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Analysis of Hardened Concrete by Using Chemical Treatment on Recycled Aggregate

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Abstract

Recycled Aggregate Concrete (RAC) is an eco-friendly and sustainable construction material in which recycled concrete aggregate (RCA) is used as a partial or full replacement for natural aggregates. This project focuses on the production, properties, and environmental benefits of RAC, developed by crushing, processing, and reusing construction and demolition waste such as concrete, sand, gravel, and slag. The increasing demand for construction materials has led to excessive consumption of natural resources and generation of large quantities of waste, creating significant environmental challenges. RAC offers a viable solution by promoting the reuse of waste materials, thereby supporting the principles of the circular economy.

The study highlights how RAC contributes to reducing landfill burden, conserving natural aggregates, and lowering energy consumption and pollution associated with traditional concrete production. In addition, RAC proves to be cost-effective compared to conventional concrete due to reduced material costs and waste management expenses. The project also examines the performance characteristics of RAC, including strength, durability, and workability, to evaluate its suitability for various construction applications.

Furthermore, the use of industrial waste as admixtures enhances both environmental sustainability and economic feasibility. With rapid urbanization and infrastructure development, especially in developing countries, the management of demolition waste has become a major concern. RAC emerges as a practical and sustainable alternative that minimizes environmental impact while maintaining acceptable structural performance. Overall, this project emphasizes the importance of adopting RAC in modern construction practices to achieve resource efficiency, waste reduction, and long-term environmental protection.

Keywords: Recycled Concrete Aggregate (RCA); Chemical Treatment; Adhered Mortar; Mechanical Properties; Sustainable Construction

How to Cite This Article

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Introduction

Recycled Aggregate Concrete (RAC) is a concrete mix that uses recycled concrete aggregate in place of natural aggregate. RAC is created by crushing and washing concrete and other construction and demolition waste, such as sand, gravel, slag, and crushed stones. RAC represents a new generation of concrete that is more environmentally responsible. Instead of using all-new materials, RAC utilizes old concrete that has been recycled, thereby saving resources and reducing waste.

RAC is beneficial for the environment because it helps conserve natural resources and reduce pollution. It is also a cost-effective choice compared to traditional concrete. RAC exemplifies the circular economy model — instead of discarding old concrete, it is reused to manufacture new concrete, significantly reducing waste and preserving natural resources.

The concrete industry is one of the largest consumers of energy and raw materials globally. Therefore, reusing industrial wastes as admixtures in construction provides both environmental and economic benefits. In countries undergoing rapid development, the management of hazardous waste materials represents one of the most challenging environmental concerns. Eco-friendly materials are being widely studied to diminish the construction industry's environmental impact and to conserve natural resources. Dumping demolition concrete waste in landfills causes capacity and environmental issues. Therefore, there is an urgent need to find suitable alternatives for concrete production.

This study investigates the effect of chemical treatment — specifically hydrochloric acid (HCl) treatment — on recycled aggregates and examines how this treatment influences the mechanical properties of hardened concrete. The primary objective is to evaluate whether chemical treatment of RCA can bring its performance closer to that of natural aggregate concrete (NAC) and identify optimal replacement levels for structural applications.

Literature Review

A comprehensive review of existing literature has been conducted to understand the current state of knowledge regarding recycled aggregate concrete and the influence of chemical treatment on aggregate performance.

Use of Recycled Brick and Tile Aggregates

Chi-Sun Poon and Dixon Chan (2006) investigated the potential of using recycled brick and tile aggregate from construction and demolition waste to replace natural sand in concrete. Hong Kong, facing a landfill crisis, had begun using recycled concrete aggregate in construction projects. This research explored the feasibility of using brick and tile aggregate to reduce waste and conserve natural resources, with a focus on replacing 20% of natural sand and its effects on workability and strength. Their findings revealed that the double mixing method effectively reduced initial slump loss. Replacing 20% of natural sand with crushed brick or tile aggregate slightly decreased concrete density but significantly improved compressive strength when the double mixing method was employed. The low drying shrinkage of the aggregate (less than 0.075%) indicated its suitability for various concrete applications.

Recycled Materials in Concrete Products

Marios N. Soutsos, Kangkang Tang, and Stephen G. Millard (2011) investigated the use of recycled materials from old buildings and construction sites to manufacture new concrete products such as bricks and paving stones. They successfully replicated the industrial wet casting process in a laboratory setting. Their study found that replacing up to 60% of coarse aggregate or 40% of fine aggregate with recycled concrete aggregate did not significantly impact the flexural strength of concrete flags. This demonstrated the potential for using recycled materials in construction product manufacturing, thereby reducing reliance on virgin natural resources.

Quality of Recycled Aggregates from C&D Waste

Martín-Morales, Zamorano, Ruiz-Moyano, and Valverde-Espinosa (2010) investigated the quality of recycled aggregate produced from construction and demolition waste. The researchers found that recycled aggregate contained impurities such as clay brick, ceramic, and gypsum, which negatively affect quality. Testing against Spanish standards showed that while the aggregate met requirements for particle shape, density, and resistance to breakage, it fell short in terms of water absorption, sulfate content, and chloride content. The study suggested blending with natural aggregates, removing gypsum before crushing, and water immersion treatment to reduce chloride content.

Global Perspective on Recycled Aggregates

Angelo De Luca, Linda Chen, and Koorosh Gharehbaghi (2020) reviewed current waste reduction strategies in the UK, Australia, and Japan concerning the use of recycled aggregates. They concluded that using recycled aggregates can be both financially and environmentally beneficial. The paper emphasized that by raising awareness and implementing effective policies, governments can encourage the increased use of recycled aggregates, significantly reducing the negative environmental impact of the construction industry.

Multi-Criteria Optimization of Recycled Concrete

Nikola Tosic, Snezana Marinkovic, Tina Dasic, and Milos Stanic (2014) employed a multi-criteria optimization method called VIKOR to compare different concrete types incorporating natural aggregates and recycled concrete aggregates at 50% and 100% replacement levels. Considering technical, economic, and environmental criteria, they found that using a mix of 50% recycled concrete and 50% natural gravel was the most optimal option. To improve cost-effectiveness, they recommended measures such as taxing natural materials, charging fees for landfilling waste, and providing subsidies for using recycled materials.

Methodology

The research methodology was designed to systematically evaluate the influence of chemical treatment on the properties of recycled concrete aggregates and the resulting hardened concrete. The following steps were carried out:

Collection of Demolition Waste

Concrete debris was collected from demolished structures such as beams, slabs, and columns. It was ensured that the collected waste was free from contaminants like wood, plastic, soil, and metals to maintain the quality of recycled aggregates.

Segregation and Pre-processing

The collected material was segregated either manually or mechanically to remove impurities such as steel bars, glass, and other unwanted materials. The concrete chunks were then sorted based on size for efficient processing.

Crushing Process

The segregated concrete waste was crushed using a jaw crusher. This process reduced large concrete pieces into smaller aggregate sizes of 20 mm and 10 mm, suitable for reuse in concrete production.

Screening

The crushed material was passed through sieves or screening machines to classify aggregates into different size grades as per IS 383 requirements. Oversized particles were re-crushed to achieve uniform grading.

Washing and Chemical Treatment

The aggregates were washed thoroughly to remove dust, dirt, and loosely adhered mortar. Chemical treatment using a dilute hydrochloric acid (HCl) solution at a 5% concentration was then applied. The RCA was immersed in the HCl solution for 24 hours, after which it was thoroughly washed with clean water and dried in an oven at 105°C for 24 hours before use. This treatment is aimed at dissolving the adhered mortar layer on the surface of the recycled aggregate, thereby improving its surface quality and reducing water absorption.

Mix Design — M40 Grade Concrete

Concrete was prepared by mixing cement, recycled aggregates, natural sand, water, and a superplasticiser admixture in proportions conforming to IS 10262:2009 and MORT&H specifications for M40 grade concrete. Seven mix variants were prepared: one control mix (M0) with 100% natural coarse aggregate (NAC), and six RAC mixes with 25%, 50%, and 100% RCA replacement — each in untreated and HCl-treated conditions. Detailed mix proportions are presented in Section 7.

Specimen Preparation and Testing

Standard specimens were cast for each mix: 150 mm × 150 mm × 150 mm cubes for compressive strength, 150 mm diameter × 300 mm length cylinders for split tensile strength, and 100 mm × 100 mm × 500 mm prisms for flexural strength. Specimens were demoulded after 24 hours and subjected to water curing. Tests were conducted at 7, 14, and 28 days in accordance with IS 516:1959, IS 5816:1999, and IS 516:1959 (Part 5) respectively. Water absorption was also measured at 28 days.

Results And Findings

The following tables present the experimental results obtained from mechanical and durability testing of all seven concrete mix variants. Results are compared across RCA replacement levels (0%, 25%, 50%, 100%) and treatment conditions (untreated vs. HCl treated).

Compressive Strength

Table 1 presents the compressive strength results at 7, 14, and 28 days for all mix variants.

Table 1. Compressive Strength Results (MPa)

Mix ID	RCA %	Treatment	7-day (MPa)	14-day (MPa)	28-day (MPa)
M0	0%	Control (NAC)	28.4	34.6	43.2
M1	25%	Untreated	24.6	30.1	38.5
M2	25%	HCl Treated	26.2	32.8	41.3
M3	50%	Untreated	21.3	26.9	34.1
M4	50%	HCl Treated	23.8	29.4	37.6
M5	100%	Untreated	17.4	22.1	29.3
M6	100%	HCl Treated	20.1	25.6	33.7

The control mix (M0) achieved a 28-day compressive strength of 43.2 MPa, exceeding the M40 design strength. Mixes with untreated RCA showed a progressive decrease in compressive strength with increasing replacement — M1 (25%), M3 (50%), and M5 (100%) achieved 38.5 MPa, 34.1 MPa, and 29.3 MPa, respectively. HCl- treated RCA mixes demonstrated notably improved compressive strength across all replacement levels. Mix M2 (25% HCl-treated RCA) achieved 41.3 MPa, closely approaching the control value. Even at 100% replacement (M6), the HCl-treated mix achieved 33.7 MPa, which is 4.4 MPa higher than its untreated counterpart.

Split Tensile Strength

Table 2 presents the split tensile strength results at 7, 14, and 28 days.

Table 2. Split Tensile Strength Results (MPa)

Mix ID	RCA %	Treatment	7-day (MPa)	14-day (MPa)	28-day (MPa)
M0	0%	Control (NAC)	2.86	3.41	4.12
M1	25%	Untreated	2.51	3.02	3.74
M2	25%	HCl Treated	2.69	3.27	3.94
M3	50%	Untreated	2.20	2.74	3.38
M4	50%	HCl Treated	2.43	2.96	3.61
M5	100%	Untreated	1.82	2.30	2.91
M6	100%	HCl Treated	2.04	2.54	3.18

The split tensile strength followed a trend similar to compressive strength. The control mix (M0) attained 4.12 MPa at 28 days. Untreated RCA mixes showed reductions proportional to the replacement percentage. HCl treatment consistently improved split tensile strength; M2 (25% HCl-treated) achieved 3.94 MPa at 28 days, representing only a 4.4% reduction compared to the control. At 100% replacement, M6 achieved 3.18 MPa versus 2.91 MPa for the untreated M5, a 9.3% improvement due to chemical treatment.

Flexural Strength

Table 3 presents the flexural strength results at 7, 14, and 28 days.

Table 3. Flexural Strength Results (MPa)

Mix ID	RCA %	Treatment	7-day (MPa)	14-day (MPa)	28-day (MPa)
M0	0%	Control (NAC)	3.92	4.68	5.84
M1	25%	Untreated	3.42	4.11	5.23
M2	25%	HCl Treated	3.71	4.44	5.62
M3	50%	Untreated	2.94	3.68	4.71
M4	50%	HCl Treated	3.26	3.98	5.07
M5	100%	Untreated	2.41	3.06	3.93
M6	100%	HCl Treated	2.74	3.38	4.39

Flexural strength results confirmed the beneficial effect of HCl treatment. The control (M0) achieved 5.84 MPa at 28 days. M2 (25% HCl-treated) achieved 5.62 MPa — only a 3.8% reduction — while the untreated M1 showed a 10.4% reduction to 5.23 MPa. At the highest RCA replacement (100%), HCl treatment improved flexural strength by approximately 11.7% compared to untreated concrete.

Water Absorption

Table 4 presents the water absorption results measured at 28 days.

Table 4, Water Absorption at 28 Days (%)

Mix ID	RCA Replacement (%)	Treatment	Water Absorption (%)
M0	0%	Control (NAC)	1.82
M1	25%	Untreated	3.24
M2	25%	HCl Treated	2.61
M3	50%	Untreated	4.57
M4	50%	HCl Treated	3.48
M5	100%	Untreated	6.39
M6	100%	HCl Treated	4.82

Water absorption increased with higher RCA content, attributed to the greater porosity and water absorption capacity of recycled aggregate compared to natural aggregate. However, chemical treatment significantly reduced water absorption in all RAC mixes. The untreated M5 (100% RCA) absorbed 6.39% compared to 4.82% for the HCl-treated M6 — a reduction of approximately 24.6%. Even at 25% RCA replacement, HCl treatment reduced water absorption from 3.24% (M1) to 2.61% (M2), confirming improved interfacial transition zone (ITZ) quality.

Discussion

The results of this study provide important insights into the behaviour of hardened recycled aggregate concrete and the effectiveness of HCl chemical treatment as an enhancement technique for recycled aggregates.

Effect of RCA Replacement on Mechanical Properties

The progressive reduction in compressive strength, split tensile strength, and flexural strength with increasing RCA content is consistent with findings reported in the existing literature. The primary cause of this reduction is the inferior quality of recycled aggregate compared to natural aggregate, characterized by a higher water absorption capacity, greater porosity, and the presence of old adhered mortar on the aggregate surface. This adhered mortar creates a weak interfacial transition zone (ITZ) between the aggregate and the new cement paste, reducing the bond strength and overall mechanical performance of the concrete matrix.

At 25% RCA replacement, the reduction in all mechanical properties was relatively modest (approximately 8–11% compared to control), suggesting that low-volume RCA incorporation with natural aggregate is a viable strategy for sustainable construction without significant structural compromise.

Effect of HCl Chemical Treatment

The application of dilute HCl treatment significantly improved the mechanical properties of RAC across all replacement levels. By dissolving and removing the old adhered mortar from the surface of recycled aggregates, chemical treatment improves surface texture, reduces porosity, and strengthens the new ITZ formed with fresh cement paste. This aligns with the findings of Martín-Morales et al. (2010), who highlighted the negative influence of adhered mortar on recycled aggregate quality.

The improvement was most pronounced at lower replacement levels (25% and 50%), where treated RCA mixes closely approached the performance of the control mix. At 25% replacement (M2), compressive strength reached 41.3 MPa at 28 days — within 95.6% of the control value — making it suitable for M40-grade structural applications. The consistent reduction in water absorption for treated mixes also indicates improved durability, which is critical for long- term structural performance under exposure conditions.

Optimum Replacement Level

Based on the experimental results, a 25% replacement of natural coarse aggregate with HCl-treated RCA is identified as the optimum level for maintaining structural performance comparable to conventional concrete. At this level, all mechanical properties remain within acceptable limits for M40 grade concrete, and water absorption is significantly lower than untreated counterparts. A 50% replacement with HCl-treated RCA can also be considered for less critical structural elements where some strength reduction is permissible.

Environmental and Economic Implications

The use of RCA in concrete production directly reduces the volume of construction and demolition waste disposed in landfills, thereby addressing a significant environmental concern particularly relevant to rapidly urbanizing regions such as Pune. By conserving natural aggregate resources and reducing the energy required for quarrying and transportation, RAC contributes to a reduction in the overall carbon footprint of the construction industry. The economic benefits are also notable, as the cost of recycled aggregate is generally lower than virgin natural aggregate, as noted by De Luca et al. (2020). The additional cost of chemical treatment must be weighed against these benefits; however, at 25% replacement, the improved structural performance justifies this investment.

Conclusion

This study investigated the effect of hydrochloric acid chemical treatment on recycled concrete aggregates and evaluated the mechanical and durability properties of the resulting hardened concrete. Based on the experimental findings, the following key conclusions are drawn:

- Recycled Aggregate Concrete (RAC) exhibits reduced compressive strength, split tensile strength, and flexural strength compared to conventional natural aggregate concrete. The reduction is proportional to the percentage of RCA replacement.
- Chemical treatment of RCA using a 5% HCl solution significantly improves the mechanical properties of RAC by removing old adhered mortar, reducing surface porosity, and strengthening the interfacial transition zone (ITZ) between aggregate and cement paste.
- At 25% RCA replacement with HCl-treated aggregate (Mix M2), the 28-day compressive strength reached 41.3 MPa — within 95.6% of the control value — confirming suitability for M40 grade structural concrete applications.
- Water absorption of RAC increases with higher RCA content but is substantially reduced by HCl chemical treatment, improving the long-term durability and impermeability of concrete.
- The optimum RCA replacement level is identified as 25% with HCl treatment, balancing structural performance, environmental sustainability, and cost-effectiveness.
- RAC presents a viable and sustainable alternative to conventional concrete, supporting waste reduction, conservation of natural resources, and the principles of the circular economy.

Limitations

This study was limited to laboratory-scale specimen testing under controlled curing conditions. The source and quality of demolition waste used for RCA production may vary significantly across different sites, which could influence results. Additionally, long-term durability performance under aggressive environmental exposure conditions (such as freeze-thaw cycles or chloride environments) was not assessed in this study.

Future Research Directions

Future research should explore the effect of other chemical treatment agents (e.g., sodium silicate, sulphuric acid, carbonation treatment) on RCA quality and concrete performance. Long-term durability studies, including chloride permeability, carbonation resistance, and creep and shrinkage behaviour, should be conducted. Additionally, life cycle assessment (LCA) studies comparing the environmental impact of RAC versus NAC production would provide a comprehensive basis for policy recommendations promoting RAC adoption in the construction industry.

Mix Design of M40 Grade Concrete

The mix design was carried out as per IS 10262:2009 and MORT&H specifications. The following tables present the complete mix design data used for all concrete mixes in this study.

Table 5. Stipulations for Proportioning (A-1)

Sr.	Stipulations for Proportioning	Values
1	Grade Designation	M40
2	Type of Cement	PPC 43 Confirming to IS-12269-1987
3	Maximum Nominal Aggregate Size	20 mm
4	Minimum Cement Content (MORT&H 1700-3A)	310 kg/m³
5	Maximum Water Cement Ratio (MORT&H 1700-3A)	0.45
6	Workability (MORT&H 1700-4)	50–75 mm (Slump)
7	Exposure Condition	Normal
8	Degree of Supervision	Good
9	Type of Aggregate	Crushed Angular Aggregate
10	Maximum Cement Content (MORT&H Cl. 1703.2)	540 kg/m³
11	Chemical Admixture Type	Superplasticiser Confirming to IS-9103

Table 6: Test Data for Materials (A-2)

Sr.	Test Data for Materials	Values
1	Cement Used	›mandal King OPC 53 Grade
2	Sp. Gravity of Cement	3.15
3	Sp. Gravity of Water	1.00
4	Chemical Admixture	ASF Chemicals Company
5	Sp. Gravity of 20 mm Aggregate	2.884
6	Sp. Gravity of 10 mm Aggregate	2.878
7	Sp. Gravity of Sand	2.605
8	Water Absorption of 20 mm Aggregate	0.97%
9	Water Absorption of 10 mm Aggregate	0.83%
10	Water Absorption of Sand	1.23%
11–13	Free (Surface) Moisture of All Aggregates	Nil

14–16	Sieve Analysis of Aggregates	Separate Analysis Done
17	Sp. Gravity of Combined Coarse Aggregates	2.882

Table 7: Final Mix Proportions per Cubic Metre — SSD Condition (A-9)

Sr.	**Iix Proportions for One Cum of Concrete (SSD Condition)**	**Quantity**
1	Mass of Cement	320 kg/m³
2	Mass of Water	138 kg/m³
3	Mass of Fine Aggregate	751 kg/m³
4	Mass of Coarse Aggregate (Total)	1356 kg/m³
	→ Mass of 20 mm Aggregate	977 kg/m³
	→ Mass of 10 mm Aggregate	380 kg/m³
5	Mass of Admixture (Superplasticiser)	1.60 kg/m³
6	Water Cement Ratio	0.43

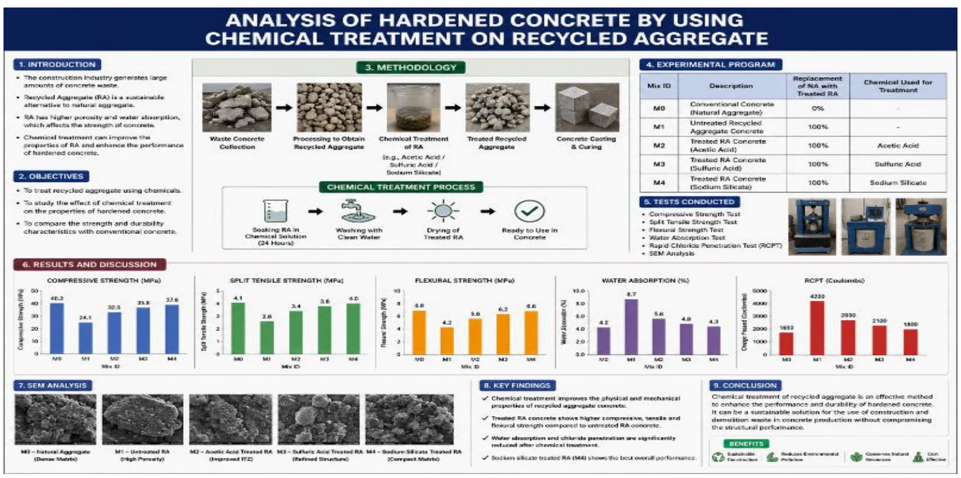

Fig. 1. *Methodology and Mechanical Performance Analysis of Recycled Aggregate Concrete*

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