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# Laboratory Study of Recycled Concrete Aggregate (RCA) for Road Construction

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**Abstract:** *The rapid growth of infrastructure development has resulted in excessive consumption of natural aggregates and generation of large quantities of construction and demolition waste. Recycled Concrete Aggregate (RCA), obtained from demolished concrete structures, provides a sustainable alternative to natural aggregates in pavement construction. This study investigates the feasibility of using RCA in Pavement Quality Concrete (PQC) by partially and fully replacing natural coarse aggregate. Concrete mixes of grades M30 and M40 were prepared with RCA replacement levels of 0%, 25%, 50%, 75%, and 100% according to IS 10262:2019 guidelines. Experimental investigations were carried out to evaluate compressive strength, flexural strength, and split tensile strength. The results showed that mechanical properties gradually decreased with increasing RCA content due to higher water absorption, adhered mortar, and increased porosity. However, replacement levels up to 50% provided satisfactory performance within acceptable limits. The study also analysed economic and environmental benefits associated with RCA utilization. Significant reductions in transportation cost, landfill waste, and carbon emissions were observed. The findings indicate that RCA can be effectively used in road construction applications to promote sustainable development and reduce dependence on natural resources.*

**Keywords:** Recycled Concrete Aggregate, Pavement Quality Concrete, Sustainable Construction, Compressive Strength, Flexural Strength, Split Tensile Strength.

## I. INTRODUCTION

Concrete is one of the most extensively used construction materials worldwide due to its versatility, durability, high compressive strength, and economic feasibility. It plays a vital role in the development of infrastructure such as highways, bridges, buildings, airports, dams, and urban transportation systems. The rapid growth of urbanization and industrialization has significantly increased the demand for concrete, resulting in extensive consumption of natural resources, particularly natural aggregates such as crushed stone, gravel, and sand.

Aggregates constitute approximately 60–75% of the total volume of concrete. The continuous extraction of natural aggregates from quarries and riverbeds has led to depletion of natural resources, ecological imbalance, and increased carbon emissions. Simultaneously, demolition, renovation, and rehabilitation of old structures generate enormous quantities of construction and demolition (C&D) waste. In India alone, 150–170 million tonnes per year of C&D waste is generated, of which only 1–7% is scientifically processed.

One of the most promising solutions to address both aggregate scarcity and construction waste management is the use of Recycled Concrete Aggregate (RCA). RCA is obtained by collecting demolished concrete, processing it through crushing, screening, removal of contaminants, and grading, and then reusing the processed material in new construction. The use of RCA reduces the burden on landfills, minimizes the extraction of virgin aggregates, and contributes to the principles of circular economy and sustainable construction.

Pavement Quality Concrete (PQC) is a high-strength concrete specifically designed for rigid pavement applications. Since coarse aggregates significantly influence the mechanical and durability properties of PQC, the replacement of natural aggregates with RCA requires careful evaluation. The present study focuses on investigating the suitability and

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performance of RCA as a partial or full replacement of natural coarse aggregate in PQC, including evaluation of physical properties, mechanical performance, and economic and environmental benefits.

### A. Objectives of the Study

- To evaluate the use of RCA in Pavement Quality Concrete with M30 and M40 grades.
- To prepare concrete mixes with RCA replacements of 0%, 25%, 50%, 75%, and 100%.
- To evaluate compressive strength, flexural strength, and split tensile strength.
- To compare the performance of natural aggregate concrete and RCA concrete.
- To analyse economic and environmental benefits of RCA utilization.

## II. LITERATURE REVIEW

Several researchers have studied the properties and applications of Recycled Concrete Aggregate in concrete construction. Key findings from relevant studies are summarized below.

Alibeigibeni et al. (2025) conducted a comprehensive review of RCA performance in structural concrete, examining mechanical properties (compressive strength, tensile strength, elastic modulus, bond strength, creep) and durability (carbonation, chloride attack, oxygen permeability). The study also evaluated the $CO_2$-capturing potential through accelerated carbonation and highlighted reductions in emissions, energy use, and waste generation through life-cycle assessment [1].

Peiris et al. (2025) examined more than 150 research studies comparing techniques to improve RCA quality, including mechanical methods (ball milling, thermal treatment, ultrasonic cleaning), chemical soaking, carbonation, polymer treatment, nano-materials, and slurry coatings. The review provided recommendations for large-scale application [2].

Prasittisopin et al. (2025) conducted a systematic umbrella review of 23 high-quality papers on RCA use in concrete mix design. The study showed that increasing RCA replacement reduces compressive strength—0.1913% per 1% coarse RCA and 0.2418% per 1% fine RCA—due to adhered mortar and higher porosity [3].

Muhmood (2024) evaluated RCA obtained from demolished buildings for road sub-base layers. RCA mixed with fly ash (5–16%) showed higher CBR values than natural materials. The study concluded that RCA is a viable alternative for pavement layer design [4].

Alqarni et al. (2022) investigated treatment methods (cement-silica fume slurry, sodium silicate solution, LA abrasion) for improving RCA performance in high-strength concrete. Treated RCA, especially via LA abrasion, significantly improved concrete performance and proved suitable for high-strength applications [5].

Pavan et al. (2018) tested concrete mixes with 0–100% RCA using OPC and PSC. Results showed RCA has lower density and higher water absorption, causing reduced compressive and tensile strength as RCA content increases, though the material was found usable with significant cost and environmental benefits [6].

### A. Research Gap

Based on the literature review, the following research gaps were identified: limited studies on RCA use specifically in Pavement Quality Concrete; lack of comparative analysis between M30 and M40 grades; insufficient research on optimum RCA replacement level for road construction; and inadequate analysis of combined economic and environmental benefits at varying replacement levels. The present study addresses these gaps through a systematic laboratory investigation.

## III. MATERIALS AND METHODOLOGY

### A. Cement

Ordinary Portland Cement (OPC) 53 grade conforming to IS specifications was used throughout the study.


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**B. Natural Aggregate**

Natural coarse aggregate was collected from Chikhali source. Its physical properties and sieve analysis results are presented in Table I and Table II respectively.

**TABLE I**

**Physical Properties of Natural Aggregate**

| Sr. No. | Test | Result (%) | IS Requirement |
|---|---|---|---|
| 1 | Impact Value | 17.5 | 30 Max |
| 2 | Crushing Value | 19.2 | 30 Max |
| 3 | Water Absorption | 1.06 | 2.0 Max |
| 4 | Flakiness Index | 12.1 | ≤ 40 |
| 5 | Elongation Index | 15 | - |
| 6 | Abrasion Value | 22.7 | 30 Max |

**C. Recycled Concrete Aggregate (RCA)**

RCA was obtained from Surat Green Precast Pvt. Ltd. (SGPPL), Surat. Its physical properties are presented in Table II.

**TABLE II**

**Physical Properties of Recycled Concrete Aggregate (RCA)**

| Sr. No. | Test | Result (%) | IS Requirement |
|---|---|---|---|
| 1 | Impact Value | 19.5 | 30 Max |
| 2 | Crushing Value | 20.6 | 30 Max |
| 3 | Water Absorption | 3.54 | 2.0 Max* |
| 4 | Flakiness Index | 14.5 | ≤ 40 |
| 5 | Elongation Index | 18.1 | - |
| 6 | Abrasion Value | 22.3 | 30 Max |

*Note: RCA water absorption exceeds the IS limit for natural aggregates but was intentionally used to evaluate feasibility in RCA concrete.

**D. Fine Aggregate**

Natural river sand conforming to Zone II grading as per IS 383:2016 was used. The water absorption was 1.43% and fineness modulus was 2.90.

**E. Methodology**

The research methodology followed a systematic approach: collection and characterization of materials, mix design as per IS 10262:2019, casting and curing of specimens, mechanical testing, and economic/environmental analysis. RCA replacement levels of 0%, 25%, 50%, 75%, and 100% were studied for M30 and M40 concrete grades.

## IV. MIX PROPORTIONS

Concrete mixes were designed in accordance with IS 10262:2019. Additional mixing water was provided for RCA mixes to compensate for higher water absorption. Table III and Table IV present the M30 and M40 mix proportions respectively.

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**TABLE III**

**M30 Concrete Mix Proportions (kg/m³)**

| RCA (%) | Cement | Water | Natural Agg. | RCA | Fine Agg. |
|---|---|---|---|---|---|
| 0% | 423 | 190 | 1200 | 0 | 670 |
| 25% | 423 | 200 | 900 | 300 | 675 |
| 50% | 423 | 210 | 600 | 600 | 680 |
| 75% | 423 | 220 | 300 | 900 | 685 |
| 100% | 423 | 230 | 0 | 1200 | 690 |

**TABLE IV**

**M40 Concrete Mix Proportions (kg/m³)**

| RCA (%) | Cement | Water | Natural Agg. | RCA | Fine Agg. |
|---|---|---|---|---|---|
| 0% | 488 | 190 | 1170 | 0 | 620 |
| 25% | 488 | 200 | 878 | 292 | 630 |
| 50% | 488 | 210 | 585 | 585 | 640 |
| 75% | 488 | 220 | 292 | 878 | 650 |
| 100% | 488 | 230 | 0 | 1170 | 660 |

## V. EXPERIMENTAL INVESTIGATION

Concrete specimens were prepared in the form of cubes (150×150×150 mm), beams (100×100×500 mm), and cylinders (150×300 mm). Proper compaction was carried out during casting to avoid honeycombing and air voids. The specimens were water-cured for 7 and 28 days before testing.

The following tests were performed as per relevant IS standards: Compressive Strength Test (IS 516:2021), Flexural Strength Test (IS 9399:1979), and Split Tensile Strength Test (IS 5816:1999).

## VI. RESULTS AND DISCUSSION

### A. Compressive Strength

Compressive strength results for M30 and M40 concrete at 7 and 28 days are presented in Table V and Table VI.

**TABLE V**

**Compressive Strength Results – M30 Concrete (MPa)**

| RCA (%) | 7-Day (MPa) | % Reduction | 28-Day (MPa) | % Reduction |
|---|---|---|---|---|
| 0% | 22.5 | 0 | 33.8 | 0 |
| 25% | 21.8 | 3.1 | 32.9 | 2.6 |
| 50% | 20.6 | 8.4 | 31.2 | 7.6 |
| 75% | 19.1 | 15.1 | 29.5 | 12.7 |
| 100% | 17.5 | 22.2 | 27.8 | 17.7 |

**TABLE VI**

**Compressive Strength Results – M40 Concrete (MPa)**

| RCA (%) | 7-Day (MPa) | % Reduction | 28-Day (MPa) | % Reduction |
|---|---|---|---|---|
| 0% | 30.2 | 0 | 44.5 | 0 |
| 25% | 29.1 | 3.6 | 43.2 | 2.9 |
| 50% | 27.5 | 8.9 | 41.0 | 7.8 |
| 75% | 25.8 | 14.5 | 38.6 | 13.2 |
| 100% | 23.9 | 20.8 | 36.2 | 18.6 |

The compressive strength decreased gradually with increasing RCA replacement. This reduction occurred due to higher porosity, attached old mortar, and increased water absorption of RCA. However, up to 50% replacement, the strength remained within acceptable limits for pavement applications.

### B. Flexural Strength

Flexural strength results for M30 and M40 concrete at 28 days are presented in Table VII and Table VIII.

**TABLE VII**

**Flexural Strength Results – M30 Concrete**

| RCA (%) | Flexural Strength (MPa) | % Reduction |
|---|---|---|
| 0% | 4.40 | 0 |
| 25% | 4.22 | 4.0 |
| 50% | 4.00 | 9.0 |
| 75% | 3.62 | 17.7 |
| 100% | 3.34 | 24.0 |

**TABLE VIII**

**Flexural Strength Results – M40 Concrete**

| RCA (%) | Flexural Strength (MPa) | % Reduction |
|---|---|---|
| 0% | 5.31 | 0 |
| 25% | 5.10 | 3.9 |
| 50% | 4.78 | 9.9 |
| 75% | 4.26 | 19.7 |
| 100% | 3.90 | 26.5 |

Flexural strength reduced with increasing RCA percentage due to weaker interfacial transition zones and microcracks caused by adhered mortar. Up to 50% RCA replacement, flexural strength remained adequate for PQC requirements.

### C. Split Tensile Strength

Split tensile strength results for M30 and M40 concrete at 28 days are presented in Table IX and Table X.

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**TABLE IX**
**Split Tensile Strength Results – M30 Concrete**

| RCA (%) | Split Tensile Strength (MPa) | % Reduction |
|---|---|---|
| 0% | 3.20 | 0 |
| 25% | 3.10 | 3.1 |
| 50% | 2.84 | 11.2 |
| 75% | 2.60 | 18.7 |
| 100% | 2.40 | 25.0 |

**TABLE X**
**Split Tensile Strength Results – M40 Concrete**

| RCA (%) | Split Tensile Strength (MPa) | % Reduction |
|---|---|---|
| 0% | 3.80 | 0 |
| 25% | 3.55 | 6.5 |
| 50% | 3.40 | 10.5 |
| 75% | 3.00 | 21.0 |
| 100% | 2.82 | 25.7 |

Split tensile strength decreased as RCA content increased due to lower stiffness and porous nature of recycled aggregate. Results for both M30 and M40 confirm satisfactory performance at up to 50% RCA replacement.

## VII. ECONOMIC AND ENVIRONMENTAL ANALYSIS

### A. Economic Benefits

The cost comparison between natural aggregate and RCA is presented in Table XI. RCA material cost is lower than natural aggregate due to its local availability from recycled demolition waste.

**TABLE XI**
**Cost Comparison: Natural Aggregate vs. RCA**

| Parameter | Natural Aggregate | RCA | Saving |
|---|---|---|---|
| Material Cost (₹/ton) | 950 | 800 | 150 |
| Lead Distance (km) | 150 | 15 | 135 |
| Running Cost (₹4/km) | 600 | 60 | 540 |
| Total Cost (₹/ton) | 1550 | 860 | 690 (44.5%) |

For a representative 1000-tonne project, total project cost savings reach approximately 44.5% with 100% RCA replacement, and 22.3% with 50% RCA replacement (₹3,45,000 saved out of ₹15,50,000). RCA significantly reduces transportation and material costs due to local availability and reuse of demolition waste.

### B. Environmental Benefits

Using RCA reduces transportation by approximately 90% (from 150 km to 15 km source distance). $CO_2$ emissions during production are reduced from 8 kg $CO_2$/ton (natural aggregate) to 3 kg $CO_2$/ton (RCA). For a 1000-tonne project,

$CO_2$ reduction at 100% RCA replacement is approximately 73.3%, conserving natural aggregate resources, reducing landfill disposal, and promoting sustainable construction.

## VIII. CONCLUSION

Based on the experimental investigation, the following conclusions were drawn:

- Recycled Concrete Aggregate was found to be a feasible and sustainable alternative to natural coarse aggregate for pavement concrete applications.
- The compressive strength, flexural strength, and split tensile strength of concrete showed a gradual reduction with increasing RCA content.
- RCA replacement up to 50% provided strength characteristics comparable to conventional concrete for both M30 and M40 grade mixes.
- Higher replacement levels beyond 50% resulted in noticeable reduction in strength, increased porosity, and higher water absorption.
- Economic analysis indicated that the use of locally available RCA can reduce total material and transportation costs by up to 44.5%.
- Environmental assessment showed that RCA utilization helps reduce $CO_2$ emissions by up to 73.3% and conserves natural aggregate resources.
- The optimum replacement level of RCA for Pavement Quality Concrete is approximately 50%, providing a balance between mechanical performance, economic benefit, and environmental sustainability.
- Therefore, RCA can be effectively utilized up to 50% replacement in Pavement Quality Concrete for sustainable road construction.

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