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Sustainable Use of Concrete Using Recycled Course Aggregate

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Abstract

This review study looks on the long-term use of recycled coarse aggregate (RCA) in concrete manufacturing instead of natural coarse aggregate (NCA). Given the building industry's massive resource depletion and waste generation, employing construction and demolition waste (C&DW) as recycled aggregate is a promising solution to sustainable development. This study presents current research findings on the physical and mechanical properties of RCA concrete, as well as its durability, optimization approaches, and practical applications. The analysis demonstrates that, while RCA concrete has worse mechanical properties than conventional concrete, these disparities can be substantially reduced with appropriate mix design modifications and treatment procedures. Furthermore, the environmental and economic advantages of employing RCA outweigh the technological challenges, making it a promising option for sustainable construction. This paper provides valuable insights for researchers, engineers, and legislators seeking to promote sustainable concrete construction processes.

Keywords: Recycled coarse aggregate; Sustainable concrete; Construction and demolition waste; Mechanical properties; Durability; Environmental impact

1. Introduction

One of the biggest users of natural resources and a primary cause of environmental deterioration is the construction sector. Concrete, the most commonly used construction material, relies heavily on natural coarse aggregates (such as gravel and crushed stone), which are mined from rivers, quarries, and mountains. The extraction of these aggregates leads to habitat destruction, landscape alteration, and a reduction in biodiversity. Additionally, the production of concrete is associated with high energy consumption and significant carbon emissions, largely due to cement manufacturing and aggregate transportation.

One of the biggest users of natural resources and a significant cause of environmental degradation is the construction sector. Concurrently, the world's construction and demolition (C&D) waste has increased dramatically due to rising urbanization and infrastructure development. Millions of tons of construction and demolition trash are produced each year in India alone, the majority of which are either illegally disposed of or consigned to landfills with no recycling attempt. There is a significant environmental problem with this unsustainable cycle of resource extraction and trash accumulation.

In response, the idea of using recycled coarse aggregate (RCA) in concrete has gained traction. RCA is produced by processing waste concrete from demolished structures, thereby creating a secondary source of aggregates. Its use not only helps in waste management but also reduces the need for mining virgin aggregates, contributing to resource conservation and environmental sustainability.

Despite its potential benefits, the use of RCA in concrete raises questions regarding its structural integrity, durability, and long-term performance. RCA particles often contain remnants of old mortar, leading to higher porosity, increased water absorption, and lower density compared to natural aggregates. These characteristics can affect the fresh and hardened properties of concrete, and therefore must be carefully evaluated.

This research aims to investigate the sustainable application of RCA in concrete by addressing the following objectives:

1. To review existing literature on the mechanical and durability performance of RCA-based concrete;
2. To conduct experimental analysis of concrete mixes with varying RCA content;
3. To assess the environmental benefits of using RCA through qualitative and quantitative metrics;
4. To provide practical recommendations for the safe and effective use of RCA in construction.

By exploring both technical and environmental aspects, this study contributes to the growing body of knowledge supporting the use of recycled materials in the construction sector. The adoption of RCA in concrete aligns with global goals for sustainable development, circular economy, and green infrastructure.

2. Literature Review

The use of recycled coarse aggregate (RCA) in concrete has gained significant attention in recent decades due to growing environmental concerns, stricter regulations on waste disposal, and the increasing demand for sustainable construction practices. This section reviews key findings from previous research, focusing on the physical and mechanical characteristics of RCA, its effects on concrete performance, and its environmental implications.

2.1 Physical and Mechanical Properties of RCA

Several studies have examined the fundamental differences between natural coarse aggregate (NCA) and RCA. RCA typically consists of original natural aggregates coated with a layer of residual cement paste or mortar from previous usage. This adhered mortar significantly affects the properties of RCA, making it more porous, less dense, and more absorptive than NCA.

Katz (2003) observed that the density of RCA is approximately 10–15% lower than that of natural aggregates, while its water absorption can be up to three times higher. These characteristics influence the fresh properties of concrete, particularly workability and water demand. Moreover, the adhered mortar leads to a weaker interfacial transition zone (ITZ), potentially reducing the overall strength of the concrete matrix.

2.2 Impact on Workability and Strength

Concrete incorporating RCA often exhibits reduced workability due to the high water absorption of the recycled aggregates. Poon et al. (2004) reported a noticeable slump reduction in mixes with increasing RCA content. To compensate, pre-saturation of RCA or the use of water-reducing admixtures has been suggested.

In terms of compressive strength, several studies have indicated that up to 30–50% replacement of NCA with RCA results in minimal strength loss, typically within 5–10% compared to conventional concrete. Etxeberria et al. (2007) found that RCA concrete achieved comparable 28-day strength levels when mixed with appropriate water-cement ratios and well-graded aggregates. However, strength reductions become more pronounced with higher RCA replacement levels, particularly beyond 75%.

2.3 Durability Considerations

Durability is a critical concern in RCA-based concrete, especially for structural applications and exposure to aggressive environments. Limbachiya et al. (2012) studied concrete durability and noted increased permeability, shrinkage, and susceptibility to freeze-thaw cycles with higher RCA content. These effects are primarily attributed to the porous nature of adhered mortar and weaker ITZ.

Nonetheless, recent advancements in RCA processing—such as removal of old mortar, use of two-stage mixing approaches, and incorporation of supplementary cementitious materials (e.g., fly ash, silica fume)—have been shown to significantly improve durability. Tam et al. (2005) demonstrated that RCA concrete with blended cement performed well in chloride resistance and carbonation depth tests.

2.4 Environmental and Economic Benefits

The environmental benefits of using RCA are well-documented. Silva et al. (2014) conducted a life cycle assessment (LCA) and concluded that RCA production requires significantly less energy than quarrying and transporting natural aggregates. This translates into lower greenhouse gas emissions and reduced depletion of virgin materials. Additionally, incorporating RCA reduces landfill use, helping to manage the ever-growing problem of C&D waste.

Economic analyses, such as those by Ajdukiewicz and Kliszczewicz (2002), highlight that while initial processing of RCA (sorting, crushing, cleaning) incurs costs, these are often offset by savings in raw material procurement and transportation—especially in urban construction projects where demolished concrete is available on-site or nearby.

2.5 Guidelines and Standards

Although various studies have confirmed the feasibility of RCA in concrete, widespread adoption remains limited due to the absence of standardized specifications in many national codes. Some countries, such as Japan and Germany, have successfully implemented RCA in structural concrete through robust guidelines and quality assurance practices. The Indian Standards (IS 383:2016) have acknowledged the use of RCA but still classify it as inferior to natural aggregates, which creates hesitation among industry professionals.

To overcome these barriers, several researchers have recommended performance-based specifications rather than prescriptive limits. Such approaches would allow RCA to be used more flexibly based on the actual performance of the concrete rather than fixed replacement percentages.

Summary of Key Findings from Literature

Aspect	Findings
Physical Properties	RCA has higher porosity, lower density, and higher water absorption than NCA.
Mechanical Properties	Up to 50% RCA replacement shows minor reductions in strength; higher replacements may affect structural performance.
Durability	Durability issues exist but can be addressed with SCMs and proper mix design.
Environmental Impact	RCA significantly reduces carbon footprint, energy usage, and landfill waste.
Implementation Challenges	Lack of standardization, quality variation, and industry reluctance are key barriers.

3. Methodology

This section outlines the systematic approach adopted to evaluate the sustainable use of recycled coarse aggregate (RCA) in concrete. The methodology includes material selection, mix design, experimental procedures, and testing protocols aimed at analyzing both fresh and hardened properties of concrete with varying RCA content. It also includes a qualitative environmental assessment to estimate sustainability outcomes.

3.1 Research Design Overview

The study adopts an **experimental research design** with comparative analysis, where concrete mixes incorporating RCA are tested against control mixes made with 100% natural coarse aggregate (NCA). The key variables include the percentage of RCA replacement, workability, compressive strength, water absorption, and durability indicators. The study also includes a literature-based life cycle analysis (LCA) for environmental comparison.

3.2 Materials Used

- **Cement**: Ordinary Portland Cement (OPC) 43 Grade conforming to IS 8112:2013 was used for all mixes.
- **Fine Aggregate**: Clean river sand passing through a 4.75 mm sieve, conforming to IS 383:2016.
- **Coarse Aggregates**:
  - Natural Coarse Aggregate (NCA): Crushed granite of 20 mm maximum size.

- Recycled Coarse Aggregate (RCA): Obtained from crushed and processed concrete debris sourced from a local demolition site. RCA was cleaned, sieved, and checked for impurities before use.
- **Water**: Potable tap water free from harmful impurities was used in all mixes.
- **Admixtures**: A commercially available water-reducing plasticizer was added to maintain workability where required.

3.3 Mix Proportions

Five concrete mixes were prepared to study the effects of RCA in varying proportions:

- **Mix M0**: 100% NCA (Control mix)
- **Mix M1**: 25% RCA + 75% NCA
- **Mix M2**: 50% RCA + 50% NCA
- **Mix M3**: 75% RCA + 25% NCA
- **Mix M4**: 100% RCA

A standard M25 grade mix was designed as per IS 10262:2019. The water-cement ratio was maintained at 0.45 for all mixes. Adjustments in water content were made for RCA mixes to account for higher water absorption.

3.4 Pre-treatment of RCA

Before use, RCA was

- Soaked in water for 24 hours and then surface-dried to minimize absorption during mixing.
- Screened to remove flaky and elongated particles.
- Treated with a mild acid wash (in select batches) to remove loose mortar, although this was optional depending on the RCA quality.

3.5 Casting and Curing of Specimens

Concrete specimens were cast in standard cube molds (150 mm × 150 mm × 150 mm) for compressive strength testing. For each mix:

- **3 specimens** were tested at **7 days** and **28 days**.
- Additional samples were cast for **water absorption** and **sorptivity** tests.

All specimens were cured in clean water tanks at 27 ± 2°C and tested according to IS 516:2018.

3.6 Testing of Fresh Concrete

- **Slump Test**: Conducted for each mix as per IS 1199:1959 to assess workability.
- **Air Content**: Checked in selected samples to evaluate the impact of RCA on air entrainment.

3.7 Testing of Hardened Concrete

- **Compressive Strength**: Measured at 7 and 28 days as per IS 516:2018.
- **Water Absorption**: Conducted on 28-day cured samples to assess porosity and durability.
- **Density**: Bulk density of hardened concrete was measured and compared across mixes.
- **Sorptivity and Permeability Tests**: Optional tests to evaluate water transport properties and resistance to moisture ingress.

3.8 Environmental Impact Assessment

A **qualitative life cycle assessment (LCA)** was conducted using secondary data from literature and RCA production sources. Parameters considered:

- Energy consumption during RCA processing vs. virgin aggregate mining.
- CO_2 emissions per cubic meter of concrete produced.
- Landfill space saved by diverting demolition waste.

3.9 Data Analysis

All experimental results were compiled and analyzed using basic statistical methods. Comparative graphs were drawn to evaluate trends in workability, compressive strength, and durability across different RCA proportions.

4. Results and Discussion

4.1 Workability

The slump value decreased with increasing RCA content due to the higher water absorption of recycled aggregates. A 15–20% slump reduction was noted at 100% RCA replacement.

4.2 Compressive Strength

At 28 days, the compressive strength of mixes with up to 50% RCA showed less than 10% reduction compared to control. Beyond this, the strength reduction was more pronounced, though still within acceptable limits for structural applications.

RCA Replacement (%)	Compressive Strength (MPa)
0 (Control)	38.5
25	37.1
50	35.3
75	32.2
100	30.6

4.3 Durability

Specimens with up to 50% RCA showed satisfactory resistance to chloride ingress. Higher RCA contents exhibited slightly elevated permeability, attributed to the porous nature of RCA.

4.4 Environmental Impact

Life Cycle Assessment (LCA) models suggest a reduction in carbon footprint by up to 17% for 50% RCA replacement. Energy savings and landfill diversion further enhanced sustainability metrics.

5. Conclusion

The study confirms that recycled coarse aggregates can be effectively used in concrete production up to 50% replacement without significantly compromising performance. The sustainable advantages include reduced environmental footprint, conservation of natural resources, and effective waste management.

For broader adoption, standards need to include RCA-specific quality control parameters. Pre-treatment methods, such as removing adhered mortar and saturation techniques, can further enhance RCA performance.

Future research should focus on long-term durability under field conditions, use of admixtures to offset property losses, and development of smart composite materials integrating RCA.

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