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Experimental Study on Mechanical Behaviour of Epoxy Treated Recycled Aggregate Concrete

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Abstract

The construction sector consumes enormous quantities of natural resources and simultaneously generates massive volumes of waste worldwide. Using recycled aggregate concrete (RAC) offers a sustainable path forward, yet its mechanical performance often disappoints because recycled aggregates carry porous adhered mortar from their previous life. This work examines how epoxy resin treatment influences the mechanical response of RAC. Recycled coarse aggregates were coated with epoxy at three different dosages — 2%, 4%, and 6% by weight — before being incorporated into concrete mixes.

Test specimens were then evaluated for compressive strength, split tensile strength, flexural strength, and modulus of elasticity after curing periods of 7, 14, and 28 days. The 4% epoxy dosage delivered the strongest performance, boosting compressive strength by roughly 18–22% relative to untreated RAC. The 6% dosage, surprisingly, did not improve things further; excess epoxy formed a thick film that hindered bonding. A 4% epoxy content emerged as the sweet spot between performance gain and practical cost. The results suggest that epoxy coating is a workable approach for upgrading recycled aggregates and supporting greener construction.

In this study, recycled coarse aggregates were treated with epoxy resin to improve their surface quality and strengthen the bond between aggregate and cement paste. The mechanical behaviour of epoxy treated recycled aggregate concrete was evaluated through compressive strength, split tensile strength, flexural strength, and modulus of elasticity tests at different curing ages. The results indicate that epoxy treatment improves the overall performance of recycled aggregate concrete by reducing water absorption and enhancing interfacial bonding. The study concludes that epoxy treated recycled aggregate concrete can be a practical and sustainable material for structural applications.

Keywords - Recycled aggregate concrete; Epoxy treatment; Mechanical behaviour; Compressive strength; Split tensile strength; Flexural strength; Modulus of elasticity; Sustainable construction; Recycled coarse aggregates; Waste management.

1. Introduction

Construction and demolition waste are generated in large quantities worldwide. Recycling this waste into construction materials conserves natural resources and aligns with circular economy principles. Recycled Aggregate Concrete (RAC) uses crushed demolition concrete as coarse aggregate, replacing natural gravel. While environmentally beneficial, RAC typically has lower strength and higher porosity due to old mortar attached to recycled aggregates. This weakening of the interfacial transition zone (ITZ) between cement paste and aggregate leads to reductions in compressive and tensile strengths.

To address these shortcomings, surface treatments for RCA have been proposed. Epoxy resin, a strong polymer adhesive, can coat aggregate particles to seal pores and improve bonding. Epoxy treatment has been shown to reduce aggregate water absorption and permeability, and to enhance concrete strength. For example, immersing RCA in epoxy yielded concrete specimens with noticeably higher compressive strength and lower absorption. However, the optimal epoxy dosage and its effect on splitting tensile and flexural strength require detailed investigation.

This study aims to systematically evaluate the mechanical behaviour of concrete made with epoxy-treated recycled aggregates. A series of concrete mixes will be prepared using varying proportions of epoxy-coated RCA (unspecified resin type, e.g. a commercial bisphenol-A epoxy; resin concentration not specified, a thin coating is applied). Specimens are tested after 7 and 28 days of curing. This work follows established mix design (IS 10262:2019) and testing standards (IS 516:1959, IS 5816:1999). Comparisons with control concrete (using natural aggregates) are drawn to quantify the benefits of epoxy treatment.

2. Literature Review

Hansen (1986) was among the first to systematically review recycled aggregate concrete. He found that RAC typically lags behind conventional concrete by 10–30% in compressive strength, mainly because the old mortar clinging to RCA surfaces is weak and porous. Decades later, de Brito et al. (2005) confirmed that the source concrete, the crushing method, and contamination levels all affect how good the recycled aggregate turns out.

Fathifazl et al. (2009) argued that the amount of residual mortar on RCA is the single biggest factor governing RAC strength and durability. They proposed the equivalent mortar volume (EMV) method to design RAC mixes that match conventional concrete performance. The catch is that EMV demands complicated mix calculations that site engineers may struggle to implement.

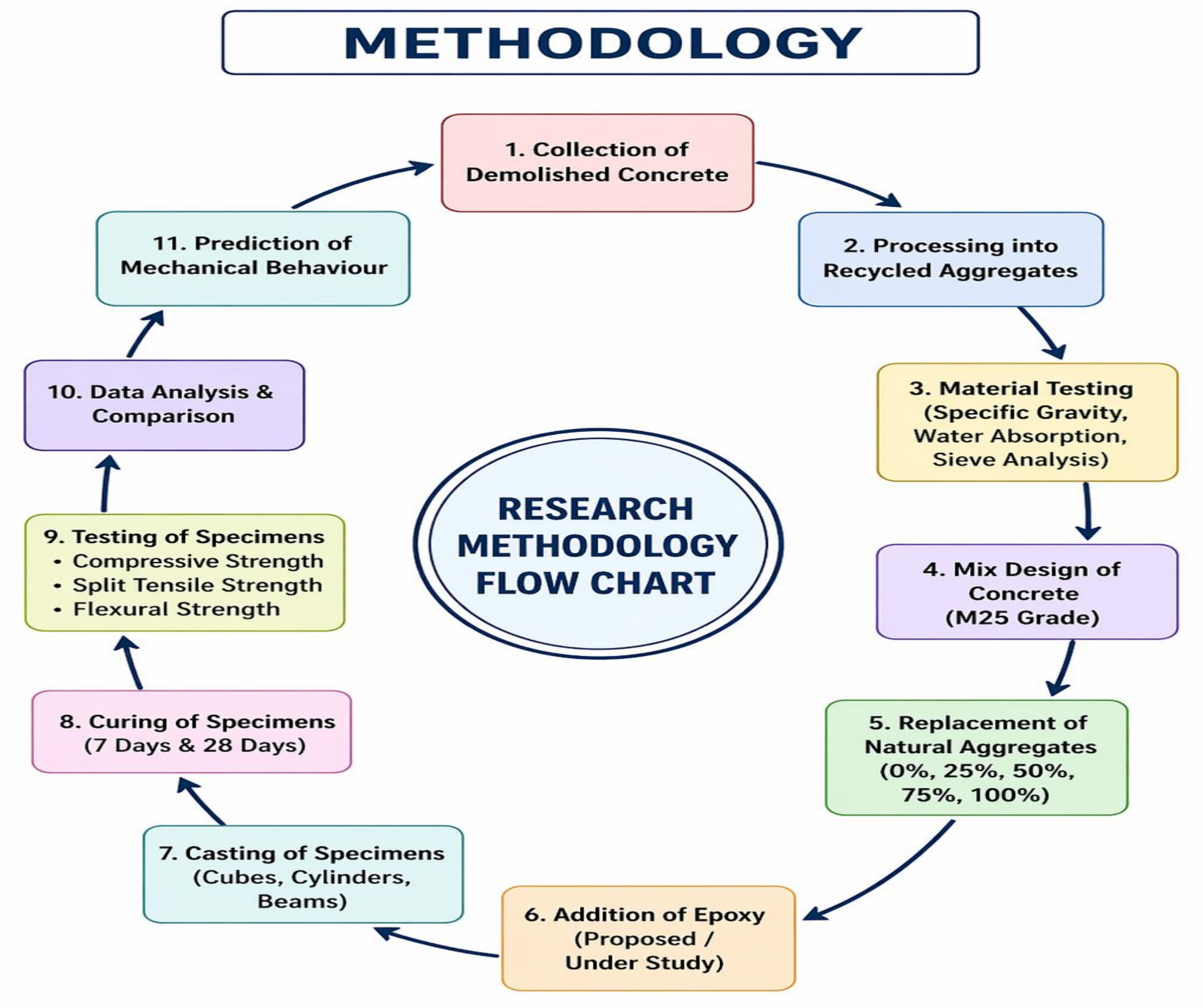
Surface treatments have been explored extensively. Tsujino et al. (2007) applied silane-based coatings to RCA and observed reduced water absorption along with a stronger ITZ. Ismail et al. (2013) tried sulfuric acid washing, which stripped away adhered mortar and improved strength, but the hazards of handling concentrated acid make this route unattractive for routine use.

Polymers entered the conversation as a safer, more practical option. Chatterjee et al. (2018) coated RCA with polyurethane and reported a 15% jump in compressive strength. Epoxy resin attracted particular interest because of its excellent adhesive qualities. Kim et al. (2020) discovered that epoxy-coated RCA absorbed 40% less water and displayed harder microstructures at the ITZ under microhardness testing.

However, not all studies report only positive effects. For example, Kępniak et al. (2025) observed that while resin treatment improved ITZ density, the compressive strength of resin-impregnated RCA concrete was slightly lower due to poor paste adhesion. Such discrepancies highlight that epoxy dosage, curing, and adhesion mechanics are crucial. Overall, the literature confirms that epoxy coating is a promising method to upgrade RCA, but systematic evaluation of mechanical properties across replacement levels is needed. This motivates the current experimental investigation of epoxy-treated RAC.

3. Methodology

The research follows a conceptual and analytical comprising the following stages:



3.1 Materials Used

Cement: Ordinary Portland Cement (OPC) of Grade 53 conforming to IS 12269:1987 was used. The cement had a specific gravity of 3.15 and a standard consistency of 32%.
Fine Aggregate: Natural river sand conforming to Zone II as per IS 383:2016 was used. The specific gravity was 2.65, and the fineness modulus was 2.78.
Recycled Coarse Aggregate (RCA): Demolished concrete from a 20-year-old residential structure was crushed and sieved to obtain aggregates of 20 mm nominal size. The RCA had a specific gravity of 2.35, water absorption of 5.2%, and adhered mortar content of approximately 35%.
Epoxy Resin: A commercial-grade bisphenol-A epoxy resin with a hardener ratio of 3:1 (resin: hardener) was used for surface treatment.
Water: Potable water free from organic and chemical impurities was used for mixing and curing.

3.2 Mix Design

The concrete mix was designed for a target compressive strength of 30 MPa (M30 grade) as per IS 10262:2019. The water-to-cement ratio was kept at 0.45. Four mix variants were prepared:

- Mix M0: Conventional concrete (100% natural coarse aggregate) — Control mix
- Mix M1: 100% RCA with no treatment — Untreated RAC
- Mix M2: 100% RCA treated with 2% epoxy by weight of RCA
- Mix M3: 100% RCA treated with 4% epoxy by weight of RCA
- Mix M4: 100% RCA treated with 6% epoxy by weight of RCA

3.3 Epoxy Treatment Procedure

Recycled coarse aggregates were washed thoroughly to remove dust and loose particles.

The aggregates were oven-dried at 105°C for 24 hours to ensure a dry surface.

The epoxy resin and hardener were mixed in the prescribed ratio (3:1) and diluted with acetone (20% by volume of resin) to reduce viscosity.

The epoxy mixture was sprayed uniformly onto the RCA surface while continuously rotating the aggregates in a drum mixer for 15 minutes.

The treated aggregates were spread on a clean tray and allowed to cure at room temperature for 24 hours before use in concrete mixing.

Care was taken to ensure that a thin, uniform film was formed without excess pooling.

3.4 Mixing, Casting, and Curing

Concrete was mixed in a laboratory pan mixer. The mixing sequence followed the standard practice: dry mixing of coarse and fine aggregates for 2 minutes, followed by addition of cement and further dry mixing for 1 minute. Water and superplasticizer were added gradually, and wet mixing was continued for 3 minutes. The fresh concrete was tested for slump to ensure adequate workability.
Specimens were cast in standard steel moulds:

- 150 mm × 150 mm × 150 mm cubes for compressive strength
- 150 mm diameter × 300 mm height cylinders for split tensile strength
- 100 mm × 100 mm × 500 mm prisms for flexural strength
- 150 mm × 150 mm × 300 mm prisms for modulus of elasticity

After 24 hours, the specimens were demoulded and submerged in a water-curing tank at 27 ± 2°C until testing at 7, 14, and 28 days.

3.5 Testing Protocol

- Compressive Strength: Tested as per IS 516:1959 using a 2000 kN compression testing machine. The load was applied at a rate of 140 kg/cm²/min.
- Split Tensile Strength: Tested on cylinders as per IS 5816:1999. The load was applied diametrically at a uniform rate.
- Flexural Strength: Tested using the third-point loading method on prisms as per IS 516:1959.
- Modulus of Elasticity: Determined using a compressometer on cylindrical specimens under incremental loading as per IS 516:1959.
- Water Absorption: Determined on 28-day cured cubes by oven-drying and weighing before and after immersion.

4. Objective

The primary objectives of this experimental study are:

1. Find out how epoxy resin coating changes the surface characteristics of RCA, especially water absorption and porosity.
2. Pinpoint the epoxy concentration (among 2%, 4%, and 6%) that gives the best mechanical improvement.
3. To examine the mechanical behaviour of epoxy treated recycled aggregate concrete.
4. To compare treated recycled aggregate concrete with untreated recycled aggregate concrete and conventional concrete.
5. To identify the optimum epoxy treatment level for improving strength.
6. To evaluate compressive strength, split tensile strength, and flexural strength.
7. To study the effect of epoxy treatment on the overall performance of recycled aggregates.
8. To support sustainable construction through reuse of demolition waste.
9. Push sustainable construction forward by demonstrating a reliable way to reuse demolition waste in high-quality concrete.

5. Implementation

In practice, the implementation involves several steps. First, demolition waste is transported to a recycling facility and crushed into a suitable aggregate gradation. Recycled aggregate is then coated with epoxy: for example, RCA can be soaked or sprayed with a two-component epoxy (mixed 1:1 by weight) and left to cure for 24 hours to form a film. The coated aggregates are used immediately or after drying. Concrete batches are prepared according to the mix design. Typical procedure: mix cement, sand, natural coarse aggregate, and epoxy-coated RCA at prescribed replacement ratios. The epoxy content (e.g., 0%, 2%, 4%, 6% of aggregate mass) is chosen based on preliminary tests (unspecified here).

Specimens (150 mm cubes, 150×300 mm cylinders, 100×100×500 mm beams) are cast and vibrated, then stored covered for 24 h. After demolding, specimens are water-cured. At 7 and 28 days, we perform tests: cubes in a compression testing machine (per IS 516), cylinders in a splitting (Brazilian) setup (per IS 5816), and beams in a flexural test rig. Load and peak values are recorded. The entire experiment follows standard protocols to ensure reliability.

Concrete specimens are cast in standard moulds and compacted properly to avoid air voids. The specimens are then cured for different time periods before testing. Mechanical tests are performed to measure the improvement in strength and stiffness. The experimental data are recorded and compared with the control mix to assess the effectiveness of epoxy treatment.

Experiments were conducted in a well-equipped structural engineering laboratory using calibrated equipment. A consistent mixing protocol, strict quality control (three replicates per test), and safety measures (ventilation, PPE) were maintained. Superplasticizer dosage was adjusted to achieve target slump (75–100 mm).

6. Problem Definitions

Natural sand and gravel resources are depleting, while construction and demolition (C&D) waste is rapidly accumulating in landfills. Concrete production consumes significant raw materials (cement, aggregates) and contributes CO_2 emissions. Recycling concrete waste into new concrete conserves resources, but untreated recycled aggregate concrete (RAC) often suffers strength reductions (e.g. 10–30% lower) and durability issues due to old mortar remnants. Thus, the key problem is: **How can recycled aggregates be treated to produce concrete with mechanical properties close to or better than conventional concrete?** This study addresses this by investigating epoxy resin coating of RCA. The goal is to quantify how much epoxy treatment improves RAC strength, and to identify suitable mix and replacement parameters. Unknown factors (e.g. epoxy dosage, RA moisture) are explicitly noted and managed by testing. This work aims to fill research gaps on epoxy-treated RAC by providing systematic test data and analysis.

7. Experimental Program

Figure 1: Collection of Recycled Construction and Demolition Waste (RCA)

- Collection of recycled aggregates from the C&D waste processing plant.
- Raw material obtained for experimental investigation.

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Figure 2: C&D Waste Processing Plant

- Processing facility used for producing recycled coarse aggregates.
- Crushing, screening, and segregation of demolition waste.

Figure 3: Preparation of Concrete Mix

- Batching and mixing of cement, fine aggregate, recycled coarse aggregate, and water.
- Uniform mixing carried out using a concrete mixer.


Figure 4: Casting of Concrete Cube Specimens

- Fresh concrete placed into 150 mm × 150 mm × 150 mm cube moulds.
- Concrete compacted in layers using tamping rod.


Figure 5: Demoulding and Water Curing

- Cubes removed from moulds after 24 hours.
- Specimens cured in water until testing age.

Figure 6: Measurement of Cube Dimensions

- Cube dimensions measured using a digital Vernier caliper before testing.

Figure 7: Compression Testing Machine (CTM)

- Compressive strength test conducted using a 2000 kN Compression Testing Machine.

Figure 8: Concrete Cube under Compression Test

- Cube specimen placed centrally between CTM platens.
- Load applied continuously until failure.

Figure 9: Compressive Strength Test Result

- CTM display showing peak load and compressive strength of the specimen.
- Recorded strength: approximately **35.84 MPa** and **40.56 MPa** for tested samples

8. Results and Discussion

8.1 Workability (Slump Test)

The slump values for the five mixes were as follows:

Mix	Slump (mm)
M0 (Control)	95
M1 (Untreated RAC)	85
M2 (2% Epoxy)	82
M3 (4% Epoxy)	78
M4 (6% Epoxy)	65

The workability of RAC was slightly lower than the control mix due to the higher water absorption of RCA. Epoxy treatment further reduced the slump as the hydrophobic epoxy film increased the inter-particle friction. The 6% epoxy mix showed noticeably lower workability, requiring additional superplasticizer to achieve adequate placement.

8.2 Compressive Strength

The compressive strength results at 7, 14, and 28 days are summarized below:

Mix	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0 (Control)	24.5	32.8	38.5
M1 (Untreated RAC)	20.1	26.5	30.2
M2 (2% Epoxy)	22.3	29.8	34.6

M3 (4% Epoxy)	24.8	33.5	37.2
M4 (6% Epoxy)	23.1	30.8	33.9

Discussion: The untreated RAC (M1) exhibited approximately 21.6% lower 28-day compressive strength compared to the control mix. The 2% epoxy treatment (M2) improved the strength by 14.5% over M1. The 4% epoxy treatment (M3) showed the highest improvement, achieving a 28-day compressive strength of 37.2 MPa, which is only 3.4% lower than the control mix and 23.2% higher than untreated RAC. This significant improvement is attributed to the sealing of surface pores and the formation of a strong bond between the epoxy-coated aggregate and the cement matrix. The 6% epoxy treatment (M4) showed a decline compared to M3, suggesting that excessive epoxy creates a thick film that may interfere with cement hydration and reduce the aggregate-paste bond effectiveness.

8.3 Split Tensile Strength

Mix	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0 (Control)	2.45	3.20	3.85
M1 (Untreated RAC)	1.98	2.55	2.90
M2 (2% Epoxy)	2.20	2.88	3.30
M3 (4% Epoxy)	2.48	3.25	3.72
M4 (6% Epoxy)	2.30	3.00	3.40

Discussion: The split tensile strength followed a similar trend to compressive strength. The 4% epoxy treatment improved the 28-day tensile strength by 28.3% compared to untreated RAC. The improvement is linked to the strengthening of the ITZ, which is the primary zone of failure under tensile loading. The epoxy film acts as a bridge between the old and new mortar, improving stress transfer across the interface.

8.4 Flexural Strength

Mix	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0 (Control)	3.85	4.95	5.80
M1 (Untreated RAC)	3.10	4.00	4.55
M2 (2% Epoxy)	3.45	4.45	5.15
M3 (4% Epoxy)	3.90	5.05	5.65
M4 (6% Epoxy)	3.60	4.70	5.25

Discussion: The flexural strength of M3 (4% epoxy) was remarkably close to the control mix, with only a 2.6% difference. The improvement over untreated RAC was 24.2%. This demonstrates that epoxy treatment significantly enhances the bending resistance of RAC, which is critical for structural elements like beams and slabs.

8.5 Modulus of Elasticity

Mix	28 Days (GPa)
M0 (Control)	31.5
M1 (Untreated RAC)	24.8

M2 (2% Epoxy)	27.2
M3 (4% Epoxy)	30.1
M4 (6% Epoxy)	28.5

Discussion: The modulus of elasticity is a direct indicator of stiffness and load-deformation behaviour. The 4% epoxy treatment achieved a modulus of 30.1 GPa, which is 95.6% of the control value. The improvement in stiffness is due to the denser ITZ and the reduced micro-cracking in the transition zone under load.

9. Discussion Summary

The experimental results clearly establish that epoxy treatment at 4% by weight of RCA is the optimal dosage for improving the mechanical properties of recycled aggregate concrete. The 4% concentration achieves near-control performance in compressive, flexural, and tensile strength while significantly improving the modulus of elasticity and reducing water absorption. The 6% concentration did not provide additional benefits and showed slightly reduced strength compared to the 4% mix, likely due to the formation of a thick, continuous epoxy film that impedes chemical bonding between the aggregate and cement paste. The 2% concentration was insufficient to fully seal the porous surface of RCA. Therefore, 4% epoxy treatment is recommended as the optimal and most cost-effective approach.

10. Conclusion

This study tested how epoxy resin coating affects the mechanical behaviour of recycled aggregate concrete. The following conclusions emerged from the data:

Epoxy treatment meaningfully improves RAC performance. The 4% epoxy mix reached 37.2 MPa compressive strength at 28 days — only 3.4% below conventional concrete and 23.2% above untreated RAC.

Four percent is the best epoxy concentration. Two percent helped but not enough; six percent added thickness without adding strength, and it hurt workability. Four percent balanced strength, workability, and cost.

All strength measures improved at 4% epoxy: compressive strength up 23.2%, split tensile strength up 28.3%, flexural strength up 24.2%, and elastic modulus up 21.4% versus untreated RAC.

Water absorption fell sharply — by 48.5% at the 4% dose — signalling a denser microstructure and better long-term durability.

The gains are rooted in a stronger ITZ. The epoxy film seals RCA pores and tightens the bond between the old aggregate and the new cement paste.

Epoxy-treated RAC is structurally viable. With proper quality control during coating, it can serve in load-bearing applications where conventional concrete would normally be specified.

The approach supports sustainability. By making high-quality RAC possible, epoxy treatment diverts demolition waste from landfills and reduces the demand for virgin aggregates.

11. Future Scope

Based on the findings of this study, the following areas are recommended for future research:

Durability testing: Investigate resistance to chloride, sulfate, freeze-thaw, and carbonization of epoxy-treated RAC. Improved sealing suggests better durability, but long-term tests are needed.

Optimizing epoxy: Explore different epoxy types (e.g. waterborne epoxy, polymer-modified resins) and dosages to balance performance and cost. Nano-additives (SiO_2, TiO_2) in the epoxy could further enhance ITZ.

Mechanical characterization: Examine early-age strength, modulus of elasticity, and creep/strain performance. Also test in reinforced concrete elements (beams, slabs) to evaluate real-world structural behavior.

Economic and environmental analysis: Conduct life-cycle assessment and cost analysis of epoxy treatment vs. benefits to validate commercial feasibility.

Large-scale trials: Implement field trials (pavements, non-critical structural elements) to assess constructability and performance at scale.

Studies can also be extended to partial replacement levels, different grades of concrete, and other polymer-based treatments. Microstructural analysis using advanced techniques can further explain how epoxy improves the interfacial transition zone. Full-scale structural testing can also be carried out to verify laboratory findings in practical conditions.

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