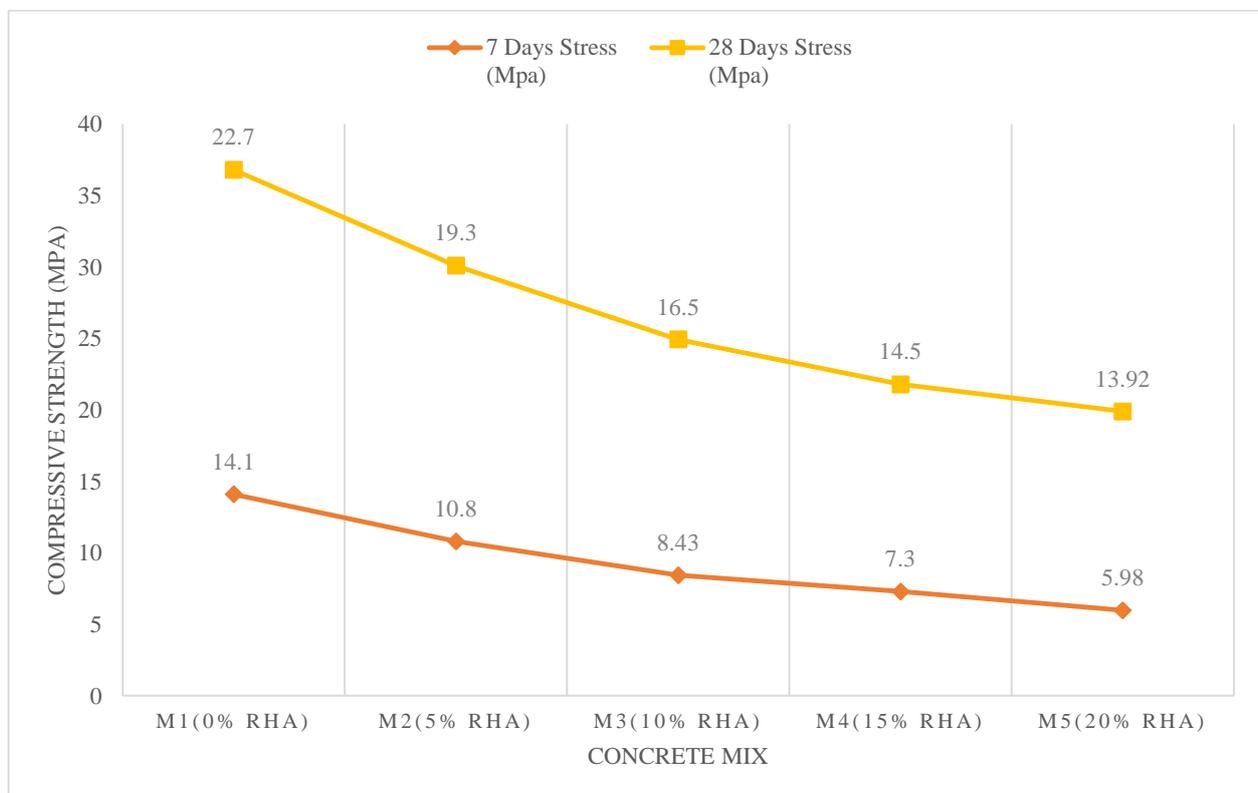**Figure 5: Compressive Strength of RHA Concrete Mixes at 7 and 28 Days**

Figure 6: Strength Reduction from Control (Rice Husk Ash)
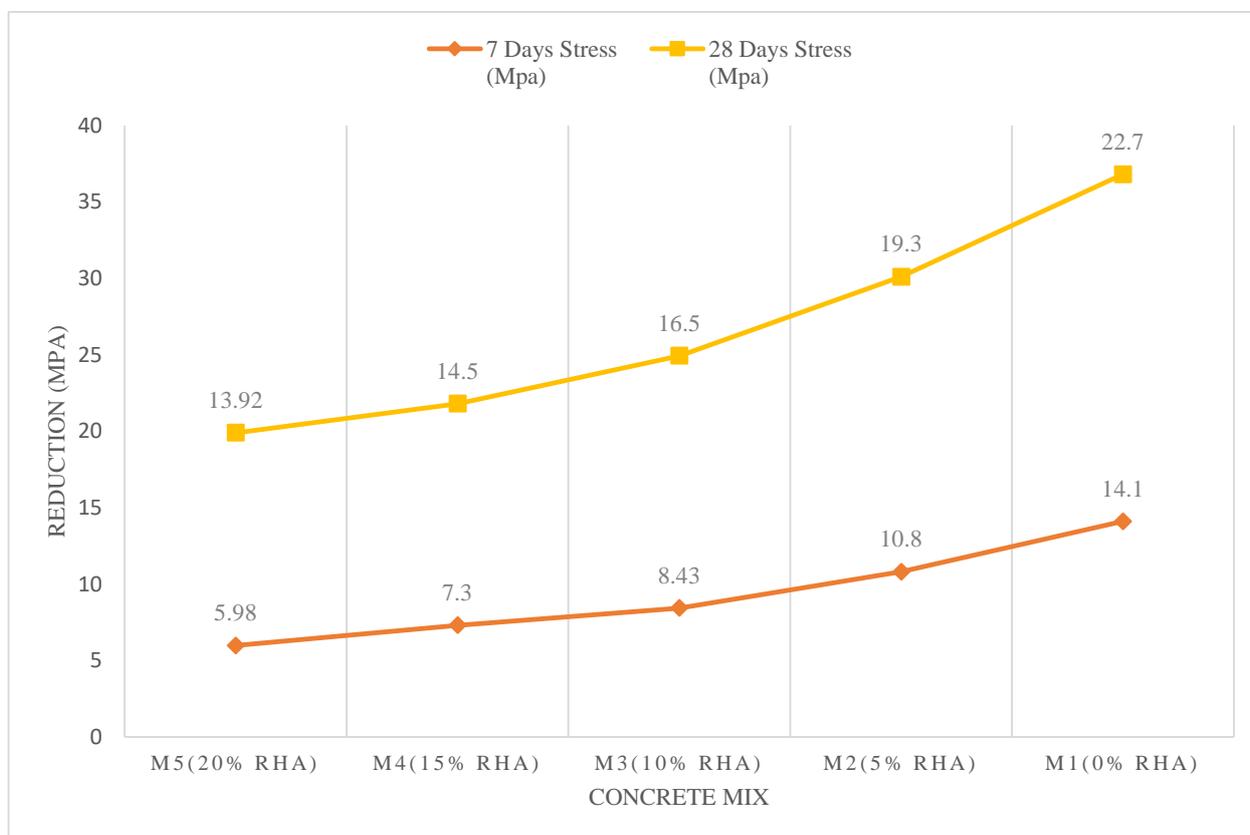
Figure 7: Strength Trend vs Rice Husk Ash %

Table 4:Optimal Replacement Levels of Cement with Rice Husk Ash (RHA)

Specimen ID	Description	Cement Replacement (%)	7-day Strength (MPa)	28-day Strength (MPa)	7-day % of Control	28-day % of Control	Strength Retention Index (mean of 7d & 28d %)	Remarks
M1	Control (0% RHA)	0	14.1	22.7	100	100	100	Reference mix
M2	5% RHA replacement	5	10.8	19.3	76.6	76.6	47.9	Low strength retention
M3	10% RHA replacement	10	8.43	16.5	59.8	59.8	38.1	Low strength retention
M4	15% RHA replacement	15	7.3	14.5	51.8	51.8	33.1	Highest retention among replacements
M5	20% RHA replacement	20	5.98	13.92	42.4	42.4	28.2	Second-best retention

Table 5:Percentage Reduction in Compressive Strength at 7 and 28 Days

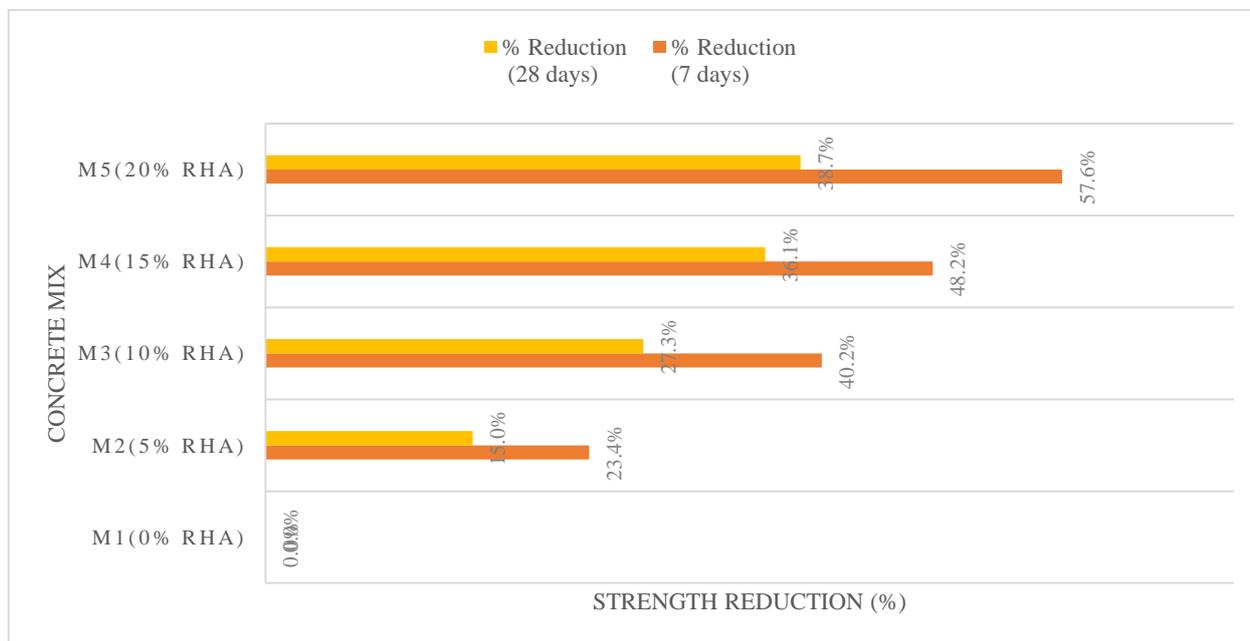| Specimen ID	Replacement Materials by RHA	7-day Strength (MPa)	28-day Strength (MPa)	% Reduction (7 days)	% Reduction (28 days)
M1	M1(0% RHA)	14.1	22.7	0.0%	0.0%
M2	M2(5% RHA)	10.8	19.3	23.4%	15.0%
M3	M3(10% RHA)	8.43	16.5	40.2%	27.3%
M4	M4(15% RHA)	7.3	14.5	48.2%	36.1%
M5	M5(20% RHA)	5.98	13.92	57.6%	38.7%

Figure 8:Percentage Reduction in Compressive Strength at 7 and 28 Days

3.3.2 Mechanism and Explanation

The reduction in compressive strength with higher RHA content is primarily attributed to the dilution effect, where cement, the primary binding agent, is partially replaced by a less reactive material, and the slower pozzolanic activity of RHA compared to the immediate hydration of cement(Vijaya, Jagadeeswari, and Srinivas 2020) (Bixapathi and Saravanan 2022) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018). Although RHA possesses pozzolanic properties, its reaction with calcium hydroxide is slower than the primary hydration of cement, leading to lower early-age strength gains(Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018) (Wang and Lee 2020). The high silica content and pozzolanic reactivity of RHA contribute to secondary reactions that form additional C-S-H gel, but this process is more time-dependent(Vijaya, Jagadeeswari, and Srinivas 2020) (Hussein et al. 2025). The minimal strength loss observed at the 5% replacement level indicates a balance where the pozzolanic benefits partially offset the dilution effect, making it a tolerable partial replacement (Vijaya, Jagadeeswari, and Srinivas 2020) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018).

3.3.3 Comparison with Literature

The finding that a 5% RHA replacement maintains strength close to the control mix aligns with several studies(Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018). For instance, one investigation reported that a 5% replacement of cement by RHA and Bamboo Leaf Ash (BLA) resulted in a 1.84% strength increase at 28 days(Munish and Mehta 2024). This supports the consensus that moderate RHA substitution ($\leq 10\%$) can maintain acceptable strength (Zareei et al. 2017)(Khankhaje et al. 2025)(Krishna, Sandeep, and Mini 2016). However, the significant strength reduction observed in this study at replacements above 10% contrasts with reports where finer RHA or optimized burning conditions yielded higher reactivity, allowing for larger replacement percentages while maintaining or enhancing strength (Vijaya, Jagadeeswari, and Srinivas 2020) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018). For example, peak strength was observed at 15% RHA(Bixapathi and Saravanan 2022), 10% RHA(Kumar and Gopi 2022)(Ali et al. 2021), and 7.5% RHA(Rajashekhar Reddy, Harihanandh, and Murali 2021) in other studies. One study found that 10% RHA replacement led to a 19.6% increase in 28-day strength, while 20% RHA resulted in a 6.9% increase(Hussein et al. 2025). This discrepancy underscores the impact of factors like the pozzolanic reactivity of the RHA, which is greatly influenced by its source, which includes processing factors such as fineness and burning conditions , the grade of concrete, and the available other supplementary materials (Ozturk et al. 2020) (Rajashekhar Reddy, Harihanandh, and Murali 2021) (Fapohunda, Akinbile, and Shittu 2017).

3.3.4 Optimal Combination and Practical Implications

According to the compressive strength results, RHA replacement at 5% (Mix M2) is the optimal combination as it still has compressive strength close to the control, while offering the benefits of sustainability (Vijaya, Jagadeeswari, and Srinivas 2020) (Bixapathi and Saravanan 2022).). Literature documents the finding that 28-day strength peaked at 5% replacement (Mayooran, Ragavan, and Sathiparan 2017) and it, together with other works, aligns with the accepted view that moderate substitution levels (≤10%) should still provide the required strength (Khankhaje et al. 2025). For cases where there is acceptable strength loss of slightly more, a 10% replacement could be used to gain further environmental benefits (Bixapathi and Saravanan 2022). The 5-10% range for replacement is documented and covers the control on strength with the gain on the environment (Tutur et al. 2023)(Munish and Mehta 2024).

3.4 Tensile Strength, Water Absorption, and Dry Density

Insufficient data in the provided summaries was available for the analysis of Tensile Strength, Water Absorption, and Dry Density. These properties were not evaluated in this study.

3.5 Environmental Performance

The incorporation of RHA as a partial cement replacement highlights significant environmental benefits. The primary mechanism for this benefit is that cement substitution directly lowers the embodied carbon footprint of the concrete, as the production of one ton of cement is estimated to emit approximately one ton of CO_2(Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018) (Tutur et al. 2023). Furthermore, the valorization of RHA, an agricultural waste product, reduces the environmental burden associated with its disposal, such as landfill use, open burning, or open-field burning(Vijaya, Jagadeeswari, and Srinivas 2020) (Bixapathi and Saravanan 2022)(Samad et al. 2022). A related study quantified this benefit, reporting a 9.9–20.6% lower CO_2 footprint compared to the control mix(Lo, Lee, and Lo 2021).

These sustainability claims are consistent with those commonly reported in supplementary cementitious material (SCM) studies, which emphasize reducing CO_2 emissions and utilizing agro-waste (Vijaya, Jagadeeswari, and Srinivas 2020) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018). This aligns perfectly with the broader consensus on the environmental advantages of using industrial and agricultural by-products like RHA(Alex, Dhanalakshmi, and Ambedkar 2016)(Krishna, Sandeep, and Mini 2016)(Igba et al. 2019)(Nalli and Vysyaraju 2022)(Zakaria et al. 2023). The environmental performance reinforces the practical implication drawn from the strength results. A replacement level of 5% to 10% RHA is recommended to balance mechanical performance with significant environmental gains(Cavalcante et al. 2018) (Bixapathi and Saravanan 2022). The range allows for considerable savings on cement and the utilization of waste while not severely compromising the concrete's compressive strength, thus aiding more eco-friendly practices in concrete production and endorsing RHA as a sustainable material in construction(Samad et al. 2022)(Zakaria et al. 2023).

4-CONCLUSION

This investigation sought to evaluate the feasibility of sustainable construction using Rice Husk Ash (RHA) as a partial replacement for cement in concrete by examining the impacts of various levels of RHA replacement on compressive strength. The experimental program characterized concrete mixes with 0%, 5%, 10%, 15%, and 20% RHA by weight of cement and gauged workability and compressive strength at 7 and 28 days. The primary finding of this research is the viable partial replacement of cement with up to 5% RHA with no significant losses in compressive strength, confirming that RHA can be added to concrete mixes without compromising key performance. The workability of fresh concrete, as gauged by slump, was 25.4 mm for mixes with 0%, 5%, and 10% RHA, but increased to 50.8 mm for mixes with 15% and 20% RHA.The compressive strength results showed a progressive decrease with increasing RHA content at both testing ages. The 28-day strength decreased from 22.73 MPa for the control mix to 19.30 MPa for the 5% RHA mix and further to 13.92 MPa for the 20% RHA mix. The reduction in strength is attributed to the dilution effect and the slower pozzolanic activity of RHA compared to cement hydration. The minimal strength loss at the 5% replacement level indicates a balance where the pozzolanic benefits partially offset the dilution effect.

Based on the compressive strength results, the optimum performance was observed at a 5% replacement level of cement with RHA. This mix maintained strength closest to the control while offering sustainability benefits. For applications where a slightly higher strength loss is acceptable for greater environmental gain, a 10% replacement could be considered, as this range of 5–10%

replacement often balances strength and environmental gains. While strength was the main focus of this study, other properties such as long-term durability and microstructural aspects require further investigation to confirm the material's comprehensive performance.

Utilization of RHA aided in conducting sustainable construction by decreasing the need for cement which in turn meant less CO_2 emissions and recycling in the construction industry by using RHA. Recycling agro-waste RHA lowers cement usage and decreases CO_2 emissions. The environmental benefits concrete with maximum of 5% RHA can be used for pavements, blocks and secondary structural components which are practical field applications where the concrete does not require high strength. In order to build on this research, there are some suggested areas for future work. RHA concrete long term durability studies to include sulfate attack and freeze-thaw cycles would be beneficial. Performance could also be optimized with studies on blended pozzolanic mixes RHA and fly ash. In terms of pozzolanic reactions and interfacial transition zone, microstructure studies using SEM and XRD would be valuable. Last, an LCA of RHA concrete would complete the environmental validation of the benefits that RHA concrete offers.

5-RECOMMENDATIONS

Considering the experimental outcomes of this study, the use of Rice Husk Ash (RHA) is recommended as a partial (up to 5% by weight) replacement for cement in concrete. This recommendation is provided since the 5% RHA mix had the closest compressive strength to the control while imparting benefits of sustainability. For use cases where a slightly higher strength loss is tolerable to achieve a higher degree of environmental benefit, a 10% replacement should be considered since this range of 5–10% replacement is typically where sustainability and strength balance is achieved.This recommendation is particularly applicable for pavements, masonry blocks, and other secondary or non-structural concrete elements where high strength is not the primary criterion. To build upon this research, future work should focus on durability studies to evaluate long-term performance, investigation of blended pozzolanic mixes, microstructural analysis using techniques like SEM and XRD, and a Life Cycle Assessment (LCA) for comprehensive environmental validation.

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