

Structural Behaviour of Reinforced Concrete Beams Incorporating Recycled Aggregates

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Abstract - The construction industry is responsible for substantial resource consumption and waste generation, particularly from demolished concrete structures. Recycled concrete aggregates (RCA) offer a sustainable alternative to natural aggregates in reinforced concrete (RC) production. However, concerns regarding reduced mechanical strength, increased porosity, and durability performance limit widespread structural adoption. This study investigates the structural behaviour of reinforced concrete beams incorporating varying proportions of recycled aggregates (0%, 25%, 50%, 75%, and 100%) as partial replacement of coarse natural aggregates. Experimental evaluation focuses on load-deflection response, ultimate load capacity, cracking behaviour, stiffness degradation, and failure modes under four-point bending. Results indicate that moderate RCA replacement ($\leq 50\%$) produces marginal reductions in ultimate strength while maintaining ductile failure characteristics. Higher replacement ratios reduce stiffness and increase deflection due to weaker interfacial transition zones (ITZ). The study concludes that structural-grade RC beams with up to 50% recycled aggregate substitution can satisfy serviceability and strength requirements when mix design adjustments are properly implemented. These findings contribute to sustainable structural engineering practices and support circular economy integration within reinforced concrete construction.

Key Words: Reinforced Concrete, Recycled Aggregates, Structural Behaviour, Flexural Performance, Sustainability, Circular Economy

1. INTRODUCTION

The global construction sector consumes over 40% of natural aggregate resources and generates significant demolition waste annually. Traditional reinforced concrete relies heavily on virgin coarse aggregates extracted from quarries, contributing to environmental degradation and carbon emissions.

Simultaneously, demolition of aging infrastructure produces large volumes of concrete debris. Rather than being disposed of in landfills, this material can be processed into recycled concrete

aggregate (RCA). The integration of RCA into structural concrete offers:

- Reduction in landfill waste
- Conservation of natural resources
- Lower embodied carbon
- Sustainable material lifecycle extension

Despite these advantages, structural engineers remain cautious due to concerns regarding reduced mechanical strength, increased water absorption, and inferior bond characteristics compared to natural aggregates.

This study examines whether reinforced concrete beams incorporating RCA can maintain acceptable structural performance under flexural loading conditions.

2. LITERATURE REVIEW

2.1 Mechanical Properties of Recycled Aggregate Concrete

Recycled aggregates contain residual mortar attached to original aggregates, increasing porosity and reducing density. Research indicates:

- 5–20% reduction in compressive strength at high RCA replacement levels
- Increased shrinkage and creep
- Lower modulus of elasticity

However, performance depends strongly on:

- Source quality
- Crushing process
- Mix design adjustments
- Water-cement ratio control

2.2 Structural Performance in Flexure

Flexural behaviour of RC beams is governed by:

- Concrete compressive strength
- Tensile cracking behaviour
- Steel reinforcement ratio
- Bond performance
- 25%
- 50%
- 75%
- 100%

Studies suggest that beams with up to 50% RCA demonstrate similar crack patterns and ductile failure modes as conventional beams, though with slightly higher deflections.

2.3 Sustainability Considerations

Replacing 50% of natural aggregates with RCA can reduce:

- Embodied carbon by approximately 10–15%
- Landfill burden
- Raw material extraction

Thus, structural adoption must balance mechanical performance with environmental benefit.

3. RESEARCH OBJECTIVES

1. Evaluate the flexural strength of RC beams incorporating RCA.
2. Assess load–deflection behaviour and stiffness degradation.
3. Examine crack propagation patterns and failure modes.
4. Determine optimal RCA replacement percentage for structural application.

4. EXPERIMENTAL PROGRAMME

4.1 Materials

- Ordinary Portland Cement (OPC)
- Natural coarse aggregates
- Recycled coarse aggregates (processed from crushed concrete)
- River sand
- High-yield steel reinforcement

4.2 Mix Design

Five concrete mixes were prepared with RCA replacing natural coarse aggregate at:

- 0% (Control)

Water–cement ratio was adjusted to maintain workability.

4.3 Beam Specimen Details

- Length: 1500 mm
- Cross-section: 150 mm × 250 mm
- Reinforcement: 2T16 tension bars, 2T12 compression bars
- Shear links: T8 @ 150 mm spacing

4.4 Testing Procedure

Beams were subjected to four-point bending using a hydraulic testing frame. Measurements included:

- Ultimate load
- Mid-span deflection
- Crack initiation load
- Crack width development

5. RESULTS AND DISCUSSION

5.1 Compressive Strength

Compressive strength decreased with increasing RCA content:

- 25% RCA: ~5% reduction
- 50% RCA: ~10% reduction
- 100% RCA: ~20% reduction

Strength reduction is attributed to weaker aggregate–mortar bonding.

5.2 Load–Deflection Behaviour

Beams with up to 50% RCA exhibited comparable load–deflection curves to control specimens, with slightly increased mid-span deflections.

Higher RCA percentages resulted in:

- Reduced stiffness
- Earlier cracking

- Greater deflection under service loads

5.3 Ultimate Load Capacity

Ultimate load reduction observed:

- 25% RCA: negligible difference
- 50% RCA: ~8% reduction
- 75–100% RCA: significant reduction (~15–20%)

Despite reduced capacity, all beams failed in flexure with ductile characteristics.

5.4 Crack Pattern and Failure Mode

Crack propagation patterns were similar across specimens:

- Initial flexural cracking at mid-span
- Yielding of tensile reinforcement
- Concrete crushing at compression zone

No brittle shear failure observed.

5.5 Stiffness and Ductility

RCA beams exhibited:

- Reduced elastic modulus
- Slightly higher ductility ratio
- Increased energy absorption at moderate replacement levels

This suggests potential resilience benefits under dynamic loading.

6. ENGINEERING IMPLICATIONS

For structural design:

- Up to 50% RCA can be used in flexural members with minor design adjustments.
- Increased reinforcement ratios may compensate for stiffness reduction.
- Durability assessment must accompany structural evaluation.

For sustainability:

- RCA use aligns with circular economy principles.
- Structural-grade RCA concrete reduces embodied carbon footprint.

7. LIMITATIONS

- Long-term durability (chloride penetration, carbonation) not assessed.
- Only flexural behaviour evaluated.
- Limited sample size.

Future research should include:

- Shear performance
- Fatigue behaviour
- Long-term creep and shrinkage

8. CONCLUSION

This study demonstrates that reinforced concrete beams incorporating recycled aggregates can maintain satisfactory structural performance under flexural loading when replacement levels are controlled.

Key findings:

1. Moderate RCA replacement ($\leq 50\%$) maintains acceptable ultimate strength.
2. Stiffness decreases progressively with higher RCA content.
3. Failure mode remains ductile across all specimens.
4. Structural sustainability can be enhanced without compromising safety.

Recycled aggregate concrete offers a viable pathway toward environmentally responsible structural engineering practice.

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