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# Enhancing Concrete Sustainability: A Critical Review of Recycled Aggregate Practices

Rahul Sharma[1,*], Harsh Rathore[2]

**Abstract**

*The surge in construction material demand, propelled by urbanization, necessitates sustainable waste management strategies. Recycling demolished waste into concrete has gained prominence due to environmental concerns and resource depletion. This review consolidates insights gleaned from various studies on the utilization of recycled coarse aggregates (RCA) in concrete. Investigations reveal that water absorption in RCA depends on adhered mortar quality, impacting mechanical properties. Various alternative materials and their mechanical performance are explored, highlighting their superiority. Studies emphasize the significance of material characteristics, including abrasion loss and soundness, aligning with transportation specifications. Porosity and permeability variations in recycled aggregate concrete (RAC) are scrutinized, influencing durability. Global research from 1945 to 1985 establishes foundational knowledge, guiding RAC production. Challenges such as workability, strength reduction, and freeze-thaw resistance are addressed, providing a comprehensive understanding. Recent studies have delved into the mechanical properties of RAC, providing valuable insights that contribute to the advancement of sustainable construction practices. This review informs the optimization of RAC formulations, contributing to eco-friendly and efficient construction practices.*

**Keywords:** Concrete durability, environmental impact, mechanical properties, recycled coarse aggregates, resource depletion, sustainable construction, waste management

## INTRODUCTION

The construction sector and concrete producers have realized that it's more practical to use available aggregates rather than searching for the perfect one. This shift acknowledges the challenges in sourcing ideal aggregates and emphasizes optimizing existing resources for satisfactory concrete performance, considering factors like cost-effectiveness and sustainability. Concurrently, the substantial increase in concrete recycling has led to the availability of hundreds of tons of recycled concrete aggregate (RCA), which can be effectively utilized in producing concrete for specific purposes. Presently, RCA primarily functions as a substitute material for natural aggregate in unbound sub-base and base pavement layers during road construction. A significant advancement in advocating for the integration of RCA into new concrete occurred with the publication of the "Specification for Concrete with Recycled Aggregate" by the RILEM Technical Committee 121 in 1994. This publication played a pivotal role in providing standardized guidelines and specifications for incorporating recycled aggregate into concrete mixes, thereby promoting its acceptance and

*__Author for Correspondence__
Rahul Sharma
E-mail: rhs.vask@gmail.com

[1]Student, Department of Civil Engineering, Sanjeev Agarwal Global Educational University, Bhopal, M.P., India
[2]Assistant Professor, Department of Civil Engineering, Sanjeev Agarwal Global Educational University, Bhopal, M.P., India

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utilization in various construction applications. This specification complemented extensive research efforts worldwide, particularly in the United States, Europe, and Japan. The research primarily aimed to deepen the comprehension of the fundamental engineering properties of locally produced RCA and its application in concrete [1–11].

Recycled aggregate concrete (RAC) is typically derived from construction and demolition waste, which encompasses materials generated from construction, renovation, and demolition endeavors. The construction and demolition sector notably constitutes a substantial source of waste in many countries. Historically, landfilling has been the predominant means of disposing of construction and demolition (C&D) waste. However, aligning with the waste management hierarchy and recognizing the resource value of discarded materials, recycling must take precedence as the primary management approach. Discussions in various forums in India have emphasized the recycling of C&D waste. The Committee's report focuses specifically on wastes arising from construction (C) and demolition (D) Activities generating construction and demolition waste encompass a wide range of materials, including excavated materials, tiles, bricks, ceramics, asphalt concrete, plaster, glass, metal and steel, plastics, wood, asphalt, and concrete rubbles [12–17].

The Committee decided to exclude other municipal wastes, such as delisting material or road sweepings, as they do not fall under C&D wastes and should be collected and disposed of separately. Sustainable waste management involves environmentally sound, socially satisfactory, and techno-economically viable practices. It adheres to the waste management hierarchy of avoiding waste generation, followed by reducing, reusing, recycling, recovering, treating, and disposing of produced waste.

An integrated approach, which includes technological, policy, administrative, and legal measures, is crucial for ensuring effective waste management practices [18–25].

Recognizing the importance of proper C&D waste management for sustainability, environmental improvement, pollution control, and conservation of land, materials, and energy resources is crucial.

## OBJECTIVES

The research aims to achieve precise objectives in the realm of recycled aggregates and concrete properties. First, it seeks to scrutinize the water absorption capacity of recycled and natural aggregates, with a focus on the influence of adhered mortar quality and quantity. Second, the investigation delves into the mechanical properties of alternative materials, emphasizing the impact of particle size and binder content. The study also examines specifications recommended by the Florida Department of Transportation (FDOT) for RCA in pavement applications, considering factors such as abrasion loss and soundness. Furthermore, the research aims to conduct a comprehensive analysis of porosity, specifically investigating the increase in porosity observed in RAC when natural aggregates are substituted with recycled coarse aggregates (RCA) [26–29].

Finally, the assessment will encompass the properties of recycled aggregates obtained from crushed concrete, including water absorption, bulk specific gravity, bulk density, cement content, and crushing value at different ages.

## LITERATURE REVIEW

The escalating demand for construction materials, driven by urbanization and population growth, has resulted in a proportional increase in the generation of demolition waste. Effectively utilizing this waste has become imperative. Heightened expectations from the public toward government organizations and industries for alternative materials have prompted a focus on the reuse of demolished waste. Recognizing the factual threat of natural resource depletion and the environmental pollution caused by waste dumping, there is a general consensus on the viability of using RCA in concrete.

 

The water absorption capacity of both recycled and natural aggregate is influenced by the quality and quantity of adhered mortar.

The mechanical properties of alternative materials such as slate waste and limestone, concluded that many alternative materials outperformed conventional ones. They emphasized that the strength and stiffness of the materials depend on the coarsest particle size and the amount of binder.

The FDOT specifications recommended that the Los Angeles abrasion loss should be less than 45%, and soundness should be less than 15%. Shiou in 2001 evaluated the physical and engineering properties of RCA and developed specifications for its use in pavement base courses. The results suggested that the Los Angeles abrasion loss should be less than 48%, and the sodium sulfate test is not applicable for RCA.

Gomez in 2002 conducted a study on the porosity of RAC, revealing a considerable increase in porosity when natural aggregate is replaced by RCA.

The properties of recycled aggregates made from crushed concrete were investigated.

Reports indicate that properties such as water absorption, bulk specific gravity, bulk density, cement content, and crushing value at various ages were found to be similar.

The comparison of specific gravity between natural aggregate and demolished concrete aggregates.

The study revealed that the specific gravity of natural aggregate was greater than that of demolished concrete aggregates.

The addition of silica fume to both RAC and natural aggregate concrete resulted in an increase in water absorption.

The testing of water absorption by conventional methods may not provide accurate results for recycled aggregate. Real-time assessment of water absorption was proposed as a method to present values at varying time intervals. This approach was considered a simple, precise, and viable alternative for measuring water absorption, particularly for recycled aggregate.

As per Torben C. Hansen's findings in 1983, extensive global research spanning from 1945 to 1985 on recycled aggregates and concrete has been compiled. This compilation serves as a guide for the production and evaluation of RAC, offering insights into design considerations.

Concrete incorporating recycled coarse aggregate and natural sand necessitates 5% more water for workability, while an additional 15% water is required when recycled sand is also used to achieve comparable workability.

Hansen's report in 1985 highlighted that 100% recycled coarse aggregate concrete demands more cement, a trend similarly observed for recycled fine aggregate. The dynamic and static modulus of elasticity were found to decrease for RAC.

Experimental studies conducted on the use of recycled aggregate in construction projects in Hong Kong have yielded significant insights. It was concluded that high-quality RAC has been successfully produced for structural applications.

Concrete mixtures incorporating recycled aggregates were thoroughly examined, revealing that air-dried aggregate concrete exhibited the highest compressive strength. Conversely, both control concrete and concrete containing waste coarse aggregates experienced a decrease in compressive strength.

Through the utilization of an orthogonal array, a systematic procedure for evaluating the optimal mixture proportioning of RAC was demonstrated.

Furthermore, variations in slump were observed for different moisture states of the aggregates in fresh concrete, highlighting the importance of moisture content in achieving desired workability.

Regarding the utilization of RCAs in concrete production, challenges with workability were identified. It was concluded that concrete containing more than 50% waste concrete aggregates tends to experience greater workability issues.

A study investigating concrete with recycled aggregate derived from high-performance concrete revealed that such concrete exhibits higher compressive strengths compared to conventional concrete.

Moreover, the interfacial bond was identified as a critical factor influencing tensile strength, with a decrease in tensile strength observed as aggregate size increases, particularly pronounced in high-strength concrete.

In high strength concrete, the onset of crack propagation was found to decrease with increasing aggregate size, while remaining relatively constant in Low Strength Concrete with similar aggregate sizes.

Considering the characteristics of saturated RAC, including high porosity, elevated water-to-cement (w/c) ratio, lower mechanical properties, and reduced frost resistance, it is advised against its structural usage under severe exposure conditions. The expulsion of water into cement paste by freeze-thaw cycles weakens RAC.

RAC, freezing and thawing resistance is very low due to an improper void system formed, which converts the total void system to a partial non-air-entrained system.

The behavior of strength–strain curves showed similarity for replacement levels from 0% to 100%. At 100% replacement, the maximum strain increased by 20%.

The elastic modulus of RAC is notably lower, with a reduction of approximately 45% compared to normal concrete when 100% replacement is implemented.

Studies comparing the modulus of elasticity between natural aggregate concrete and RAC indicate that the latter typically exhibits a 20%–25% lower modulus of elasticity than natural aggregate concrete.

Research suggests that the mechanical performance of RAC, including its compressive strength, can be improved by employing a two-stage mixing approach.

It has been observed that the compressive strength of RAC is significantly influenced by the water-to-cement (w/c) ratio of the mix.

Additionally, investigations into RAC have revealed that it often displays a higher ratio of prism compressive strength to cube compressive strength compared to normal concrete. The failure mode of RAC is predominantly shear, with a relatively short failure process.

The use of coarse RCA along with fine RCAs as sub-base materials. They concluded that size fractions of < 0.15 and 0.3–0.6 mm were likely the principal cause of the self-cementing properties of fine RCAs.

 

The study investigated the properties of concrete incorporating recycled fine and coarse aggregates under ambient and elevated temperatures. Findings indicated that concretes with a 10% aggregate replacement with fine waste glass, coarse waste glass, or both exhibited superior properties in both fresh and hardened states compared to those with higher replacement percentages, at both ambient and high temperatures. Experimental test results of RAC beams subjected to low-velocity impact. Beams with varying amounts of recycled coarse aggregate were tested for acceleration, strains, support reaction histories, as well as physical and mechanical properties. The study observed that 25% recycled coarse aggregate concrete had no significant influence on the strength of concrete.

The study examined the flexural behavior of RAC beams in comparison to natural aggregate concrete beams under short-term loading conditions. It aimed to assess the feasibility of utilizing RAC in structural concrete elements. Results indicated satisfactory flexural behavior of RAC beams compared to natural aggregate concrete beams under both service and ultimate loading conditions.

The study investigated the mechanical properties of confined RAC under axial compressive loading, employing both steel tubes and glass fiber-reinforced plastic tubes for confinement. The study noted changes in strength and deformation, observing a decrease in peak strength and an increase in corresponding strain with an increase in the replacement of recycled coarse aggregate concrete.

The study focused on evaluating the mechanical and material properties of concrete incorporating recycled coarse aggregate. The study observed and analyzed residual compressive and tensile strengths, modulus of elasticity, damage, and failure patterns. Results suggested that concrete with fully or partially replaced recycled coarse aggregate demonstrated good performance under elevated temperatures.

The study comprehensively assessed the strength and permeability characteristics of fiber-reinforced high-performance concrete manufactured using recycled coarse aggregate. It conducted evaluations on various mechanical properties such as compressive, tensile, flexural, and shear strengths, alongside examining chloride ion permeability. The outcomes demonstrated the efficacy of incorporating recycled coarse and fine aggregates in the production of fiber-reinforced high-performance concrete.

## CONCLUSION

The extensive literature review on recycled aggregates and concrete offers valuable insights into their properties, challenges, and potential opportunities for utilization in construction practices. The research objectives aim to build upon existing knowledge by investigating specific aspects of recycled aggregates and concrete, addressing issues such as water absorption, mechanical properties, specifications, porosity, and innovative assessment methods.

The findings from these objectives are anticipated to contribute to the understanding of RAC's performance and its suitability for various applications. The study seeks to provide practical recommendations for optimizing mixture proportions, enhancing mechanical properties, and addressing workability issues associated with recycled aggregates. Additionally, the research aims to contribute to the ongoing discourse on sustainable construction practices by evaluating the environmental implications of using recycled materials in concrete.

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