Assessment of Concrete Properties by Partial Replacement of Fly Ash and Rice Husk Ash with Cement and Recycled Aggregate with Natural Coarse Aggregate

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Abstract: ***Concrete production consumes substantial quantities of Portland cement and natural aggregates, resulting in the depletion of natural resources and significant greenhouse gas emissions. At the same time, coal-based power generation, rice processing, and construction and demolition activities generate substantial volumes of fly ash (FA), rice husk ash (RHA), and waste concrete, which present major disposal and environmental challenge concrete technology, therefore, focuses on incorporating such industrial and agricultural by-products as supplementary cementitious materials and recycled aggregates to reduce environmental impact while maintaining or improving mechanical and durability performance. This paper reviews and extends existing research on the combined use of FA, RHA, and recycled concrete aggregate (RCA) in structural concrete, with emphasis on compressive and flexural strength development for M25 grade concrete. A two-stage experimental program was conducted: in Stage 1, cement was partially replaced by FA and RHA at an overall binder replacement level of 25%, distributed across seven mixes varying from 25% FA to 25% RHA; in Stage 2, the optimum FA-based mix from Stage 1 was used as the base binder while natural coarse aggregate (NCA) was partially replaced by RCA at 10–40% by weight. For all mixes, cubes (150 mm) and beams (100×100×500 mm) were cast and tested for compressive and flexural strength at 7, 14, and 28 days in accordance with IS 516:1959. Stage 1 results showed that replacing 25% of cement by FA alone (75% cement + 25% FA) increased compressive strength by about 25–27% and flexural strength by about 25% at all ages relative to conventional M25 concrete. Progressive substitution of FA by RHA within the 25% replacement (up to 25% RHA) reduced both compressive and flexural strengths, indicating that for the RHA used in this study, fineness and reactivity were not sufficient to match the performance of FA at the same dosage. In Stage 2, using the optimum binder (75% cement + 25% FA), partial replacement of NCA with RCA at 10% further increased compressive strength by roughly 29% and flexural strength by about 34% compared to conventional concrete without FA or RCA, whereas higher RCA contents (20–40%) led to gradual strength reductions, though many mixes still performed competitively. The experimental findings align with previous studies showing that FA and RHA can act as effective pozzolanic materials, and that RCA can be used to partially replace NCA without compromising strength, provided its higher absorption and lower density are properly accommodated in the mix design. The results suggest that for M25 concrete under Indian conditions, an optimum sustainable mix can be obtained by replacing about 25% of cement with FA and about 10% of NCA with RCA, while RHA requires careful control of production and fineness to avoid strength penalties. The study contributes to the growing body of evidence supporting the integrated use of industrial and agricultural by-products and recycled aggregates in structural concrete, and provides data that can inform future code provisions and practical guidelines for sustainable construction.***

Keywords: fly ash; rice husk ash; recycled concrete aggregate; sustainable concrete; M25 concrete; compressive and flexural strength.

1. Introduction

Concrete is the backbone of modern infrastructure due to its versatility, relatively low cost, and ability to be produced from widely available materials. Conventional concrete, however, depends heavily on Portland cement and natural aggregates, both of which are associated with high environmental burdens in terms of energy consumption, CO_2 emissions, and ecological degradation from quarrying and river sand mining. The cement industry is a major source of anthropogenic CO_2, while indiscriminate extraction of river sand and stone aggregates has led to lowering of water tables, erosion of riverbeds, and instability of bridge foundations in many regions.[2]

Simultaneously, rapid industrialization and urbanization generate substantial volumes of waste materials, including fly ash from coal-fired thermal power plants, rice husk ash from rice milling and combustion, and construction and demolition waste from aging or demolished structures. Fly ash is produced in large quantities as a by-product of coal combustion and is difficult to dispose of safely if not utilized productively, posing air and groundwater pollution risks. Rice husk ash, when rice husk is burned under uncontrolled conditions, is often dumped as waste despite its significant silica content and potential pozzolanic reactivity. Recycled concrete aggregate is produced by crushing waste concrete to reclaim aggregate, and is commonly used for road base or fill, but its use in structural concrete remains limited despite growing evidence of feasibility. These trends create a strong motivation to adopt waste utilization strategies that transform such by-products into valuable resources for concrete production.[1]

Pozzolanic materials such as FA and RHA have the potential to react with calcium hydroxide liberated during hydration of cement to form additional calcium silicate hydrate, which is the principal strength-giving compound in hardened concrete.

This secondary C–S–H formation refines the pore structure, reduces permeability, and improves resistance to sulfate attack, alkali–silica reaction, carbonation, and chloride ingress, all of which are critical for the durability of reinforced concrete structures. Indian Standard IS 3812 recognizes FA as a supplementary cementitious material and permits its use as an admixture, as a pozzolanic material, and as fine aggregate in concrete, with evidence that even small additions (up to about 5% in OPC) can improve performance. Numerous investigations have demonstrated that at moderate replacement levels, FA can improve long-term strength and durability while reducing the heat of hydration and mitigating thermal cracking, though early-age strength is often lower due to slower pozzolanic reaction rates.[1]

RHA, when produced by controlled burning and adequate grinding, can also act as a reactive pozzolan due to its high amorphous silica content and large specific surface area. Studies have shown that finely ground RHA (particle size below about 75 µm) can replace cement in the range of 10–30% without compromising compressive, tensile, and flexural strengths, and can, in some cases, enhance durability indicators such as resistance to chloride ingress and sulfate attack. However, performance of RHA is highly sensitive to combustion temperature, duration, and grinding fineness; poorly controlled RHA may be crystalline or coarsely ground and behave more as an inert filler, reducing strength when used at high dosages. Thus, optimization of RHA processing and dosage is essential for reliable performance.[1]

RCA, on the other hand, contributes to sustainability primarily through conservation of natural aggregates and reduction of construction and demolition waste. RCA particles consist of original natural aggregate coated with a layer of old mortar, which increases water absorption and reduces density relative to virgin aggregates, often lowering mechanical properties and durability of recycled aggregate concrete. Experimental work has shown that compressive strength, modulus of elasticity, and flexural strength of RAC tend to be lower than those of conventional concrete at equivalent water–cement ratios, particularly at high RCA replacement levels. However, internal curing effects arising from water stored in the porous old mortar can mitigate self-desiccation and shrinkage, and with proper attention to additional water demand, pre-soaking of RCA, and adjusted mix design, partial replacement levels of 20–50% RCA can often be achieved without unacceptable strength losses.[1]

In the Indian context, these approaches are particularly relevant. Thermal power plants continue to produce vast amounts of FA, and national policy encourages its use in cement and concrete, but on-the-ground utilization remains below potential. Rice-producing regions have abundant rice husk waste that can be converted into RHA under controlled conditions, providing a locally available pozzolan. Urban redevelopment and infrastructure upgrades generate large quantities of demolition concrete that can be processed into RCA rather than landfilled. Integrating FA, RHA and RCA into structural concrete aligns with national sustainable development objectives and offers a pathway towards circular economy in the construction sector.[5]

The thesis "Assessment of Concrete Properties by Partial Replacement of Fly Ash and Rice Husk Ash with Cement & Recycled Aggregate with Natural Coarse Aggregate" addresses these issues through a two-stage experimental program on M25 concrete. Stage 1 partially replaces cement by FA and RHA at an overall replacement of 25% across seven mixes and evaluates compressive and flexural strength at 7, 14, and 28 days to identify the optimum binder composition. Stage 2 then adopts the best-performing FA–cement blend and partially replaces NCA with RCA at 10–40%, again testing compressive and flexural strength at the same ages. The present paper recasts that work as a review-cum-experimental study, synthesizing prior literature with the new results to propose practical replacement ranges for FA, RHA, and RCA in M25 concrete under Indian conditions.[3]

2. Literature Review

2.1 Studies from 2007–2011

1) **Mhatre M.B., Chore H.S., Dode P.A. (2007) – Ways to facilitate the use of recycled aggregate concrete**
Describes methods to encourage the use of recycled aggregate concrete (RAC), including mix design approaches that account for higher absorption and lower density of RCA. The paper reports that with appropriate design, RAC can approach the performance of conventional concrete and provides guidance for practitioners.
2) **Padma Rao P., Pradhan Kumar A., Bhaskar Singh B. (2009) – Use of recycled concrete aggregate in making concrete: An overview**
Presented at the 34th "Our World in Concrete & Structures" conference, this overview summarizes properties of RCA and its effects on concrete compressive strength and workability. It concludes that RCA can be safely used in structural concrete within certain replacement limits, and highlights areas for further research.
3) **Bahoria B.V., Parbat D.K., Naganaik P.B., Waghe U.P. (2011) – Strength development of mortar and concrete containing fly ash**
Investigates the influence of FA on strength development in mortar and concrete, showing that appropriate FA contents can enhance long-term strength while lowering the heat of hydration. The paper recommends optimal FA dosages and curing regimes to achieve improved performance.
4) **Yadav S.R., Pathak S.R. (2011) – Performance of recycled aggregate concrete**
Evaluates RAC mixes with varying levels of RCA, focusing primarily on compressive strength and cost effectiveness. The authors show that target strengths can be maintained with well-designed mixes using RCA, supporting its environmental and economic advantages.
5) **Nagalakshmi R. (2011) – Comprehensive literature review on use of waste product in concrete**
Reviews different industrial and agricultural wastes used in concrete, with emphasis on RHA as a cement replacement. Concludes that RHA can improve strength and durability when used at controlled fineness and dosage, and calls for more experimental validation.

6) **Murali G., Vivek Vardhan C.M., Rajan G., Janani G.J., Shifu Jajan N., Ramyasri R. (2011) – Characterization of recycled aggregate concrete**
Provides an extensive characterization of RAC, covering physical properties of RCA, compressive and split tensile strength, and durability indicators. The study confirms that although RAC properties are somewhat inferior, satisfactory performance can be achieved with suitable quality control.

2.2 Studies from 2012–2013

7) **Vijayakumar G., Vishaliny H., Govindarajulu D. (2012) – Experimental study on recycled aggregate concrete**
Examines the mechanical properties of RAC with different RCA replacement levels and reports slight reductions in strength with increasing RCA. Concludes that moderate RCA contents are acceptable for structural applications with a proper mix design.
8) **Damodhara Reddy B., Aruna Jyothy S., Shaik F. (2012) – Performance evaluation of recycled aggregates used in concrete**
Tests compressive, flexural and split tensile strengths of concrete containing RCA, along with density and absorption measurements. Finds that 50% replacement of NCA by RCA leads to small strength reductions (around 0.4–0.3%) and is still recommended for many uses.
9) **Vyas C.M., Pitroda J. (2012) – Effect of fly ash additive on concrete properties**[1]
Investigates FA as an additive in OPC concrete, studying workability, strength, and durability. The paper shows that FA can improve long-term strength and durability while reducing cost and environmental impact.
10) **Vijayakumar G., Vishaliny H., Govindarajulu D. (2012) – Studies on RHA as partial replacement in PPC**
Evaluates RHA as an admixture to Portland pozzolana cement (already containing FA), at replacement levels of 5–15%. Demonstrates that moderate RHA contents can enhance compressive and flexural strength over curing periods up to 56 days.
11) **Karim M.R., Zain M.F.M., Jamil M., Lai F.C., Islam M.N. (2012) – Strength of mortar and concrete as influenced by RHA**[1]
Studies the physical and chemical properties of RHA and its effect on consistency, setting time, and strength activity index in mortar and concrete. Concludes that RHA is a promising pozzolanic material and suggests future work on ternary blends with FA, palm oil fuel ash, and slag.
12) **Tam V.W.Y., Wang K., Tam C.M. (2013) – Ways to facilitate use of recycled aggregate concrete**
Summarizes differences between RCA and natural aggregates, and proposes guidelines to facilitate RAC use, including mix design modifications and quality control. Reports reductions in density, strength, and rigidity when using RCA, but confirms feasibility for structural applications with proper design.
13) **Chang H., Morgan R., Aziz U., Herfellner S., Ho K. (2013) – Performance and implementation of low-quality recycled concrete aggregate**
Simulates low-quality site concretes with high water–cement ratios, crushes them to obtain RCA, and produces new RAC. Shows that RCA can be a reasonably low-cost aggregate and that internal curing due to high RCA absorption can offset some quality drawbacks.
14) **Umapathy U., Mala C., Siva K. (2013) – Some hardened properties of air entrained recycled aggregate concrete**
Investigates compressive and flexural strength of air-entrained RAC, focusing on the influence of air content on strength. Finds that higher air content reduces strength but improves workability and resistance to freeze–thaw and scaling.
15) **Manikandan T., Mohan M., Siddaharamaiah Y.M. (2013) – Studies on RHA as partial replacement of cement in concrete production**
Conducts numerous aggregate and concrete tests to assess the suitability of RHA as a partial cement replacement in structural concrete. Recommends practical replacement levels and discusses implications for strength and durability.
16) **Marthong C., Agrawal T.P. (2013) – Study on exchange of coarse aggregate by recycled aggregate in concrete**
Evaluates the mechanical properties of concrete where natural coarse aggregate is partially replaced by RCA. Concludes that RCA replacement up to an optimum level is feasible without large strength penalties.
17) **M.N.N. Khana, Jamil M., Karim M.R., Zain M.F.M. (2013) – Use of recycled rice husk ash bottles as fine aggregates in concrete**
Uses crushed waste plastic bottles and RHA as fine aggregate replacement in concrete, studying strength and workability. Reports that recycled bottles with RHA can be used without significantly affecting coarse aggregate quality, while providing sustainable waste management.
18) **Phani Madhavi T., Sampathkumar V., Guneasekaran P. (2013) – Partial exchange of sand with quarry dust in concrete**
Examines quarry dust as a partial sand replacement and evaluates its effect on workability and strength. Identifies replacement ranges where quarry dust can be safely used without major strength loss.
19) **Chandana Sukesh, Bala Krishna K., Sri Lakshmi Sai Teja P., Kanakambara Rao S. (2013) – FA and recycled coarse aggregate in concrete: literature review**
Reviews use of FA and RCA in concrete, emphasizing new opportunities for the construction industry. Suggests that the combined use of FA and RCA can support sustainable concrete if a proper mix design is followed.
20) **Ganiron T.U. Jr. (2013–2014) – Effect of waste plastic bottles as fine aggregate in concrete**
Designs a concrete mix with crushed waste bottles as fine aggregate and evaluates effects on workability and strength. Finds water demand decreases as bottle content increases and notes minimal impact on coarse aggregate quality.

2.3 Studies from 2014–2015

21) **Dabhade A.N., Choudhari S.R., Gajbhiye A.R. (2014) – Evaluation of recycled and reused waste material**

aggregates
Uses compressive, split tensile, density, fineness modulus, water absorption, impact value, and crushing value tests on mixes with 0–100% RCA and varying water–cement ratios. Demonstrates the technical feasibility of RCA and highlights the sustainability benefits.

22) **Akinkurolere O.O. (2014) – Assessment of concrete power using partial exchange of coarse aggregate for waste tiles and cement for RHA**
Evaluates the combined use of waste ceramic tiles as coarse aggregate and RHA as cement replacement, testing compressive and flexural strengths. Concludes that waste tiles and RHA can be used without affecting design strength within certain replacement ranges.
23) **Tiles + RHA + PFA/GGBS/GLP composite study (circa 2014–2015)**
Replaces 20–50% of coarse aggregate with waste ceramic tiles and 10–20% of cement with RHA, PFA, GGBS, and glass powder, casting 81 cubes tested at 7, 17, and 28 days. Recommends waste tiles as an alternative coarse aggregate and RHA–pozzolan blends as viable cement replacements.

3. Methodology

1) M25 concrete with mix proportion 1:1:2 (binder:sand: coarse aggregate) was used for all batches.
2) Stage 1: Seven binder combinations were prepared with 25% total binder replacement by FA and/or RHA (0–25% FA, 0–25% RHA in different proportions), keeping sand and NCA constant.
3) Stage 2: The optimum Stage 1 mix (75% cement + 25% FA) was adopted; NCA was partially replaced by RCA at 10, 20, 30, and 40% by weight, plus control batches without FA or RCA.
4) For each batch, nine 150 mm cubes and six 100×100×500 mm beams were cast and cured in water at 27±2 °C, and tested for compressive and flexural strengths at 7, 14, and 28 days according to IS 516:1959.

4. Key Results and Discussion

1) The mix with 75% cement + 25% FA (no RHA) achieved the highest compressive and flexural strengths among all Stage 1 mixes, with about 25–27% and 25% improvements, respectively, over conventional M25 concrete at 7, 14, and 28 days.
2) Increasing RHA share within the 25% binder replacement progressively reduced both compressive and flexural strengths, indicating that the RHA used required better control of fineness or dosage for optimum performance.
3) In Stage 2, using the 75% cement + 25% FA binder, replacement of 10% NCA by RCA further increased compressive strength to about 29% and flexural strength to about 34% above conventional concrete, likely due to beneficial internal curing and synergy between the pozzolanic binder and RCA.
4) RCA contents above 10% led to gradual decreases in strength, reflecting the adverse influence of higher porosity and weaker old mortar, although many mixes still met M25 strength requirements.

5. Need of the Study

1) To reduce CO_2 emissions and embodied energy of M25 concrete by partially replacing Portland cement with FA and, where feasible, properly processed RHA.
2) To conserve natural aggregates and mitigate environmental damage from quarrying and river sand mining by introducing RCA in structural-quality concrete.
3) To experimentally determine the combined optimum replacement levels of FA, RHA, and RCA for M25 concrete under Indian standards so that strength and serviceability are not compromised.
4) To provide data that can inform revisions of codes and guidelines (e.g., IS 456, IS 3812) regarding integrated use of SCMs and RCA in structural concrete.
5) To support sustainable construction practices and circular economy objectives by demonstrating technically viable, resource-efficient concrete mixes for real projects.

6. Conclusion

The integrated review and experimental study demonstrate that carefully designed combinations of FA, RHA, and RCA can produce sustainable M25 concrete with equal or superior strength relative to conventional mixes while reducing environmental impact. Stage 1 results clearly indicate that a 25% replacement of cement by FA alone yields significant strength enhancements, with compressive strength increasing by approximately 25–27% and flexural strength by about 25% at 7, 14, and 28 days compared to the control mix. This confirms the well-established benefits of FA as a pozzolanic material that refines pore structure, reduces permeability, and improves long-term strength and durability when used at moderate dosages. In contrast, substituting part of the FA with RHA within the same total replacement level led to reductions in both compressive and flexural strengths, underscoring the sensitivity of RHA performance to production parameters such as burning temperature and grinding fineness. For the specific RHA used in this study, high replacement levels were not advantageous, suggesting that RHA should be used at lower dosages or with improved processing to fully exploit its pozzolanic potential.

Stage 2 findings further reveal that incorporating RCA into the optimized FA and cement binder can be beneficial up to a certain limit. When 10% of NCA was replaced by RCA in the 75% cement + 25% FA mix, both compressive and flexural strengths increased beyond those of the Stage 1 optimum, by about 29% and 34% respectively, relative to the original conventional concrete. This suggests that at low replacement levels, the negative effects of RCA (higher absorption, weaker old mortar) can be more than offset by internal curing effects and favorable interaction with the pozzolanic binder. However, as RCA content increased to 20–40%, strengths declined progressively, reflecting the growing influence of the more porous, weaker RCA matrix; nonetheless, many mixes still satisfied M25 strength requirements, indicating that higher RCA levels might be acceptable for non-critical structural or secondary applications with appropriate design safety margins.

Overall, the results imply that an environmentally optimized M25 concrete mix under Indian conditions can reasonably target about 25% FA as cement replacement and about 10% RCA as coarse aggregate replacement, with RHA used only after careful optimization of fineness and dosage. Such a mix would reduce cement consumption and natural aggregate demand, lower embodied CO_2, and provide a beneficial use for industrial and demolition waste, aligning with national sustainability goals. From a practical standpoint, the study emphasizes the need for integrated design of the binder and aggregate systems rather than isolated substitutions, as the combined effects on workability, strength, and durability are non-linear. For standards and codes, the experimental evidence supports expanding guidance on FA and RCA use in structural concrete, and opens the door for formally recognizing well-processed RHA as a supplementary cementitious material in future revisions. Further research is recommended on durability indicators such as chloride permeability, shrinkage, creep, and field performance, and on extension of these findings to other strength grades and structural elements to fully establish FA–RHA–RCA concretes as mainstream options in sustainable construction.

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