Recycled Concrete: A Sustainable Material for Modern Construction – A Systematic Review

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Abstract

The rapid expansion of urbanization and infrastructure development has led to a significant increase in the demand for natural construction materials while also producing large quantities of construction and demolition (C&D) waste.Among these waste materials, demolished concrete constitutes a major proportion and poses serious environmental challenges due to landfill disposal and depletion of natural aggregate resources. Recycling demolished concrete into Recycled Concrete Aggregate (RCA) has emerged as an effective solution to promote sustainable construction practices and support the principles of the circular economy.

This systematic review presents a critical analysis of recent studies on recycled concrete, focusing on its production process, mechanical properties, durability characteristics, environmental benefits, economic feasibility, and practical applications. Previous studies indicate that recycled concrete exhibits satisfactory engineering performance for both structural and non-structural applications when proper aggregate processing techniques, optimized mix design, and supplementary cementitious materials such as fly ash, silica fume, and Ground Granulated Blast Furnace Slag (GGBS) are used. Although recycled concrete generally exhibits slightly lower compressive strength and greater water absorption than conventional concrete, recent improvements in recycling techniques have considerably enhanced its overall performance.

The review concludes that recycled concrete represents a promising sustainable construction material capable of reducing landfill waste, conserving natural resources, lowering carbon emissions, and supporting environmentally responsible infrastructure development Future research should focus on improving the long-term durability, maintaining consistent quality of recycled aggregates, and encouraging the large-scale application of recycled aggregate concrete in construction projects.

. **Keywords:** Recycled Concrete, Recycled Concrete Aggregate (RCA), Construction and Demolition Waste, Sustainable Construction, Circular Economy, Green Concrete, Durability

1. Introduction

The construction industry is a key contributor to the economic growth and infrastructure development of every nation. With the rapid pace of urbanization, industrialization, and population growth, the demand for construction materials has increased significantly. Among these materials, concrete continues to be the most widely used worldwide because of its high compressive strength, durability, easy availability, and cost-effectiveness. However, the continuous use of natural aggregates, including sand, gravel, and crushed stone, has led to the depletion of natural resources, environmental degradation, and ecological imbalance.

Simultaneously, the demolition of aging buildings, bridges, pavements, and other infrastructure generates millions of tonnes of construction and demolition (C&D) waste annually. A considerable portion of this waste consists of concrete debris, which is traditionally disposed of in landfills. Such disposal practices occupy valuable landfill space, increase environmental pollution, and represent a significant loss of reusable construction materials.

Recycling demolished concrete into Recycled Concrete Aggregate (RCA) has emerged as an environmentally sustainable alternative to conventional aggregate production. The recycling process involves collecting concrete waste, removing contaminants such as steel reinforcement, wood, asphalt, and plastics, followed by crushing, screening, and grading to produce reusable aggregates suitable for new construction applications.

The use of recycled concrete provides several environmental, economic, and technical benefits. It helps reduce the amount of waste sent to landfills, preserves natural aggregate resources, decreases greenhouse gas emissions, lowers transportation costs, and promotes the principles of sustainable development and the circular economy. Several studies have reported that recycled concrete can be effectively used in residential buildings, highways, pavements, precast concrete products, retaining walls, and foundation works, provided that appropriate quality control practices are implemented.

Despite these benefits, recycled concrete still faces certain challenges, including increased water absorption, lower density, and reduced compressive strength because of the adhered mortar attached to recycled aggregates. However, recent developments in aggregate treatment methods, optimized mix designs, and the use of supplementary cementitious materials such as fly ash, silica fume, and Ground Granulated Blast Furnace Slag (GGBS) have considerably improved the strength, durability, and overall performance of recycled aggregate concrete.

This review aims to systematically evaluate the current state of knowledge on recycled concrete technology by examining previous research, identifying existing challenges, highlighting recent technological developments, and proposing future research directions for sustainable construction practices.

2.Recycled Concrete Technology

Recycled concrete technology has emerged as an important innovation in sustainable construction by converting construction and demolition (C&D) waste into useful construction materials. This technology involves the processing of demolished concrete to produce Recycled Concrete Aggregate (RCA), which can be used as a partial or complete replacement for natural coarse aggregates in the production of new concrete. By reducing the need for natural aggregate extraction and limiting the environmental impacts associated with landfill disposal, this approach contributes to sustainable resource management.

The recycling process generally consists of five major stages: collection of demolished concrete, removal of contaminants, crushing, screening and grading, and quality testing. During the collection stage, concrete waste is transported from demolished buildings, bridges, pavements, and industrial structures to recycling facilities. Contaminants such as reinforcing steel, timber, plastics, asphalt, glass, and gypsum are removed using magnetic separators and manual sorting. The cleaned concrete is then crushed using jaw crushers or impact crushers to obtain aggregates of the desired size. Finally, the aggregates are screened, graded, and tested for engineering properties before being used in new concrete production.

The quality of Recycled Concrete Aggregate (RCA) is influenced by several factors, including the properties of the parent concrete, the crushing method used, the quantity of adhered mortar, and the storage conditions. The presence of attached mortar generally results in higher water absorption and lower aggregate density. However, advanced processing methods, such as mechanical grinding, thermal treatment, carbonation treatment, and chemical pre-soaking, can significantly enhance the quality and performance of recycled aggregates.

The incorporation of supplementary cementitious materials, including fly ash, Ground Granulated Blast Furnace Slag (GGBS), silica fume, and metakaolin, further improves the mechanical properties and durability performance of recycled aggregate concrete. These materials enhance the interfacial transition zone (ITZ), decrease porosity, and help overcome the reduction in strength associated with the use of recycled aggregates.

Recent developments in recycling technologies, such as automated crushing systems, AI-based material sorting techniques, and carbon dioxide curing methods, have further enhanced the quality and sustainability of recycled concrete. These advancements have increased its suitability for both structural and non-structural construction applications.

3. Literature Review

A systematic literature review was carried out to assess recent advancements in recycled concrete technology. Research articles published in internationally recognized journals were analyzed to investigate the mechanical properties, durability performance, environmental effects, economic viability, and practical applications of recycled concrete aggregate.

The review reveals that the majority of researchers consider recycled concrete a sustainable substitute for conventional concrete when appropriate mix design methods and quality control practices are applied. Although recycled aggregates typically show greater water absorption and reduced density compared to natural aggregates, these drawbacks can be effectively controlled through suitable aggregate processing techniques and optimized concrete mix designs.

Various studies have indicated that replacing natural aggregates with recycled aggregates at levels of approximately 30–50% can achieve concrete properties similar to conventional concrete. However, higher replacement ratios may require the addition of supplementary cementitious materials or chemical admixtures to maintain adequate strength and durability performance.

From an environmental perspective, recycled concrete significantly reduces landfill waste, decreases extraction of natural aggregates, lowers greenhouse gas emissions, and supports circular economy principles. Economically, recycled aggregate reduces transportation and disposal costs, particularly in urban regions where demolition waste is readily available.

Overall, the findings from the reviewed literature indicate that recycled concrete has significant potential for promoting sustainable infrastructure development. However, additional research is needed to address challenges related to long-term durability, standardization, and its widespread application on a large scale.

Table 1. Summary of Previous Research on Recycled Concrete

Author	Year	Research Focus	Major Findings
McNeil & Kang	2013	Properties of RCA	RCA concrete showed slightly lower compressive strength but satisfactory structural performance.
Safiuddin et al.	2013	Sustainable Concrete	RCA effectively replaced natural aggregate while reducing environmental impacts.
Tam et al.	2018	Review of RCA Applications	Proper quality control significantly improves recycled concrete performance.
Silva et al.	2019	Aggregate Treatment	Surface treatment reduced water absorption and enhanced strength.
Xiao et al.	2020	Structural Concrete	Recycled aggregate concrete demonstrated satisfactory structural behavior.
Behera et al.	2021	Sustainability	RCA reduced carbon emissions and natural resource consumption.
Kou & Poon	2022	Durability	Supplementary cementitious materials improved durability performance.
Thomas et al.	2023	Green Concrete	RCA contributed to sustainable construction and waste reduction.
Mandal &Shiuly	2025	Mechanical Performance	Mechanical properties improved with optimized mix proportions.
Morales Rapallo &Kuchta	2025	Systematic Review	Self-compacting recycled concrete exhibited promising engineering performance.

Research Gap: Although extensive research has demonstrated the feasibility of recycled concrete, several important research gaps remain:

- Lack of globally standardized guidelines for recycled aggregate quality assessment.
- Limited long-term durability studies under aggressive environmental conditions.
- Insufficient research on recycled concrete for high-rise and earthquake-resistant structures.
- Limited application of Artificial Intelligence (AI) and Machine Learning (ML) in recycled concrete mix design optimization.
- Inadequate life-cycle cost analysis for large-scale infrastructure projects.
- Need for carbon-neutral recycling technologies to further reduce greenhouse gas emissions.

These research gaps highlight the need for continued investigation to improve the performance, reliability, and large-scale implementation of recycled concrete in sustainable construction.

4. Discussion

4.1 Mechanical Properties of Recycled Concrete

The mechanical performance of recycled aggregate concrete (RAC) is mainly influenced by the quality of recycled concrete aggregate (RCA), the percentage of natural aggregate replacement, water–cement ratio, and the adopted mix design. In comparison with conventional concrete, RAC usually shows a minor decrease in compressive strength because of the presence of residual old mortar attached to recycled aggregates. This adhered mortar increases the porosity of aggregates and decreases their density, which leads to weaker bonding at the interface between the aggregate and cement paste.

However, various researchers have found that maintaining the RCA replacement level within the range of 30–50% allows recycled aggregate concrete to achieve compressive strength values suitable for structural applications. The addition of supplementary cementitious materials, including fly ash, silica fume, GGBS, and metakaolin, further improves strength performance by modifying the pore structure and enhancing the interfacial transition zone (ITZ).

Recent studies also indicate that advanced aggregate treatment methods, including carbonation curing, mechanical grinding, and chemical pre-treatment, substantially improve the quality of RCA. Consequently, recycled concrete has become increasingly suitable for reinforced concrete buildings, pavements, bridges, precast elements, and other structural components.

4.2 Durability Performance

Durability is a crucial parameter that influences the long-term performance of recycled concrete. Because of the presence of remaining mortar on recycled aggregates, recycled concrete generally shows higher water absorption and permeability compared to conventional concrete. These characteristics may increase its vulnerability to chloride ingress, sulphate attack, freeze–thaw cycles, and carbonation effects.

However, recent developments in concrete technology have considerably enhanced the durability performance of recycled concrete. The incorporation of mineral admixtures helps reduce permeability by filling fine pores and promoting the formation of additional calcium silicate hydrate (C–S–H) gel. Furthermore, the use of low water–cement ratios and high-performance super plasticizers contributes to improved durability characteristics.

Experimental studies have shown that well-designed recycled concrete can provide durability performance comparable to conventional concrete under normal service conditions..

4.3 Environmental Benefits

The environmental advantages of recycled concrete are among its most significant contributions to sustainable construction.

The recycling of demolished concrete:

- Reduces construction and demolition waste sent to landfills.
- Conserves natural aggregates such as sand and crushed stone.
- Reduces quarrying activities.
- Lowers greenhouse gas emissions.
- Minimizes transportation energy.
- Supports circular economy principles.
- Conserves natural ecosystems.

Studies have shown that recycled aggregate concrete can reduce carbon emissions associated with aggregate production while significantly decreasing landfill requirements.

4.4 Economic Benefits

The economic viability of recycled concrete depends on local availability of demolition waste, transportation distance, and recycling facilities.

Major economic advantages include:

- Reduced landfill disposal cost.
- Lower transportation expenses.
- Reduced consumption of natural aggregates.
- Lower material procurement costs.
- Improved resource utilization.
- Increased sustainability of construction projects.

In metropolitan regions where demolition waste is abundant, recycled concrete often becomes more economical than natural aggregate concrete.

4.5 Challenges Associated with Recycled Concrete

Despite its advantages, several technical and practical challenges continue to limit widespread adoption of recycled concrete.

Major Challenges

- Higher water absorption.
- Lower density.
- Variability in aggregate quality.
- Presence of adhered mortar.
- Lack of standardized specifications.
- Limited awareness among construction professionals.
- Higher processing cost in some regions.
- Insufficient recycling infrastructure.

Addressing these challenges requires improved recycling technology, better quality control, government policies, and updated construction standards.

Table 2. Advantages and Limitations of Recycled Concrete

Advantages	Limitations
Reduces landfill waste	Higher water absorption
Conserves natural resources	Slight reduction in compressive strength
Lower carbon	Quality variation of RCA

Advantages	Limitations
emissions	
Supports circular economy	Lack of standardized specifications
Sustainable construction	Additional processing required
Lower disposal costs	Limited awareness
Reduces environmental pollution	Higher porosity

Figure 1. Recycled Concrete Production Process

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      Demolition of Structures
                 |
                 ▼
   Collection of Concrete Waste
                 |
                 ▼
 Removal of Steel & Contaminants
                 |
                 ▼
         Crushing Process
                 |
                 ▼
        Screening & Grading
                 |
                 ▼
          Quality Testing
                 |
                 ▼
Production of Recycled Aggregate
                 |
                 ▼
      New Concrete Production
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5. Future Research Directions

Although recycled concrete technology has advanced considerably over the last decade, several opportunities remain for future investigation.

Future research should focus on:

- Development of high-performance recycled concrete.
- Artificial Intelligence (AI)-based mix proportion optimization.
- Carbon-neutral recycling technologies.
- Self-healing recycled concrete.
- Nano-material modification of recycled aggregate.
- Long-term durability assessment.
- Life-cycle assessment (LCA).
- BIM-integrated sustainable construction.
- 3D-printed recycled concrete.
- Large-scale field implementation.

These research areas are expected to improve the structural performance, sustainability, and commercial acceptance of recycled concrete in future infrastructure projects.

6. Conclusion

Recycled concrete has become a highly promising sustainable construction material for overcoming the environmental and economic issues associated with rapid urban growth and expanding infrastructure demands. The conversion of demolished concrete into Recycled Concrete Aggregate (RCA) offers an effective approach to reducing construction and demolition waste, conserving natural resources, and limiting environmental impacts.

The systematic review conducted in this study shows that recycled concrete can provide satisfactory engineering performance for various structural and non-structural applications when suitable quality control practices are adopted. Although recycled aggregate concrete generally demonstrates slightly increased water absorption and a minor reduction in compressive strength compared with conventional concrete due to the presence of adhered mortar, these challenges can be reduced through optimized mix design, effective aggregate processing methods, and the inclusion of supplementary cementitious materials such as fly ash, silica fume, and Ground Granulated Blast Furnace Slag (GGBS).

From an environmental viewpoint, the use of recycled concrete helps minimize landfill waste, reduce the consumption of natural aggregates, decrease greenhouse gas emissions, and promote the principles of the circular economy. In terms of economic benefits, it can lower transportation and waste disposal expenses, especially in urban regions where demolished concrete is easily accessible.

Despite these benefits, issues related to aggregate quality variation, durability evaluation, standardization, and large-scale adoption require further research. Future studies should emphasize the development of advanced recycling techniques, AI-assisted mix design optimization, carbon-neutral concrete technologies, and improved long-term durability performance.

Overall, recycled concrete is a feasible and sustainable substitute for conventional concrete and has significant potential to support environmentally responsible infrastructure development in the future.

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