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Comprehensive Review of Recycled Aggregate Concrete in Construction: Suitability, Properties, and Sustainable Practices

Deepika Patel[1,*], Harsh Rathore[2]

Abstract

Concrete production, integral to construction and demolition processes, generates substantial waste. This waste can be repurposed as recycled aggregates in new concrete production, offering sustainable solutions and addressing resource management and environmental concerns. This literature review explores the utilization of construction and demolition waste as aggregates in recycled aggregate concrete (RAC), with a focus on key areas, including the suitability of RAC, its fresh properties, mix design, mechanical characteristics, and durability. Researchers such as Khalaf and Oikonomou have endorsed demolition waste as a reliable alternative, particularly for fire-resistant applications. Additionally, Kumar Neeraj Jha has emphasized global challenges and the critical need for government support to promote the widespread adoption of recycled aggregates. Fresh property studies conducted by Girish and Panda have underscored the significance of yield stress and plastic viscosity for RAC's concrete performance. Notably, mechanical characteristics studies indicate that RAC can match the mechanical strength of conventional concrete, with potential improvements achievable through the incorporation of supplementary materials and innovative techniques. Durability studies have showcased RAC's potential for enhancements through surface treatments and the use of supplementary cementitious materials. This work provides insights into the current state of research on recycled aggregate concrete, emphasizing its potential to address environmental concerns while maintaining structural performance in construction applications.

Keywords: Recycled aggregate concrete, construction and demolition waste, fresh properties, mix design, mechanical characteristics, Durability

INTRODUCTION

Concrete production is a fundamental component of construction and demolition processes. The construction industry faces a significant challenge in ensuring that planned activities are completed safely, sustainably, and efficiently, contributing to economic development and societal well-being. The demands of globalization and population growth have led to an increased need for concrete, which, in turn, has elevated the amount of waste generated by construction activities. Effective resource management and the utilization of construction and demolition waste have become crucial in addressing these challenges. Much research is being conducted to tackle the obstacles associated with using this waste in various applications.

In any construction project, various materials such as concrete, steel, bricks, stones, glass, and more are essential. However, concrete remains the primary construction material due to its adaptability and suitability for evolving environments. To ensure

***Author for Correspondence**
Deepika Patel
Email: deepikapatel3999@gmail.com

[1]Student, Department of Civil Engineering, Sanjeev Agarwal Global Educational University, Bhopal, Madhya Pradesh, India
[2]Assistant professor, Department of Civil Engineering, Sanjeev Agarwal Global Educational University, Bhopal, Madhya Pradesh, India

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the responsible use of resources, environmental protection, cost-effectiveness, and energy conservation, it is imperative to incorporate construction and demolition waste as aggregates in new concrete production. This approach shows significant promise when applied on a large scale.

A substantial portion of concrete, approximately 70%, consists of aggregates, making it a key focus for waste material reuse. Various waste materials, including slag, power plant waste, concrete waste, mining debris, and quarry waste, can serve as suitable aggregates. Researchers are actively investigating the structural feasibility, economic viability, and cost-effectiveness of using construction and demolition waste as aggregates. These studies adapt the characteristics of these waste materials to region-specific parameters and assess their variations over time. Researchers are particularly interested in understanding how the inclusion of recycled aggregates in concrete impacts strength, mechanical properties, and durability. A comprehensive literature review has been conducted to evaluate the suitability of recycled aggregates for use in structural concrete production [1–17].

OBJECTIVES

The objectives of this literature review are twofold: firstly, to comprehensively evaluate the current state of research regarding the utilization of recycled aggregate concrete (RAC) in construction and demolition processes, covering key aspects such as its suitability, fresh properties, mix design, mechanical characteristics, and durability. Secondly, to synthesize the findings from a diverse range of studies to provide a holistic understanding of the potential benefits and challenges associated with RAC adoption in the construction industry. By achieving these objectives, this review aims to contribute to the knowledge base, inform industry stakeholders, and stimulate further research in the pursuit of sustainable and efficient construction practices [18–25].

LITERATURE REVIEW

Review of Existing Literature on the Use of Construction and Demolition Waste in Recycled Aggregate Concrete

In his research, Khalaf explored the use of demolition waste as an alternative aggregate in concrete production and concluded that it is a dependable option. Additionally, the study suggested that C&D waste could find applications where low density and fire resistance are desired.

Concrete recycling, specifically proposing Greek specifications for recycled concrete aggregates (RAC) based on international experiences and practices. The research put forward testing guidelines and limits for RAC to serve as a foundation for both pilot projects and larger-scale initiatives, promoting the economic and environmentally friendly use of RAC while conserving natural resources [26–40].

Various challenges related to the utilization of recycled aggregates from C&D waste, offering a brief overview of the global landscape of recycled aggregate usage and government involvement in recycling initiatives. The study identified key obstacles to the widespread adoption of recycled aggregates, including a lack of awareness programs, insufficient government support, and the absence of specifications or codes governing the reuse of these aggregates in new concrete.

The researchers noted that their study employed concrete with a strength grade of 35MPa and a slump range of 75mm to 100mm, primarily for applications such as pile caps, ground slabs, external works, mass concrete, and minor concrete work. They suggested further investigations to explore the expanded utilization of recycled aggregates for structural purposes.

Review of Fresh Properties of RAC in Existing Literature

The rheological behavior of concrete, focusing on yield stress and plastic viscosity, which are crucial for concrete performance. They applied the Newtonian model using the Bingham equation to establish the relationship between yield stress and plastic viscosity.

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A study using recycled coarse aggregates from a 25-year-old building to produce self-compacting concrete (SCC) and analyze its behavior compared to normal concrete. The authors found that as the replacement percentage of recycled aggregates increased, the strength of SCC decreased. Concrete made with 100% replacement of recycled aggregates exhibited reduced compressive strength, split tensile strength, and flexural strength when compared to conventionally vibrated concrete. The study concluded that SCC could marginally achieve the required compressive strength, up to a 30% replacement of recycled coarse aggregates.

The water absorption capacity of recycled aggregates through Si-based polymer treatment. Two types of recycled aggregates were used in the study. It was observed that, in a laboratory environment, the water absorption behavior of recycled coarse aggregates (RCA) and crushed recycled aggregates (CRA) decreased by 7 times and 9 times, respectively, when treated with Si-based polymer compared to untreated RCA.

The impact of compound admixtures on the properties of recycled aggregate concrete (RAC) and assessed Bingham parameters using rheographs. The researchers observed differences between the direct volume replacement method and the equivalent mortar volume (EVM) method. Direct volume replacement increased the fresh concrete density compared to the EVM proportioning method. The addition of superplasticizer reduced yield stress, but the study did not provide conclusive evidence regarding plastic viscosity, although a marginal reduction was noted.

The impact of recycled aggregate on the mechanical and tribological behavior of concrete. The research included tests to determine absorption capacity, physical and mechanical properties, and the characterization of constituents. The results revealed that recycled aggregates had a higher porosity, approximately 17% greater than natural gravel, which resulted in lower wear resistance and absorption capacity. To maintain the same workability while using a superplasticizer, there was a decrease in compressive strength of 13%. The friction performance at the interface increased with an increase in the percentage of recycled aggregate, and the value of plastic viscosity for a 100% replacement ratio was almost twice that of reference concrete.

The effects of different quantities of concrete extracted from a 15-year-old reinforced cement concrete culvert that had not been exposed to any chemicals. The study involved replacing coarse aggregates with percentages of 0%, 25%, 50%, and 100% in concrete mixes. Both manual and jaw crushers were used to obtain recycled aggregates, resulting in a reduction in adhered mortar. The research analyzed various properties, including depth of chloride penetration, modulus of elasticity (Ec), water absorption, volume of voids, density of hardened concrete, and indirect tensile strengths. The study found that strength properties at 7 days were better compared to 28 days when using 100% replacement of coarse aggregate. Due to the adhered mortar on recycled aggregates, water absorption and voids volume were slightly higher, by 1.81% and 2.59%, respectively, compared to conventional aggregates. The study concluded that field-recycled coarse aggregates could be used in concrete. The surface of recycled coarse aggregate was found to be more porous with a rough texture due to the adhered mortar, which also exhibited slower strength achievement compared to virgin aggregate concrete at 28 days of curing.

Review of Literature on Recycled Aggregate Concrete (RAC) Mix Design

A full factorial technique to optimize various concrete mix proportions. The parameters considered for optimization encompass w/c (water-cement) ratios, CA/TA (coarse aggregate/total aggregate) ratios, and FA/TA (fine aggregate/total aggregate) ratios. Through regression analysis, mathematical polynomial models are developed to establish a relationship between mix proportions and compressive strength in concrete.

The influence of recycled coarse aggregate on concrete mix design and its impact on durability properties. The research suggests that the replacement of natural aggregates with recycled aggregates results in reduced strength. However, the study finds that replacement levels of up to 80% can be acceptable, provided necessary corrections are applied during mix design. The study also evaluates the Ultrasonic Pulse Velocity (UPV) of Recycled Aggregate Concrete (RAC), which exhibited favorable results, achieving values exceeding 4 km/s. Permeability of concrete is observed to increase with rising recycled coarse aggregate content, although continuous curing over time gradually reduces this effect.

On three distinct mix designs for normal aggregate concrete, varying parameters such as water-cement ratio, the amount of water reducers, and air-entraining agents. These parameters are tested with three different grades of aggregate sizes (9.5 mm, 12.5 mm, and 19 mm). The three mix design methods explored are the direct weight replacement method (DWR), equivalent mortar replacement (EMR), and direct volume replacement method (DVR). The study concludes that the DVR method offers improved workability when compared to DWR and EMR methods. Importantly, these methods do not significantly impact compressive strength and elastic modulus.

The researcher optimizes concrete mixtures using experimental data. The approach involves a full factorial design that incorporates major factors and varying levels known to influence concrete compressive strength. A total of 27 trial mixes are considered, with varying levels of key factors. The research employs analysis of variance (ANOVA) to reveal.

Review of Mechanical Characteristics of Recycled Aggregate Concrete (RAC)

In this study methods to improve the compressive strength of recycled aggregate concrete. They introduced a two-stage mixing approach (TSAM) to reduce strength variations between natural aggregate concrete and recycled aggregate concrete. TSAM resulted in increased density, improved interfacial transition zone, and higher strength compared to conventional mixing methods.

The shear and compressive strength of Recycled Coarse Aggregate (RCA) concrete with strengths ranging from 20-50 MPa. The study found that, for the same mix proportion and slump, the 28-day cylinder strength and indirect shear strength of RAC were 90% of those of normal aggregate concrete (NAC). For cylinder strength in the range of 25-30 MPa, the modulus of elasticity of RAC was approximately 3% lower than that of NAC.

The behavior of recycled aggregate concrete in the production of structural concrete. The study included the use of silica fume and fly ash, resulting in a 10% reduction in strength and a 13% reduction in flexural strength compared to 100% replacement with recycled aggregates.

The feasibility of using RAC with the inclusion of clay bricks in primary concrete structures. The mix designs and physical and mechanical properties of concrete with CCB and RCA were affected when the inclusion level exceeded a certain limit.

The post-fire mechanical performance of concrete made with recycled concrete coarse aggregates. They found that despite differences in the thermal properties of the matrix, the aggregate interface did not influence the material's thermal response.

Behavior of recycled aggregate concrete with a grade of M35, including the addition of silica fume. They suggest that the inclusion of more than 15% silica fume does not significantly affect the concrete's strength properties and is particularly beneficial for acid resistance.

The fundamental mechanical properties of recycled aggregate concrete with partial replacement of fine recycled aggregate. They concluded that there is an 18% reduction in bond strength of recycled aggregate concrete compared to natural aggregate concrete. The author also proposed a predictive equation for bond strength based on the replacement ratio of recycled aggregates and compressive strength.

In this study, researchers explored the enhancement of recycled aggregate concrete behavior by considering TSMA (thermally stable microcapsules) and immersing the recycled aggregates in polymer solutions with varying concentrations prepared under laboratory conditions. Recycled aggregates included 90-day-old recycled aggregate and conventional recycled aggregates from demolition waste. The author suggested that a polymeric film was developed, and the results were found to be promising.

Review of the existing literature on the Durability Characteristics of Recycled Aggregate Concrete (RAC)

An experimental study to improve the quality of Recycled Concrete Aggregate (RCA) through various surface treatment methods, including water and diluted acid. The results indicated that RCA treated with nitric acid yielded better results compared to hydrochloric and sulfuric acid treatments.

The research on M35, M40, and M45 grade recycled aggregate concrete prepared following IS 10262:2009 standards for durability studies. They considered replacement ratios of 0%, 20%, 40%, 60%, 80%, and 100%. The results indicated that the 40% replacement ratio exhibited lower sorptivity and water absorption compared to conventional concrete, while still remaining within acceptable limits.

How pore internal pressure caused by moisture evaporation and thermal stresses due to temperature gradients play a critical role in concrete spalling. Particularly, spalling is more likely to occur in ultra-high performance and high-performance concrete with low permeability, leading to increased pore pressure and potentially explosive spalling.

The residual mechanical strength of recycled aggregate concrete exposed to different temperatures. They compared six concrete mixes using coarse aggregates from recycled concrete aggregate, river gravel, and crushed limestone aggregate. The results showed that recycled aggregate performed better at elevated temperatures compared to conventional concrete.

The strength and durability of recycled aggregate with wastewater in the United Arab Emirates. While the effect on axial and bending strength was moderate, significant effects were observed on durability properties, which could be improved by adding fly ash and ground granulated fly ash.

The creep strain of recycled aggregate concrete using aggregates from concrete. They found that creep increased with higher coarse aggregate content, with a 32% average increase at a 100% replacement ratio. Even a 20% increase in replacement ratio led to a 12% increase in concrete creep. The role of recycled concrete aggregates in relation to creep depended on the adhered mortar, and the effect varied with the design strength of concrete, although this aspect wasn't clearly depicted in the graph depicting creep coefficient versus compressive strength.

A study in which a small portion (20%) of both fine and coarse recycled aggregates from high-performance concrete mixes (HPC) were replaced to enhance performance. Various combinations of replacements were tested, and most of them yielded slightly better results than the control mix. The hybrid mixes also exhibited favorable characteristics in terms of workability, strength, and resistance to sulphate attack.

The contaminants present in recycled aggregates that could affect the strength and durability of concrete. They proposed minimizing the workability issues of Recycled Concrete Aggregates (RCA) by wetting the aggregates and incorporating supplementary cementitious materials as partial replacements for Ordinary Portland Cement (OPC).

CONCLUSION

The literature review underscores the growing importance of recycled aggregate concrete (RAC) as a sustainable solution in the construction industry. Researchers have explored various aspects of RAC, from its suitability as an alternative to natural aggregates to its fresh properties, mix design considerations, mechanical characteristics, and durability aspects.

Several key findings emerge from the reviewed studies:

- Demolition waste can serve as a reliable alternative aggregate, offering fire-resistant applications and environmental benefits.
- Global challenges and the need for government support are highlighted, indicating the importance of policy measures to promote recycled aggregates.
- Fresh properties of RAC, such as yield stress and plastic viscosity, are critical for concrete performance, and they can be optimized for specific applications.
- Mix design techniques, including optimization through experimental data, provide insights into achieving workable and structurally sound RAC mixes.
- RAC can match the mechanical strength of conventional concrete, with potential improvements through the incorporation of supplementary materials.
- Durability studies indicate that RAC can exhibit favorable performance, especially when subjected to treatments and quality-enhancing measures.

In conclusion, RAC offers a promising avenue for addressing environmental concerns and resource management in the construction industry. Further research and development are needed to optimize RAC production processes, enhance its performance, and promote its widespread adoption in construction projects.

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