

REVIEW ON EXPERIMENTAL INVESTIGATION ON THE EFFECT OF RECYCLED BUILDING MATERIAL ON HIGH STRENGTH CONCRETE

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ABSTRACT

The increasing demand for concrete in modern construction has led to significant environmental challenges, including the depletion of natural aggregates, excessive energy consumption, and the accumulation of construction and demolition (C&D) waste. This research aims to address these issues by evaluating the mechanical performance of high-strength concrete (HSC) incorporating various recycled building materials. The study investigates the suitability of recycled concrete aggregate (RCA), recycled fine aggregate (RFA), recycled brick aggregate (RBA), glass powder, and plastic waste as partial or full replacements for natural aggregates and supplementary cementitious materials in M35, M60, and M80 concrete grades.

A comprehensive experimental program was conducted to assess the influence of different replacement levels (25%, 50%, 75%) on compressive strength, split tensile strength, flexural strength, water absorption, acid resistance, chloride ion penetration, and crack propagation behavior. Specimens were tested at multiple curing ages (28 and 60 days) to evaluate short-term and long-term performance.

The results reveal that up to 50% replacement of natural aggregates with recycled materials can be achieved without significant compromise in mechanical strength or, especially when supported with supplementary cementitious materials such as silica fume and fly ash. M80 concrete demonstrated superior performance retention compared to M35 and M60 grades due to its dense matrix and lower water-cement ratio. Workability declined with increasing recycled content but was effectively managed using polycarboxylate-based superplasticizers. Durability studies showed higher permeability and acid susceptibility in mixes with high recycled content, underscoring the importance of mix optimization.

Keywords: Workability, Durability, construction, optimization

INTRODUCTION

Concrete continues to be the most essential and widely used material in the modern construction industry. Globally, it is the second most consumed substance after water, with an annual consumption exceeding 30 billion tons. It serves as the structural backbone of critical infrastructure, including high-rise buildings, roads, bridges, flyovers, tunnels, airports, marine structures, industrial plants, and dams. Its long-standing popularity is largely attributed to properties such as:

Despite its technical advantages, conventional concrete production has come under scrutiny due to its environmental footprint. From the extraction of raw materials to cement manufacturing and eventual waste disposal, each stage of the concrete lifecycle contributes to ecological degradation, carbon emissions, and resource depletion.

As the global population and urban infrastructure expand rapidly, sustainable development in the construction sector is no longer optional—it is a necessity. Governments, engineers, and researchers are being increasingly tasked with identifying materials and processes that can fulfill performance demands while minimizing environmental harm. Among the promising solutions is the reuse of construction and demolition waste to replace traditional natural aggregates and cement partially.

- **Environmental Impact of Conventional Concrete**

Concrete is typically made by mixing cement, water, fine aggregates (like natural river sand), and coarse aggregates (like gravel or crushed stone). The extraction and processing of these materials are resource-intensive and contribute significantly to environmental degradation. The key environmental concerns are detailed below:

A. Aggregate Mining

The global construction sector consumes over 50 billion tons of sand and gravel annually, making it the largest mining industry worldwide.

In many regions, riverbeds, coastal areas, and forests are indiscriminately mined, leading to:

- o Severe soil erosion
- o Loss of aquatic biodiversity
- o Disruption of natural water flow and groundwater tables
- o Increased risk of floods and habitat destruction

Moreover, these activities are often unregulated in developing countries, leading to illegal sand mining operations that further exacerbate environmental and social problems.

B. Cement Production

Cement, the key binder in concrete, is manufactured by heating limestone and clay at high temperatures (~1450°C) in rotary kilns.

This process, known as calcination, releases massive amounts of CO₂:

- o ~60% from the chemical decomposition of limestone ($\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$)
- o ~40% from the combustion of fossil fuels used in kilns

The cement industry contributes approximately 7–8% of total global carbon dioxide emissions, making it the third-largest industrial emitter after steel and oil.

Other emissions include NO_x, SO₂, and particulate matter, contributing to air pollution and acid rain.

Need for Recycled Building Materials

In response to the growing sustainability crisis, the construction industry is exploring the reuse and recycling of building materials. This involves processing construction waste to extract valuable components that can replace natural aggregates or cement in new concrete production. The key motivations behind this shift include:

A. Sustainable Resource Management

- Using recycled aggregates reduces the need for virgin sand and gravel, thus helping preserve natural habitats and landscapes.
- It promotes a circular economy, where waste from one construction cycle becomes input for another.
- Recycled concrete aggregates can be derived from:
 - o Old concrete structures
 - o Broken bricks and blocks
 - o Tiles and ceramics
 - o Crushed mortar and cement plaster

B. Reduction in Environmental Pollution

- Properly recycling construction waste minimizes the load on landfills and curbs illegal dumping.
- It helps reduce the carbon footprint associated with transporting and extracting fresh materials.
- It cuts down on energy consumption and water use required in raw material processing.

High-Strength Concrete (HSC) and Its Challenges

High-Strength Concrete (HSC) is generally defined as concrete with a compressive strength exceeding 40 MPa, and it is widely adopted in modern construction due to its superior mechanical properties, enhanced durability, and capacity to reduce the size of structural members while maintaining required load-bearing capabilities. Typically, HSC achieves this strength through a low water-cement ratio—usually below 0.35—which helps create a dense and compact microstructure. Additionally, supplementary cementitious materials such as fly ash, silica fume, and slag are incorporated to further improve strength, durability, and resistance to environmental degradation.

Need for the Study

The need for this research is rooted in addressing both environmental sustainability and technical performance.

Environmental Sustainability

- **Resource Conservation:** Resource conservation in the construction industry is essential for ensuring the sustainable use of natural materials and reducing the environmental footprint of building activities. By incorporating recycled and reused building waste materials, the consumption of virgin resources such as natural sand, gravel, crushed stone, timber, and metals is significantly minimized.
- **Waste Reduction:** Waste reduction is a critical aspect of sustainable construction practices, aimed at minimizing the generation of waste materials throughout a building's lifecycle — from design and construction to renovation and demolition.
- **Emission Reduction:** Emission reduction is an essential goal in modern construction practices, as the industry is a significant contributor to greenhouse gas (GHG) emissions, particularly carbon dioxide (CO₂), which results from the extraction, processing, transportation, and manufacturing of construction materials.

Structural Relevance

Structural relevance refers to the ability of recycled and reused building waste materials to meet the necessary strength, durability, and performance standards required for various structural applications in construction. When integrating waste materials into new construction projects, it is essential to ensure that these materials can reliably perform under load-bearing conditions and environmental stresses, without compromising the safety and stability of the structure. Advances in material processing technologies have made it possible to produce high-quality recycled aggregates from demolished concrete, bricks, and other inert materials, which can partially or fully replace natural aggregates in structural concrete and road base applications.

- There is limited experimental data on how recycled aggregates influence the mechanical and durability performance of high-strength concrete, especially in grades like M60 and M80.
- Construction standards currently lack clear guidelines on acceptable replacement percentages for recycled materials in HSC.
- Engineers require empirical evidence to validate the use of recycled materials in structural elements subjected to high stresses and environmental exposure.

Significance of the Study

The importance of this research extends across environmental, engineering, economic, and policy-making

domains. The study not only addresses the environmental challenges posed by

traditional concrete production and construction waste but also demonstrates viable engineering solutions and cost-effective alternatives using recycled building materials in high-strength concrete (HSC). The findings are critical in guiding future practices in sustainable construction, material innovation, and infrastructure resilience.

Environmental Contributions

The environmental implications of this study are profound in the context of sustainability and climate resilience:

- **Reduction in Virgin Resource Exploitation:** The partial replacement of natural coarse and fine aggregates with RCA, RFA, and other recycled materials significantly reduces the dependency on river sand and gravel mining, which are linked to riverbank erosion, groundwater depletion, and ecological damage.
- **Curbing Carbon Emissions:** The cement industry is responsible for nearly 8% of global CO₂ emissions. By reducing the volume of cement and virgin aggregate usage through substitutions with pozzolanic glass powder and other recycled materials, the total embodied carbon of concrete is effectively lowered.

Engineering Insights

This research contributes novel technical knowledge and practical insights for civil and structural engineering:

- **Comprehensive Performance Evaluation:** The study provides experimentally verified data on the behavior of M35, M60, and M80 grade concrete with varying proportions of recycled aggregates. It assesses not only strength characteristics but also durability under simulated environmental exposure conditions.
- **Customized Mix Design Optimization:** Through the results, engineers are better equipped to design concrete mixes that maintain required compressive, tensile, and flexural performance, while also improving workability through appropriate adjustments in water-cement ratio, admixture dosing, and SCM inclusion.

Economic and Practical Benefits

The economic and implementation benefits of this study are substantial, particularly in developing countries and high-demand urban areas:

- **Cost Savings:** Recycled aggregates are generally more affordable than natural aggregates, particularly in regions where sand and stone are either heavily taxed, depleted, or have high transportation costs.
- **Material Security:** In places facing aggregate shortages or supply chain disruptions (such as post-disaster areas or dense urban zones), recycled materials provide a local and readily available alternative.

- **Encouragement of Local Industry:** Recycling concrete waste supports the development of regional crushing, screening, and grading facilities. This promotes micro and small-scale enterprise growth and job creation, especially in peri-urban zones.

1.2 Scope of the Study

This study is intentionally broad in its scope to allow for multi-faceted evaluation across strength, durability, and structural performance dimensions of concrete made with recycled materials. It seeks to bridge the gap between laboratory research and practical field application for high-strength concrete development using sustainable materials.

Performance Parameters Analyzed

This study focuses on evaluating several critical performance parameters of concrete mixes containing recycled building waste materials to understand their mechanical behavior and long-term durability. The primary parameters analyzed include:

- **Compressive Strength:** This fundamental property was measured at both 28 and 60 days to assess early-age strength development and long-term performance. Compressive strength indicates the concrete's ability to withstand axial loads and is a key criterion for structural design. Testing at multiple curing ages helps to understand how the incorporation of recycled materials influences strength gain over time.
- **Split Tensile Strength:** Concrete is inherently weak in tension, and split tensile strength tests are conducted to evaluate its resistance to tensile stresses and cracking. This parameter is essential in determining the concrete's ability to resist forces that cause splitting and failure, especially in structural elements subjected to bending and tension.

LITERATURE REVIEW

- **Mousavi et al.(2025)** studied geopolymer-based high-strength concrete incorporating 50% RCA and concluded that tensile performance remained comparable to control mixes. This was due to the formation of N-A-S-H (sodium aluminosilicate hydrate) gels, which provided excellent bonding even in mixes with RCA.
- **Lamba et al.(2024)** investigated the use of recycled carbon fibers in combination with RCA in HSC. Their study revealed that flexural strength and impact resistance improved significantly, indicating that fibers can bridge cracks and reduce stress concentrations in mixes with weaker RCA bonds.
- **Silva et al.(2018)** confirmed that RAC mixes have reduced flexural capacity beyond 50% replacement levels. However, strength retention was possible with matrix densification techniques, such as using glass powder or nano-silica.
- **Verian et al.(2018)** performed comparative studies on

high-strength concrete (HSC) containing recycled aggregates and found that when combined with supplementary cementitious materials (SCMs) such as silica fume and fly ash, concrete with 30% RCA achieved strength comparable to conventional mixes. The addition of SCMs improved the matrix density and enhanced hydration, thus mitigating the adverse effects of porous RCA.

- **Pedro et al.(2017)** observed that load-deflection curves of RAC beams with 25–30% RCA showed similar ductility and peak load behavior as natural aggregate concrete, reinforcing the idea that partial replacement is viable even in structural elements. Key Conclusions from Literature.
- **Xiao et al.(2012)** noted that although compressive strength reduction is typically observed with recycled aggregates, strength tends to improve over time (e.g., at 90 days) due to internal curing caused by water-retaining properties of adhered mortar.
- **Zega et al.(2011)** evaluated concrete mixtures with various replacement levels of RCA and concluded that up to 40% replacement of natural coarse aggregate with RCA did not significantly compromise compressive strength. The authors attributed this to effective packing and compensatory hydration facilitated by proper water-to-cement (w/c) ratio control.
- **Tam et al.(2007)** found that pre-soaking RCA prior to mixing reduces its water absorption during hydration, allowing for more consistent water-cement ratios. Their experiments demonstrated that pre-saturated RCA improved bond strength at the ITZ, resulting in 5–10% improvement in split tensile strength compared to dry-mix RAC.
- **Evangelista et al.(2007)** reported that replacing fine aggregates with RFA reduced tensile strength more severely than RCA due to the larger surface area and poorer particle shape. However, when combined with fly ash, the reduction was minimized.
- **Poon et al.(2004)** conducted foundational studies that revealed that the presence of old, adhered mortar on RCA particles weakens the interfacial transition zone (ITZ)—a critical microstructural region in concrete. As a result, concrete mixes with RCA showed 10–15% lower compressive strength compared to control mixes with natural aggregates.
- **Limbachiya et al.(2000)** showed that compressive strength reduction can be reduced to <5% when the RCA is processed (cleaned, graded) and used in combination with high-performance admixtures.

CONCLUSIONS

Up to 50% replacement of natural aggregates with recycled aggregates (RCA/RFA) is feasible in M60 and M80 HSC

without significant compromise in mechanical performance. M80 grade concrete shows better long-term performance due to its lower water-cement ratio and denser matrix. Beyond 75% replacement, the concrete shows sharp deterioration in compressive, tensile, and flexural performance. Workability is a critical concern, requiring precise adjustment of admixture dosage and mix water. For structural applications involving aggressive environments, recycled aggregate mixes should include SCMs to maintain performance.

For Construction Practice:

Limit recycled aggregate use to $\leq 50\%$ for structural-grade HSC.

Always pre-treat RCA/RFA by soaking or acid-washing to reduce dust and improve ITZ quality.

Use superplasticizers and mineral admixtures to mitigate strength and workability losses.

Monitor water absorption of aggregates and adjust water-cement ratio accordingly.

For Standards and Policy Makers:

Develop codal provisions for the use of recycled materials in HSC based on extensive regional testing.

Encourage certified recycling plants to produce clean, graded RCA and RFA.

Incentivize green construction practices that use recycled building materials through rating systems like GRIHA, IGBC, and LEED.

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