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Experimental Investigation on the Use of Recycled Aggregate in Concrete- A Review

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Abstract- The construction industry is one of the largest consumers of natural resources, particularly coarse and fine aggregates, and at the same time it generates a massive amount of construction and demolition (C&D) waste. Rapid urbanization, redevelopment activities, and infrastructure expansion have increased the volume of demolished concrete waste, which is commonly disposed of in landfills or dumped in open areas. This practice creates severe environmental issues such as land pollution, dust generation, and depletion of natural aggregate sources. Therefore, the reuse of recycled aggregate (RA) obtained from demolished concrete is gaining significant attention as an eco-friendly and sustainable alternative to natural aggregate (NA). Recycled aggregate concrete (RAC) has emerged as a promising material in sustainable construction, offering the dual advantage of reducing C&D waste disposal and conserving natural resources. This review paper presents a detailed evaluation of experimental investigations conducted on recycled aggregate concrete over the last decade. The paper discusses the influence of recycled coarse aggregates (RCA), recycled fine aggregates (RFA), and recycled powders (RP) on the fresh properties, mechanical properties, durability performance, and structural behavior of concrete. It highlights the findings of major studies related to compressive strength, tensile strength, flexural strength, modulus of elasticity, workability, density, water absorption, shrinkage, permeability, frost resistance, and chloride penetration. Additionally, the review includes innovative treatment and improvement techniques such as heating treatment, ball milling method, slurry mixing approach, nano-silica incorporation, mineral admixtures (fly ash, silica fume, slag, alccofine), and fiber reinforcement. The study also identifies key research gaps such as limited durability studies in Indian climatic conditions, lack of standardized mix design methodology for RAC, insufficient dynamic structural performance analysis, and limited field-scale applications. Finally, this review concludes that recycled aggregates can be effectively used in concrete production, particularly at partial replacement levels (20–40%) without significant loss of strength. With suitable treatments and the use of supplementary cementitious materials, higher replacement levels can also be achieved while maintaining adequate performance. Thus, RAC has strong potential for sustainable and economical construction practices.

Keywords: Recycled Aggregate Concrete (RAC), Recycled Coarse Aggregate (RCA), Recycled Fine Aggregate (RFA), Construction and Demolition Waste, Sustainable Concrete.

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its high compressive strength, durability, availability of raw materials, and versatility. Concrete production requires large quantities of natural resources such as cement, sand, and coarse aggregates. Among these constituents, aggregates occupy nearly 60–75% of concrete volume. The continuous extraction of natural aggregates from riverbeds and quarries has caused environmental degradation such as soil erosion, riverbank instability, groundwater depletion, and ecological imbalance. At the same time, rapid urbanization and infrastructure development have increased construction and demolition activities, generating huge quantities of waste materials. C&D waste consists of concrete debris, bricks, tiles, mortar, ceramics, asphalt, steel, wood, and other materials.

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Disposal of such waste in landfills is not only costly but also harmful to the environment. In developing countries like India, demolition waste is often dumped in open lands or low-lying areas, leading to land pollution and health hazards. Recycling of demolished concrete into aggregates provides a sustainable solution. Recycled aggregates are produced by crushing old concrete and separating aggregates from adhered mortar. However, recycled aggregates generally have inferior properties compared to natural aggregates due to adhered cement paste, higher porosity, micro-cracks, and increased water absorption. These factors influence the mechanical and durability performance of recycled aggregate concrete. The utilization of recycled aggregates in concrete has become an important research area. Many researchers have conducted experimental investigations to evaluate the feasibility of using recycled aggregates in structural and non-structural concrete applications. Recent studies have also focused on improving recycled aggregate quality through mechanical and chemical treatment methods. This review paper compiles and analyzes experimental research conducted worldwide, highlighting the influence of recycled aggregates on concrete properties and identifying future research directions.

II. LITERATURE REVIEW

The utilization of recycled aggregate in concrete has become an important area of research due to increasing construction and demolition (C&D) waste generation and the rapid depletion of natural aggregate sources. Several researchers have carried out experimental investigations to evaluate the feasibility of using recycled aggregates, recycled fine aggregates, recycled powders, plastics, ceramics, and treated demolition waste materials in concrete production. These studies mainly focused on fresh properties, mechanical strength performance, durability behavior, microstructural characteristics, and treatment techniques for improving recycled aggregate quality. A detailed review of the available literature is presented below.

Osei, D. Y. (2014) – This research investigated the partial and full substitution of crushed granite with recycled plastic in concrete production. Concrete mixes were prepared with 25%, 50%, 75%, and 100% volume replacement of natural aggregate by recycled plastic, alongside a 1:2:4 control mix. Workability was assessed using the compacting factor test, and compressive strength was measured at 7, 14, 21, and 28 days. Results showed that as the percentage of recycled plastic increased, both density and compressive strength decreased; however, workability was not significantly affected. The study concluded that recycled plastic can be used as a partial replacement for conventional aggregates, enabling the production of both lightweight and structural concrete while promoting sustainability and reducing environmental impacts.

Niranjani, S., Rajagopalan, S., Rajalakshmi, S., Rathnavathi, M., & Manimaran, S. (2017) – This study examined concrete mixes with 25%, 50%, and 75% replacement of natural aggregate (NA) with recycled aggregate (RA) and included mineral and fiber admixtures: fly ash (10% by weight of cement), silica fume (7.5% by weight of cement), and glass fiber (0.3% by weight of fine aggregate). Tests conducted included compressive strength, tensile strength, and flexural strength. Results demonstrated that optimal combinations of RA and admixtures produced concrete with satisfactory structural performance, strength, and durability. The study highlighted that RA generally has 3–10% lower density and higher water absorption (3–5 times) than NA due to adhered cement paste, and that up to 30% RA replacement does not significantly affect concrete strength, while fiber and admixture incorporation can further enhance mechanical and durability properties.

Santosh Kumar et al. (2017) carried out an experimental investigation on recycled aggregate concrete (RAC) using the Pre-Soaked Slurry Two Stage Mixing Approach (PSTSMA) to enhance the mechanical performance of concrete. In this study, recycled coarse aggregates (RCA) were used as a replacement for natural coarse aggregates in M40 grade concrete at replacement levels of 30%, 50%, and 100%. The experimental program mainly evaluated the compressive strength, split tensile strength, and flexural strength of RAC prepared using PSTSMA and compared the results with the Normal Mixing Approach (NMA). The findings revealed that the PSTSMA method significantly improved the bonding in the interfacial transition zone (ITZ), leading to better strength performance. It was observed that replacing 30% RCA using PSTSMA did not significantly affect the concrete characteristics and provided strength results comparable to conventional concrete. Moreover, PSTSMA improved the strength of recycled aggregate concrete by approximately 6.35% at 28 days compared to concrete prepared with the normal mixing method. Overall, the study concluded that PSTSMA is an effective mixing technique for producing recycled aggregate concrete with enhanced mechanical properties, and it is particularly suitable for partial replacement levels such as 30% RCA without compromising performance.

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Gopalsamy, P., Poornima, E., Abdul Razick, M., Yasar Arafath, N., & Sundar, V. (2017) – This study focused on the experimental evaluation of using recycled concrete aggregate (RCA) as a partial replacement for natural coarse aggregates in concrete. RCA was obtained from demolished concrete structures including buildings, bridges, roads, and water tanks. Concrete mixes were prepared with replacement levels ranging from 5% to 75%. The research highlighted that using RCA can reduce dependence on natural aggregates, minimize construction waste disposal, and lower overall material costs. While higher replacement percentages led to slight reductions in compressive strength, mixes with moderate RCA content demonstrated acceptable structural performance, making RCA a viable sustainable alternative for concrete production in urban construction.

Denisiewicz et al. (2019) conducted an experimental investigation on concrete prepared using different types of recycled aggregates to evaluate its suitability for structural construction. The recycled aggregates were obtained from three waste sources: sanitary ceramics (SC) such as washbasins and toilet bowls, building ceramics (BC) such as solid bricks, and concrete rubble (CR). The study examined key engineering properties including compressive strength, bending tensile strength, total shrinkage, water absorption, watertightness, and frost resistance. The experimental results indicated that concrete made with sanitary ceramic aggregates (SC) and concrete rubble aggregates (CR) demonstrated satisfactory strength and durability performance, making them suitable for structural applications. In particular, these concretes showed acceptable compressive strength, lower shrinkage behavior, good watertightness, and adequate frost resistance. However, concrete produced with building ceramic aggregates (BC) exhibited comparatively weaker mechanical properties and durability performance, leading the authors to conclude that BC-based recycled aggregate concrete is not recommended for structural use. The research also highlighted that durability aspects such as frost resistance and watertightness of recycled aggregate concrete are still insufficiently discussed in existing literature, emphasizing the importance of further investigations in this area. Overall, the study confirmed that sanitary ceramics and concrete rubble waste can be effectively reused as sustainable recycled aggregates in concrete structures without significantly compromising performance.

Dilbas et al. (2019) conducted an experimental investigation on properties of recycled aggregate concrete using an optimized Ball Milling Method (BMM). The study applied a mechanical treatment method to recycled aggregates (RA) with an optimization process using the Los Angeles test machine. It was observed that the initial water absorption value of untreated RA (8.95%) was significantly reduced to 0.84% after BMM. Concrete mixes with 0–60% recycled aggregate were prepared, and results showed that the use of improved RA (RA-i) up to 60% did not negatively affect the physical and mechanical properties of concrete. The study concluded that the optimized BMM effectively enhanced the quality of recycled aggregates and allowed their higher utilization (up to 60%) in concrete without compromising strength and durability.

Agarwal, A., Bhusnur, S., & Shanmuga Priya, T. (2020) – The study investigated concrete made from laboratory concrete waste by replacing natural aggregates (NA) with recycled aggregates (RA) at 20%, 40%, and 60% levels and partially replacing cement with 1%, 3%, and 5% nano-silica (NS). Results indicated that using RA alone decreased strength, but incorporating nano-silica improved both strength and durability. The optimum combination was 40% RA and 3% NS, achieving maximum compressive, tensile, and flexural strength, improved microstructure, enhanced durability (measured via water sorptivity and rapid chloride penetration), and reduced CO_2 emissions, demonstrating a sustainable approach to concrete production.

Rajprasad and Pannirselvam (2020) carried out an experimental investigation on concrete using treated recycled aggregate. The study emphasized the problem of large quantities of demolition waste being dumped in low-lying areas, leading to environmental concerns and depletion of natural resources. Recycled aggregates obtained from demolition waste were tested for basic properties such as specific gravity, crushing strength, impact value, water absorption, and abrasion. Concrete mixes were prepared with replacement levels of 25%, 50%, 75%, and 100% of recycled aggregates. The experimental results showed that treated recycled aggregates provided satisfactory mechanical performance and were effective for use in concrete. The study concluded that with proper treatment methods, recycled aggregates can be efficiently utilized in construction, contributing to sustainable development.

Ahmed et al. (2021) carried out an experimental study on the utilization of recycled concrete aggregates (RCA) obtained from construction and demolition (C&D) waste to reduce environmental pollution and minimize the depletion of natural aggregate resources. The study emphasized that construction and demolition waste is one of the largest waste streams in India, and its disposal in landfills creates serious environmental and economic concerns.

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In their experimental program, demolished concrete waste was collected and processed by performing sieve analysis to separate aggregates into different sizes. The recycled aggregates were further treated using a heating process to improve their usability in concrete production. The study investigated the performance of concrete by replacing natural coarse aggregates with demolished concrete aggregates (DCA) at various replacement levels of 10%, 20%, 30%, 50%, and 100%. The concrete specimens prepared with different replacement percentages were tested and compared with nominal conventional concrete. The results indicated that recycling demolished concrete aggregates can significantly contribute to sustainable construction by reducing landfill disposal and conserving natural resources. The study concluded that recycled aggregates can be effectively used in new concrete production, especially at partial replacement levels, while also addressing the growing challenge of demolished waste management in India.

Azevedo et al. (2021) performed an experimental investigation on recycled aggregate concrete filled steel tubular (RACFST) stub columns under axial compression. The study included twenty- three composite circular columns with varying replacement ratios of natural coarse aggregate by recycled aggregate (0%, 30%, and 50%), along with four control steel columns. The results showed that RACFST stub columns exhibited load-carrying capacities and behavior similar to natural aggregate concrete-filled steel tubes (NACFST) due to the confinement effect of the steel tubes. The confinement significantly enhanced the strength and ductility of recycled aggregate concrete. Furthermore, design predictions from Eurocode 4 (EC4) and AS/NZS 2327 were found to be consistent with experimental results, while NBR 8800 and AISC 360-16 provided more conservative estimates of column strength. The study concluded that recycled aggregate concrete is a feasible and sustainable alternative for use in steel-concrete composite columns without compromising structural performance.

Tabsh and Alhoubi (2022) investigated the use of recycled fine aggregate (RFA) from demolition waste as a partial or full replacement of natural sand in concrete. The study considered eight concrete mixes: four with low cement content (target strength 30 MPa) and four with high cement content (target strength 55 MPa), with replacement levels of 0%, 25%, 50%, and 100% RFA. Tests conducted included compressive strength, splitting tensile strength, and modulus of rupture at 28 days, following ASTM standards. Results showed that RFA exhibited cementitious properties and contributed to strength development. Concrete with recycled fine aggregate achieved at least 75% of the strength of control mixes. In low cement mixes (30 MPa), 25% and 100% replacement of natural sand by RFA provided compressive and tensile strengths comparable to or exceeding those of conventional concrete. The study concluded that RFA is a viable sustainable alternative to natural sand in structural-grade concrete.

Kim et al. (2022) carried out an experimental study on structural concrete incorporating recycled aggregates and recycled powder derived from construction and demolition (C&D) waste, aiming to promote complete utilization of all size fractions produced during the recycling process. The study investigated the influence of three recycled concrete materials: recycled coarse aggregate (RCA, 4.75–25 mm), recycled fine aggregate (RFA, 0.15–4.75 mm), and recycled powder (RP < 0.15 mm) on both fresh and hardened properties of concrete. Natural coarse and fine aggregates were replaced with RCA and RFA at 30%, 60%, and 100%, while ordinary Portland cement was partially replaced with RP at 10%, 20%, and 30%. The experimental program evaluated workability, air content, compressive strength, splitting tensile strength, and elastic modulus, along with correlations between mechanical properties. The results indicated that concrete properties generally deteriorated with increasing replacement levels, regardless of recycled material type. The reduction in performance was found to be most significant with RFA, followed by RCA, and the greatest decline occurred when RCA and RFA were used together. Additionally, concrete containing 30% RP showed a greater decrease in strength compared to mixes with 100% RCA or 100% RFA. However, the authors concluded that despite the reductions, all tested mixes could still be suitable for structural applications depending on environmental exposure conditions. Furthermore, a cost and environmental impact analysis revealed that mixes containing 10% RP and 20% RP provided improved cost-benefit performance compared to conventional concrete using 100% cement and natural aggregates. The study concluded that the combined use of recycled aggregates and recycled powder offers a promising sustainable solution for effective recycling of C&D waste in structural concrete production.

Chaudhary et al. (2022) performed an experimental investigation to evaluate the strength performance of concrete produced using recycled demolished construction materials as coarse aggregate, with the objective of assessing its suitability for non-load bearing structural components such as boundary walls and partition walls. In this study, crushed demolished construction waste materials of size 10 mm to 60 mm were used as a partial and full replacement for natural coarse aggregates. The replacement levels were varied systematically from 10% to 100% by weight of coarse aggregate.

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Concrete mixes were prepared using Indian Standard (IS) recommended design mix, and the compressive strength of different mixes was compared with a control mix containing natural aggregates. The results indicated that the maximum 28-day compressive strength was achieved when 60% demolished waste aggregate was used in the concrete mix. Additionally, the compressive strength values remained comparable to the conventional control mix up to 80% replacement level, showing that recycled demolished construction waste can effectively replace natural aggregates without major loss of strength. The study concluded that demolished construction waste aggregates have strong potential for sustainable concrete production, especially for non-load bearing applications, while also reducing landfill waste and conserving natural resources.

Sahi et al. (2023) conducted an experimental study on the application of recycled coarse aggregates (RCA) in rigid pavement concrete to address the growing problem of concrete waste disposal and depletion of natural resources. The study emphasized that concrete is one of the most widely used construction materials due to its durability, versatility, and cost-effectiveness; however, the increasing demand for aggregates and the large generation of demolition waste has created a need for sustainable alternatives. In this research, RCA was obtained from demolished slab pieces, which were crushed into suitable sizes and reused as coarse aggregate, while natural sand was used as fine aggregate. The concrete mix design was carried out using the trial and error method, and proportions were calculated as per Indian Standard (IS) codes along with IRC: 44-2008 guidelines for M30 grade cement concrete. A constant water–cement ratio of 0.5 was maintained for all mixes. The replacement of natural coarse aggregate with recycled aggregate was done at 0%, 20%, 40%, 60%, 80%, and 100% levels. Standard cube specimens (150 mm × 150 mm × 150 mm), along with beam and cylinder moulds, were cast to evaluate concrete performance. The study concluded that the use of recycled aggregates in rigid pavement concrete is a practical approach for sustainable construction, contributing to effective waste management and conservation of natural resources, while maintaining satisfactory compressive strength characteristics for pavement applications.

Chen et al. (2023) investigated the effect of curing conditions and admixtures on the meso- structure of recycled aggregate concrete (RAC) using X-ray computed tomography (CT). The study incorporated slag powder and fly ash as mineral admixtures, with steam curing as the primary curing condition. X-ray CT was used to analyze the pore structure, aggregate distribution, and interfacial transition zone (ITZ). Results indicated that steam curing increased pore volume and complexity, with pore morphology evolving from spherical to flat and slender as curing temperature rose. The porosity of micron pores in RAC was found to be around 2.3%, with more than 85% of pores having an aperture below 300 µm. The ITZ thickness between recycled aggregate and new mortar was about 200 µm, while cracks within recycled aggregate were measured at widths of 300–400 µm. The study concluded that curing conditions significantly influence the meso-structural characteristics of RAC, which in turn affect its mechanical and durability performance.

Govardhan & Gayathri (2023) conducted an experimental study on ternary blended recycled aggregate concrete (RAC) incorporating slag cement, alccofine, and glass fibers. Various replacement levels of recycled concrete aggregate (RCA) were tested, with alccofine used as a supplementary cementitious material to partially replace cement, and glass fibers added to enhance tensile and flexural properties. Tests included slump cone (workability), compressive strength, split tensile strength, and flexural strength. Results showed that while RCA alone exhibited inferior properties compared to natural coarse aggregate, the combined use of Portland slag cement (PSC) and alccofine improved long-term strength. Furthermore, the inclusion of glass fibers significantly enhanced crack resistance, tensile strength, and flexural performance. The study concluded that integrating RCA with slag cement, alccofine, and glass fibers can mitigate the drawbacks of RCA, improve overall mechanical performance, and support sustainable construction practices by reducing natural aggregate consumption and utilizing construction and demolition waste effectively.

Elsheikh, A., Al-Zayadi, S. K., & Albo-Hassan, A. S. (2024) – This study focused on using recycled concrete aggregates (both coarse and fine) as 100% replacements for natural aggregates in concrete production, exploring four concrete mixes: NCA-NFA, NCA-RFA, RCA-NFA, and RCA-RFA. The research examined fresh properties (workability and density) and mechanical properties (compressive, flexural, and split tensile strength). The results showed that although recycled aggregate concrete (RAC) exhibited some reductions in strength compared to conventional concrete, the decreases were within acceptable limits. Importantly, 100% replacement of natural coarse aggregate with RCA or natural fine aggregate with RFA was found feasible, highlighting a practical and sustainable approach to repurposing concrete waste, reducing landfill burden, and promoting circular economy practices.

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Bankar, N., Sarwade, S., & Phule, S. (2025) – This study explored the use of recycled concrete aggregates (RCA) in hot mix asphalt (HMA) for flexible pavement construction. RCA obtained from milling processes was analyzed for physical and mechanical properties including gradation, aggregate impact value, crushing value, specific gravity, flakiness and elongation index, Los Angeles abrasion value, and water absorption. Asphalt mixes were prepared with RCA contents of 0%, 10%, 20%, and 30%. Marshall stability, deformation, and moisture damage resistance tests were conducted, and optimum binder content (OBC) was determined for each mix. Results indicated that RCA can be effectively incorporated into bituminous mixtures, with varying percentages influencing OBC and mechanical performance, demonstrating RCA's potential for sustainable road construction while reducing natural aggregate consumption and construction waste.

Kishan Kumar Pandey, Vijay Tembhre, Ashutosh Kohad, and Abhishek Meshram (2025)- conducted an experimental investigation on the use of recycled aggregate in green concrete with the objective of evaluating its suitability in the construction industry. The study focused on replacing natural aggregates with recycled aggregates at varying proportions of 0%, 20%, 40%, 60%, 80%, and 100%. Laboratory tests such as slump test for workability and compressive strength test for hardened concrete performance were performed. The results revealed that the compressive strength gradually decreased as the proportion of recycled aggregate increased. However, up to 20% replacement of natural aggregate with recycled aggregate, the concrete was able to achieve the target mean strength, indicating its potential for use in structural applications without compromising safety and strength requirements. Beyond 20% replacement, a notable reduction in compressive strength was observed, making it less suitable for structural grade concrete. The authors concluded that recycled aggregate concrete (RAC) can be effectively utilized in partial replacement, thus promoting sustainable practices in the construction industry by reducing natural resource consumption and encouraging waste material utilization.

Zhong et al. (2025) conducted an experimental investigation on the flexural fatigue performance of recycled aggregate concrete (RAC) reinforced with a hybrid combination of basalt fiber (BF) and polyacrylonitrile fiber (PANF) to enhance its applicability in road and bridge engineering. The study aimed to reduce dependency on natural aggregates and promote sustainable utilization of waste concrete by using recycled coarse aggregate in new concrete production. A total of twelve concrete mix proportions were designed to evaluate the influence of BF and PANF on RAC performance. Initially, flexural strength tests were conducted, followed by flexural fatigue tests under different stress levels. To evaluate fatigue life behavior, the authors applied Weibull distribution theory, and developed both single logarithmic and double logarithmic fatigue prediction equations to estimate ultimate fatigue strength. The experimental results revealed that the incorporation of BF and PANF significantly improved the flexural strength and fatigue life of recycled aggregate concrete. The best performance was observed in the hybrid fiber mix containing 0.1% BF and 0.15% PANF, which showed the highest improvement in fatigue resistance. Additionally, the Weibull distribution model demonstrated a good fit for fatigue life analysis, and the double logarithmic fatigue equation was found to provide more accurate fatigue strength predictions compared to the single logarithmic model. Overall, the study concluded that hybrid fiber reinforcement is an effective approach to enhance the durability and fatigue performance of RAC, supporting its potential use in high-performance pavement and bridge structures.

III. GAP IDENTIFIED

After reviewing the above literature in detail, the following major research gaps have been identified regarding the experimental investigation and practical application of recycled aggregate concrete (RAC): Most of the existing research studies strongly focus on compressive strength evaluation up to 28 days, while limited studies provide long-term performance data such as 56 days, 90 days, 180 days, and one-year strength development, which is highly important because recycled aggregate concrete often shows delayed hydration benefits when supplementary cementitious materials are used; moreover, even though several researchers concluded that partial replacement of natural aggregates with recycled aggregates (20–40%) produces acceptable strength, there is still a lack of uniformity in defining the "optimum replacement percentage," because results vary widely depending on the source of recycled aggregate, crushing method, adhered mortar content, and aggregate grading, which indicates that a generalized conclusion cannot be applied universally without proper classification of recycled aggregates; additionally, the majority of investigations are laboratory-based and do not represent real site conditions such as field mixing, transportation delays, improper curing, temperature variations, and moisture fluctuations, hence large-scale field trials and pilot construction projects are insufficiently reported in literature; further, the durability performance of recycled aggregate concrete is still underexplored, particularly with respect to permeability, chloride diffusion, carbonation depth, sulfate attack, alkali-silica reaction, freeze-thaw resistance, shrinkage, and creep behavior, even though durability is the most critical factor determining service life of concrete structures, and studies like Denisiewicz et al. (2019) highlighted that durability parameters such as frost resistance and watertightness require deeper investigation; similarly, although researchers such as Chen et al. (2023) studied meso-structure and ITZ behavior using X-ray CT, advanced microstructural investigations using SEM, XRD, FTIR, and mercury intrusion porosimetry are still limited, and there is inadequate correlation between microstructural observations and macro-level mechanical performance, making it difficult to establish predictive models for recycled aggregate concrete behavior; another significant gap is the lack of standardized mix design methodology for RAC, since most studies have used trial-and-error methods or modified conventional IS/ACI mix design approaches, but recycled aggregates have different water absorption, density, and grading properties, which require dedicated mix design procedures for accurate water-cement ratio control and consistent workability; moreover, the water absorption issue of recycled aggregates remains a major challenge, and although treatment techniques such as heating, ball milling, and slurry mixing have shown positive improvements, there is still limited research comparing treatment methods based on cost-effectiveness, energy consumption, and feasibility for mass production, especially in developing countries like India where recycling plants may not have advanced processing facilities; additionally, the role of recycled fine aggregate (RFA) is not sufficiently studied compared to recycled coarse aggregate (RCA), and most researchers reported that RFA causes greater strength reduction due to higher surface area and absorption, but detailed experimental investigations on optimized gradation, pre-treatment, and partial replacement levels of RFA are still lacking; furthermore, the combined utilization of recycled aggregates along with recycled powder, ceramic waste, and other industrial by-products is an emerging concept, but very few studies have investigated full-scale utilization of all recycling fractions, even though Kim et al. (2022) highlighted the importance of utilizing recycled powder for complete sustainability; in addition, although the use of supplementary cementitious materials such as fly ash, silica fume, slag cement, and alccofine has been proven to enhance RAC properties, there is still a research gap in developing optimized ternary and quaternary blended concrete mixes that maximize strength and durability while minimizing cost and carbon emissions; another critical gap is the limited study on structural behavior of RAC elements, as only a few studies like Azevedo et al. (2021) evaluated recycled aggregate concrete in steel tubular composite columns, while there is insufficient experimental evidence on reinforced concrete beams, slabs, columns, shear walls, and full-frame structures under flexure, shear, torsion, and seismic loading conditions, which is essential to validate RAC for major structural applications; similarly, fatigue performance and impact resistance of RAC are rarely explored, although Zhong et al. (2025) studied fatigue behavior using hybrid fibers, yet further research is required on cyclic loading performance for pavements, bridges, and industrial floors where repeated loading governs design; additionally, fire resistance and elevated temperature behavior of recycled aggregate concrete is another under-researched area, even though recycled aggregates contain old mortar which may behave differently under thermal stress; also, the shrinkage and creep properties of RAC require deeper investigation because higher porosity and weaker ITZ may cause increased deformation and long-term deflection, affecting serviceability of structures; another major research gap lies in the absence of comprehensive life cycle assessment (LCA) studies that compare recycled aggregate concrete with conventional concrete in terms of embodied energy, carbon footprint, economic feasibility, and sustainability indices, because although many papers mention environmental benefits qualitatively, only limited studies provide quantitative sustainability evaluation; further, there is insufficient research on establishing practical guidelines for quality control and classification of recycled aggregates based on source concrete strength, contamination level, and crushing process, and due to this, the performance of RAC remains inconsistent and unpredictable; additionally, the influence of contaminants such as bricks, tiles, gypsum, wood, plastics, and soil mixed with demolished waste aggregates is not sufficiently studied, even though such contamination is common in Indian demolition waste and may drastically reduce concrete performance; moreover, studies on recycled aggregates in special concretes such as self-compacting concrete, geopolymer concrete, high performance concrete, fiber reinforced concrete, and lightweight concrete are limited, even though these advanced concretes are increasingly used in modern infrastructure; finally, there is a lack of integration of recycled aggregate concrete into Indian codes and standards such as IS 456 and IS 383, and without proper codal provisions, large-scale acceptance of RAC in structural applications remains limited, therefore future research should focus on generating strong experimental evidence that supports inclusion of RAC guidelines in Indian standards, promoting sustainable and circular construction practices.

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CONCLUSION

Based on the detailed review of experimental investigations carried out by various researchers on recycled aggregate concrete (RAC), it can be concluded that the use of recycled aggregates obtained from construction and demolition waste is a highly promising and sustainable solution for reducing environmental pollution, minimizing landfill disposal problems, and conserving rapidly depleting natural aggregate resources. Most studies confirmed that recycled aggregates generally possess higher water absorption, lower density, and weaker interfacial transition zone characteristics due to the presence of adhered old mortar, which results in a reduction in workability, compressive strength, split tensile strength, and flexural strength as the replacement percentage increases. However, it was also observed that partial replacement levels, particularly in the range of 20% to 40% recycled coarse aggregate, can produce concrete with mechanical performance comparable to conventional concrete, making it suitable for structural applications. Several investigations further demonstrated that the drawbacks of recycled aggregates can be effectively minimized by adopting improvement methods such as heating treatment, ball milling method, pre-soaking techniques, and advanced mixing approaches like PSTSMA, which enhance bonding and reduce porosity. Moreover, the incorporation of supplementary cementitious materials such as fly ash, silica fume, slag cement, and alccofine, along with nano-materials like nano-silica, significantly improves microstructure, strength development, and durability properties of RAC by densifying the cement matrix and strengthening the ITZ. Fiber reinforcement using glass fiber, basalt fiber, and hybrid fiber combinations was also found to be highly effective in improving tensile strength, crack resistance, fatigue life, and flexural performance, thereby increasing the applicability of recycled aggregate concrete in pavements, bridge decks, and structural components subjected to repeated loading. Overall, the reviewed literature strongly supports that recycled aggregate concrete can be successfully utilized in both structural and non-structural construction, particularly when optimized replacement levels and appropriate treatment or admixture techniques are adopted. Therefore, recycled aggregate concrete has strong potential to contribute to green construction and circular economy practices, but further long-term durability studies, large-scale field applications, and standardized mix design guidelines are required to promote its wider acceptance and inclusion in design codes and construction standards.

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