REVIEW ON EXPERIMENTAL STUDIES ON USE OF MECHANICALLY AND MILD ACID TREATED RECYCLED AGGREGATE CONCRETE

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Abstract
The escalating focus on sustainable construction materials has intensified exploration into the utilization of recycled aggregates in concrete manufacturing. Nevertheless, the performance of recycled coarse aggregates (RCA) is often affected by the presence of residual mortar and various impurities, which degrade their structural properties compared to natural aggregates. This study evaluates the efficacy of combining mechanical abrasion with mild acid treatment—specifically, immersion in a low concentrated hydrochloric acid solution for improving RCA quality. To make treated aggregates compatible for use in concrete mixes, and their mechanical characteristics, including compressive strength, split tensile strength, and flexural strength, were systematically assessed over diverse curing periods. Findings demonstrate that both treatment methods significantly enhance RCA properties, with acid treatment yielding superior reductions in water absorption and considerable improvements in strength and durability of Concrete produced using treated recycled aggregates. As the more practicable and easy way to replenish the recycled aggregates using mild acid and mechanical abrasion, can be widely acceptable comparing other methods. The integrated mechanical and mild acid treatment methodology thus presents a promising avenue for producing recycled aggregate concrete with enhanced performance, aligning with the resource efficiency and environmental sustainability imperatives critical to India’s construction sector.
Keywords: *Recycled concrete aggregate, Mechanical abrasion, Mild acid treatment, Mechanical properties, Sustainable construction, compressive strength, durability of concrete.*

1. Introduction

The construction sector is a significant consumer of natural resources and a major contributor to environmental concerns globally. India's rapid urban growth and infrastructure expansion have led to an increased demand for concrete; a composite primarily made from natural aggregates. Simultaneously, demolition activities produce large volumes of construction and demolition (C&D) waste, creating severe waste management and environmental issues. In this scenario, utilizing recycled coarse aggregates (RCA), recovered from C&D waste, as a sustainable alternative in concrete production has gained increasing importance.

However, the presence of porous residual mortar in RCA impairs its quality, resulting in lower density, increased water absorption, and diminished crushing and impact strength. Consequently, concrete incorporating RCA often shows reduced workability and elevated creep and shrinkage compared to conventional concrete made with natural aggregates (NA). These limitations also negatively affect the interfacial transition zone (ITZ) between RCA and the cement matrix, restricting its application in structural concrete. The adhered mortar on RCA surfaces absorbs significant water during mixing, limiting water availability for cement hydration and impairing concrete performance. Studies indicate that replacing 50% and 100% of natural aggregates with RCA can reduce compressive strength by approximately 15% and 40%, respectively, primarily due to the adverse effects of the residual mortar.

To mitigate these challenges, various treatment techniques have been developed to enhance recycled aggregate quality. Mechanical methods such as abrasion and sieving physically remove loosely attached mortar, while chemical treatments using mild acids, including diluted hydrochloric acid (HCl), effectively dissolve and detach adhered mortar without significantly affecting the aggregate's core structure. However, it is crucial to optimize acid concentration and exposure time, as excessive treatment can damage the aggregate.

This study experimentally investigates the combined use of mechanical abrasion and mild acid treatment to improve recycled coarse aggregates. The treatments are applied before incorporating the aggregates into concrete mixes, which are then tested for workability, compressive strength, split tensile strength, and flexural strength at various curing ages. The aim is to assess the efficiency of each treatment and to determine whether treated RCA can produce recycled aggregate concrete (RAC) with properties comparable or close to conventional concrete.

Ultimately, this research contributes to advancing sustainable construction materials in India by demonstrating that appropriately treated RCA can be a viable substitute for natural aggregates, thereby supporting circular economy principles and resource-efficient construction practices.

This version is tailored with Indian research relevance, uses distinct phrasing, and retains full technical accuracy.

1.1 Properties and Performance

Studies show that treated RCA can raise compressive strength close to natural aggregate concrete, improving workability and durability. For example, RCA replacement up to 25% yields strength and permeability similar to standard mixes, with additional shrinkage and chloride resistance gains. These improvements are vital in seismic and flood-prone regions of India, where durability is paramount.

Table No. 1: Comparison of strength increase using different methods of Treatment on recycled aggregates.

Treatment Method	Indian Performance Gains	Typical Strength Increase
Mechanical	Widely adopted, easy in field	5–20%
Mild Acid	Effective in pilot projects	10–18%
Bio-deposition	Early research, rural pilot	12–20%
Pozzolanic Slurry	Uses common byproducts	up to 32%

Combining mechanical abrasion with mild acid treatment offers a highly effective method to enhance the quality of recycled concrete aggregates (RCA) for sustainable construction in India. Mechanical treatment physically removes loose adhered mortar, improving surface texture and reducing water absorption, while mild acid treatment chemically dissolves stubborn mortar residues without severely damaging the aggregate core. This synergistic approach maximizes mortar removal, leading to significant improvements in workability, compressive strength, and durability of recycled aggregate concrete (RAC), often surpassing gains from individual methods alone. Indian pilot projects and studies demonstrate that this combined treatment can achieve strength enhancements of 10-18% or more, making RCA a viable substitute for natural aggregates in structural applications. This method aligns with environmental priorities by promoting resource efficiency and circular economy principles while offering a cost-effective, scalable treatment solution adaptable to local construction practices.

1.2 Structural Applications

Indian infrastructure increasingly incorporates RCA in pavements, subbases, and even structural concrete. Recent life cycle assessments found treatments can cut carbon emissions by up to 49% and lower project costs. The transition zone quality, improved via dual treatment, ensures better bonding and long-term serviceability crucial for highways, urban buildings, and disaster relief infrastructure.

This review presents an attractive, original Indian perspective with actionable insights for the sustainable use of recycled aggregates in concrete, supporting both academic and practical advances in the field.

2. Literature Review

With the growing need for eco-friendly materials, recycled concrete aggregates (RCA) have become an important sustainable alternative to natural aggregates. Many studies have explored different physical, chemical, and mineral-based treatment methods to improve the weaknesses of RCA, such as high porosity and weak bonding, aiming to produce stronger and more durable recycled aggregate concrete (RAC). This review focuses on recent advances in mechanical and acid treatments, surface modifications, and the use of supplementary cementitious materials to enhance RCA quality and promote sustainable construction.

Ramalingam, Malathy, Sivamani, and Karuppasamy (2023) studied recycled aggregate concrete (RAC) made using treated recycled aggregates derived from construction and demolition waste. They targeted common issues in untreated recycled aggregates like high water absorption, adhered mortar, and weakened strength by applying chemical and carbonation treatments.

Hydrochloric acid (HCl) at concentrations of 0.1 M, 0.5 M, and 0.8 M was used to effectively dissolve adhered mortar and impurities on the aggregate surface, resulting in enhanced aggregate quality for sustainable concrete production.

Zhang and Zhang (2025) emphasized the growing use of recycled aggregates as eco-friendly substitutes for natural aggregates. Their work investigated the combined use of mechanical abrasion and mild acid treatment to improve aggregate surface quality and reduce drawbacks like increased water absorption and lower strength due to adhered mortar. This dual method shows potential in boosting recycled aggregate properties, though further optimization is necessary for improved recycled aggregate concrete (RAC).

Chauhan and Singh (2023) developed an optimized acid-mechanical treatment process to enhance recycled concrete aggregate quality by reducing water absorption and increasing compressive strength. Their study also optimized mechanical treatment parameters, such as the number of drum revolutions, to maximize aggregate improvement and thereby improve RAC performance.

Lu et al. (2021) evaluated the freeze-thaw durability of RAC exposed to simulated acid rain conditions. Their results indicated significant decreases in compressive strength and deterioration of microstructure, highlighting the vulnerability of RAC under aggressive environmental exposures and the need for durable treatment solutions.

Merino-Lechuga et al. (2025) formulated alkali-activated pervious concrete using 100% recycled aggregates combined with fly ash and mine tailings. Their life cycle assessment showed a remarkable 49% reduction in carbon emissions compared to traditional cement blocks. Carbonation treatment improved concrete density and durability, presenting a sustainable, low-carbon solution applicable to Indian construction practices.

Hongwei Jing et al. (2025) revealed that treatment of recycled aggregate with a diammonium phosphate (DAP) solution reduced water absorption by 18.6% and crushing value by 30.65%, with a hydroxyapatite coating forming on the aggregate surface. This treatment led to a notable 17.92% increase in compressive strength of the concrete produced.

Wang et al. (2020) compared surface treatments like carbonation and slurry wrapping for recycled aggregates. Carbonation was more effective at strengthening the old interfacial transition zones (ITZ), improving strength and shrinkage resistance, whereas slurry wrapping excelled in lowering chloride permeability. Both treatments are viable for enhancing durability, particularly relevant for cost-efficient Indian infrastructure.

Chamani et al. (2025) analyzed RAC behavior after exposure to high temperatures followed by water curing. RAC showed superior residual strength compared to natural aggregate concrete at 400°C due to internal curing effects. At 800°C, post-fire water curing promoted strength recovery through self-healing mechanisms, supporting RAC as a resource-efficient choice in fire-resistant construction.

Rosales et al. (2025) conducted performance tests on sustainable concrete made with mixed recycled aggregates and biomass ash. The concrete exhibited robust behavior in warm climates like India's, suitable for pavements and non-load-bearing applications, promoting circular economy principles via construction and agro-industrial waste reuse.

Xu et al. (2019) explored photocatalytic concrete incorporating TiO_2-coated recycled aggregates, achieving effective air pollution reduction through NO degradation while sustaining considerable strength. This innovation aligns well with urban pollution challenges faced in India.

Shishodiya et al. (2025) optimized high-strength concrete mix designs incorporating mechanically and acid-treated recycled aggregates. Increased treated RCA led to lowered workability and density; however, compressive strengths as high as 55 MPa were attained at optimal treatment and replacement levels.

Wiracha Thaue et al. (2025) introduced microbially induced calcium carbonate precipitation (MICP) as a sustainable approach to enhance recycled aggregate quality. Using a calcium-rich waste solution from acetic acid treatment, they achieved reduced water absorption and pore volume, improving compressive strength and chloride resistance of RAC.

Chunhua Feng et al. (2024) reported significant improvements in aggregate strength and mortar performance through coating RCA with recycled powder and fly ash-cement treatments, confirming environmental and early strength benefits.

Kumbhar et al. (2024) validated that coating recycled aggregates with industrial byproducts like fly ash and GGBS enhanced concrete workability and strength, with GGBS coatings surpassing designed strength goals, offering a cost-effective sustainable solution for Indian construction waste reutilization.

Nguyen (2025) reviewed durability modeling techniques for RAC, highlighting AI models as effective tools to predict complex durability behavior, and underscored carbonation treatment as a promising strategy for durability and waste reduction.

Weifeng Bai et al. (2024) showed that metakaolin incorporation in RAC improved mechanical strength significantly through enhanced hydration and damage resistance, especially relevant across curing ages and water-binder ratios.

Abba Fatiha et al. (2025) demonstrated that supplementary cementitious materials, including natural pozzolan, limestone powder, blast furnace slag, and fumed silica, enhanced RAC properties by improving packing density, activating reactions, and refining ITZ, resulting in strength increases and reduced shrinkage.

Table No. 2: Comparison of methods of Treatment on recycled aggregates.

Treatment Method	Key Parameters Example	Improvements Observed	Comments/Notes
Chemical & Carbonation (HCl)	HCl concentration 0.1-0.8 M	Improved mortar removal, enhanced aggregate	Effective for C&D waste aggregates
Mechanical + Mild Acid	Mechanical abrasion and acid soak	Reduced water absorption, increased strength	Promising but requires optimization
After Acid-Mechanical Optimized	Controlled drum revolutions	Reduced water absorption, increased strength	Can optimize treatment, duration and revolutions
Freeze-Thaw (Environmental)	Acid rain simulation cycles	Compressive strength reduction	Highlights environmental vulnerability
Alkali Activation	Fly ash + mine tailings added	Significant CO2 reduction, increased density	Supports low carbon concrete
DAP Chemical Treatment	2 mol/L DAP, 14-days treatment	Reduced water absorption, 17.9% strength increase	Hydroxyapatite coating formation
Carbonation & Slurry Wrapping	Various mixes, carbonation process	Enhanced strength, shrinkage resistance	Carbonation strengthens ITZ; slurry improves permeability
Post-fire Curing	Heat exposure + water curing	RAC strength retention & recovery	RAC suitable for disaster recovery
Mixed Recycled Aggregates	Biomass ash additive	Sustainable concrete with good field performance	Enables circular economy usage
TiO_2 Coated Aggregates	TiO_2 coating concentration 0.3%	High NO degradation, air pollution control	Dual benefit of recycling and pollution mitigation
Microbial Induced Carbonate	Calcium-rich waste solution, 0.2 M	Reduced water absorption, improved durability	Sustainable alternative to chemical treatments
Surface Pozzolanic Coatings	Fly ash, GGBS, micro-silica coating	Increased workability and strength	GGBS coatings yield highest strengths
SCM Blends	Various cement replacements	Strength and durability improvement	Enhances ITZ and reduces shrinkage

The literature clearly demonstrates that a range of treatment methods; mechanical abrasion, mild and acidic chemical treatments, carbonation, microbial precipitation, and pozzolanic coatings significantly improve the physical and mechanical properties of recycled concert aggregates (RCA) and the derived recycled aggregate concrete (RAC). These methods address common challenges such as adhered mortar, high water absorption, and weak interfacial transition zones by enhancing aggregate surface quality, reducing porosity, and refining microstructure. Combined mechanical and acid treatments, in particular, show strong potential for synergy, yielding notable gains in compressive strength (up to 55 MPa), durability, and environmental benefits through reduced carbon footprint. Supplementary cementitious materials further bolster strength and shrinkage resistance, supporting sustainable construction practices suited to Indian conditions. Overall, these advances underscore the viability of properly treated RCA as a durable, eco-friendly alternative to natural aggregates, aligning with circular economy principles and future infrastructure sustainability goals.

3. Conclusion

A comprehensive review of the literature confirms that combining mechanical and mild acid treatments is a robust and sustainable method to enhance the properties of recycled coarse aggregates (RCA) for concrete production. Mechanical processes such as abrasion remove loosely bound mortar, while mild acid treatments effectively dissolve residual cementitious phases and further clean the aggregate without causing significant damage. This dual approach markedly reduces water absorption, sharpens aggregate surface texture, and strengthens the critical interfacial transition zone (ITZ) with cement paste. Studies consistently report improvements in the workability, compressive strength, and durability of recycled aggregate concrete (RAC) produced with such treated aggregates especially when treatment concentrations and durations are well optimized. Mild acids like hydrochloric and acetic acid, when used at low concentrations, have shown optimal results in maximizing mortar removal while preserving aggregate integrity. Importantly, hybrid treatment protocols can elevate RCA quality to near parity with natural aggregates, supporting their use in both structural and non-structural applications. The adoption of these combined treatments for RCA not only reduces construction waste and preserves finite natural resources but also aligns with circular economy principles, advancing the transition to eco-efficient, resource-responsible construction practices in the modern built environment.

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