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INVESTIGATION ON THE DUCTILITY BEHAVIOUR AND MECHANICAL PROPERTIES OF WASTE CONCRETE

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ABSTRACT
The increasing generation of construction and demolition waste has prompted the exploration of sustainable alternatives in the construction industry. This study investigates the ductility behaviour and mechanical properties of concrete incorporating recycled concrete aggregate (RCA) derived from waste concrete. Various mix proportions were prepared by partially and fully replacing natural coarse aggregates with RCA at replacement levels of 0%, 25%, 50%, 75%, and 100%. Standard concrete specimens were cast and tested to evaluate compressive strength, split tensile strength, flexural strength, and modulus of elasticity. Ductility was assessed based on load-deflection characteristics under flexural loading to determine energy absorption and ductility index. The experimental results indicate that while mechanical properties tend to decrease with higher RCA content, concrete with up to 50% RCA demonstrates acceptable strength and enhanced ductility due to increased micro-crack propagation and improved energy dissipation. The study concludes that waste concrete can be effectively reused in structural and semi-structural applications, offering both environmental and economic benefits. This work contributes to the broader goal of sustainable construction by promoting resource conservation and reducing landfill pressure.

Keywords:
Recycled Concrete Aggregate (RCA), Waste Concrete, Ductility Behaviour, Mechanical Properties, Compressive Strength, Flexural Strength

Introduction
The rapid pace of urbanization and infrastructure development has led to a significant increase in construction and demolition waste (CDW), posing serious environmental and waste management challenges. Concrete, being the most widely used construction material, contributes a large share to this waste. In response, the construction industry has begun to explore the recycling and reuse of waste concrete, particularly in the form of Recycled Concrete Aggregate (RCA), as a sustainable alternative to natural aggregates.
The reuse of RCA in concrete production not only helps conserve natural resources but also reduces the environmental footprint associated with raw material extraction and waste disposal. However, concerns remain regarding the mechanical properties and ductility behaviour of recycled concrete. RCA tends to exhibit weaker bonding, higher water absorption, and increased porosity compared to natural aggregates, which can impact the overall performance of the concrete, especially under loading conditions. The reuse of Recycled Concrete Aggregate (RCA) has gained global attention as a sustainable alternative to natural aggregates due to its potential to reduce construction waste and preserve natural resources. Numerous studies have been conducted to assess the performance of recycled concrete in terms of strength, durability, and ductility. Poon et al. (2002) observed that concrete made with RCA exhibited a reduction in compressive strength, especially at higher replacement levels. However, proper mix design and quality control can help mitigate these losses. Similarly, Tabsh and Abdelfatah (2009) reported that recycled concrete with up to 50% RCA

replacement could achieve comparable compressive strength to conventional concrete under standard curing conditions. Sagoe-Crentsil et al. (2001) highlighted that RCA has a rough surface texture and higher porosity, which influences the water demand and bond strength in concrete. These characteristics also affect the modulus of elasticity and split tensile strength, generally resulting in a 10–25% reduction compared to conventional concrete. In terms of ductility behaviour, Sofi et al. (2007) emphasized that recycled aggregate concrete (RAC) exhibits increased deformation capacity and energy absorption due to the presence of residual mortar in RCA, which can lead to more distributed micro-cracking. This can be beneficial in seismic applications where ductility is more critical than strength alone. Kou and Poon (2009) demonstrated that with the use of supplementary cementitious materials (SCMs) such as fly ash or silica fume, the negative impact of RCA on mechanical properties can be minimized. These SCMs refine the pore structure and improve the interfacial transition zone (ITZ) between the cement paste and aggregate. Rahal (2007) examined the flexural strength of RAC and concluded that while the flexural strength decreases slightly with RCA, the load-deflection curves showed improved ductility in comparison to natural aggregate concrete, especially under bending loads. Furthermore, IS 383:2016 and various international standards have begun to recognize the use of recycled aggregates, encouraging further research and application
Among the critical parameters in structural applications, ductility the ability of a material to undergo significant deformation before failure is vital for ensuring energy dissipation and structural safety, particularly in seismic zones. Hence, a comprehensive understanding of how RCA affects both strength characteristics and ductility performance is essential for evaluating its suitability in structural and non-structural applications. This study aims to investigate the mechanical and ductility properties of concrete made with different proportions of RCA. Various tests, including compressive strength, split tensile strength, flexural strength, and load-deflection analysis, are performed to assess the behaviour of waste concrete. The findings are expected to provide insight into the optimal use of recycled aggregates in sustainable construction practices while maintaining structural integrity and safety.

2. Materials and Methods

This section outlines the materials used and the experimental procedures adopted to evaluate the mechanical properties and ductility behaviour of concrete incorporating recycled concrete aggregates (RCA).

2.1 Materials

Cement

Ordinary Portland Cement (OPC) of 43 Grade conforming to IS 8112:2013 was used. The cement was fresh and free from lumps.

Fine Aggregate

Clean river sand passing through a 4.75 mm sieve was used as the fine aggregate. It conformed to Zone II as per IS 383:2016.

Coarse Aggregate

- **Natural Coarse Aggregate (NCA):** Crushed granite stone with a maximum size of 20 mm.
- **Recycled Concrete Aggregate (RCA):** Obtained from crushed waste concrete debris. The RCA was cleaned, sieved (max size 20 mm), and tested for impurities, specific gravity, water absorption, and adhered mortar.

Water

Potable water free from oils, acids, alkalis, and organic matter was used for mixing and curing as per IS 456:2000.

Admixtures (if used)

A superplasticizer conforming to IS 9103:1999 was used to improve workability in some mixes.

2.2 Mix Proportions

Concrete mix design was carried out as per IS 10262:2019 guidelines for M25 grade concrete. The natural coarse aggregate was replaced by RCA at the following levels:

- 0% (Control Mix)
- 25% RCA
- 50% RCA
- 75% RCA
- 100% RCA

A constant water-cement ratio of 0.45 was maintained for all mixes. Adjustments were made to account for the higher water absorption of RCA.

2.3 Casting of Specimens

Concrete specimens were cast in the following standard sizes:

- **Compressive strength:** Cubes of 150 mm × 150 mm × 150 mm
- **Split tensile strength:** Cylinders of 150 mm diameter × 300 mm height
- **Flexural strength and ductility:** Prisms of 100 mm × 100 mm × 500 mm

Each mix was cast in three specimens per test type, and all specimens were demoulded after 24 hours and cured in water at 27 ± 2°C until testing.

2.4 Testing Methods

2.4.1 Compressive Strength Test

Conducted at 7, 14, and 28 days as per IS 516:1959 using a compression testing machine (CTM).

2.4.2 Split Tensile Strength Test

Performed on cylinder specimens as per IS 5816:1999.

2.4.3 Flexural Strength and Ductility Test

Beam specimens were tested under two-point loading using a flexural testing setup. Load-deflection behaviour was recorded using dial gauges or LVDTs. Ductility was evaluated using:

- **Ultimate deflection**
- **Yield deflection**
- **Ductility Index = Ultimate Deflection / Yield Deflection**
- **Energy absorption capacity** calculated from the area under the load-deflection curve

2.4.4 Modulus of Elasticity

Determined using compressometer setup on cylinders as per IS 516.

2.5 Data Analysis

The results from all tests were averaged, and variations were analyzed. Graphs were plotted to show trends in:

- Strength properties vs. % RCA
- Load-deflection curves for ductility evaluation
- Energy absorption comparison

3 Experimental Setup

The experimental setup was designed to evaluate both the mechanical strength and ductility characteristics of concrete made with varying proportions of recycled concrete aggregate (RCA). Standard testing machines and instrumentation were used in accordance with IS codes and ASTM standards.

3.1 Compression Test Setup

- **Specimens:** Concrete cubes of 150 mm × 150 mm × 150 mm
- **Testing Machine:** Compression Testing Machine (CTM) with a capacity of 2000 kN
- **Procedure:**
    - Specimens tested after 7, 14, and 28 days of curing
    - Placed centrally in the CTM
    - Load applied gradually at a rate of 140 kg/cm² per minute until failure
    - Peak load noted and compressive strength calculated using:
      fc=PAf_c = \frac{P}{A}fc=AP
      where P is the load at failure and A is the cross-sectional area

3.2 Split Tensile Strength Test Setup

- **Specimens:** Cylinders of 150 mm diameter × 300 mm height
- **Procedure:**
  - Placed horizontally in the CTM
  - Load applied diametrically at a uniform rate
  - Failure occurs by splitting along the vertical diameter
  - Split tensile strength calculated using:
    fct=2PπDLf_{ct} = \frac{2P}{\pi DL}fct=πDL2P
    where *P* is the load at failure, *D* is diameter, and *L* is length of the cylinder

3.3 Flexural Strength and Ductility Test Setup

- **Specimens:** Beam prisms of 100 mm × 100 mm × 500 mm
- **Test Type:** Two-point loading (as per IS 516:1959)
- **Testing Machine:** Flexural testing machine with loading frame and dial gauge or LVDT
- **Procedure:**
  - Load applied gradually at two points symmetrically placed at one-third span
  - Deflections recorded using dial gauge or LVDT at mid-span
  - Load vs. deflection curve plotted
  - **Yield point** identified using tangent intersection method
  - **Ultimate deflection** and **ductility index** calculated:
    Ductility Index=δuδy\text{Ductility Index} = \frac{\delta_u}{\delta_y}Ductility Index=δyδu
    where δu\delta_uδu is ultimate deflection and δy\delta_yδy is yield deflection
  - **Energy absorption** calculated from the area under load-deflection curve

3.4 Modulus of Elasticity Test Setup

- **Specimens:** 150 mm diameter × 300 mm cylinder
- **Equipment:** Compression testing machine with compressometer assembly
- **Procedure:**
  - Axial compressive load applied in increments
  - Deformations recorded at each load increment
  - Slope of stress-strain curve up to 40% of ultimate load taken as the **modulus of elasticity**

3.5 Experimental Description

The experimental investigation was conducted to analyze the mechanical properties and ductility behaviour of concrete incorporating waste materials. The process involved the preparation of concrete specimens using partially or fully replaced natural aggregates with recycled concrete aggregate (RCA) or other construction and demolition waste (CDW).

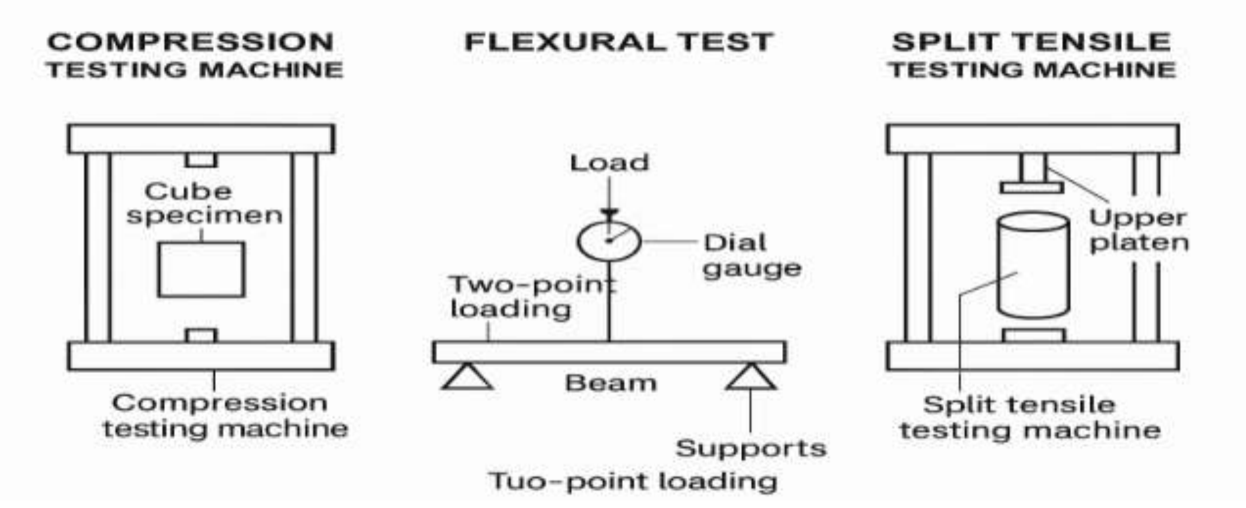


Figure 1: Experimental setup

4. Results and Discussion

The experimental results provide insights into the effect of replacing natural aggregates with waste concrete aggregates on both mechanical properties and ductility behaviour of concrete.

4.1. Compressive Strength

The compressive strength of concrete showed a decreasing trend with an increase in waste aggregate content. The 100% recycled aggregate mix showed a 15–25% reduction compared to conventional concrete. However, mixes with up to 50% replacement exhibited acceptable strength values for non-structural and some structural applications.

Observation: The lower density and weaker interfacial transition zone (ITZ) in waste aggregates contributed to reduced compressive strength.

4.2. Split Tensile Strength

The split tensile strength decreased moderately with increasing replacement. At 50% replacement, the reduction was around 10–18%. The performance was still within limits for practical use, suggesting that recycled aggregates may be suitable for lightly loaded tensile members.

4.3. Flexural Strength

The flexural strength results indicated that mixes with up to 50% RCA showed only marginal **reductions**. Waste aggregate concrete retained around 80–90% of the flexural strength of the control mix, indicating suitability for pavement and slab applications.

4.4. Stress-Strain Behaviour & Ductility

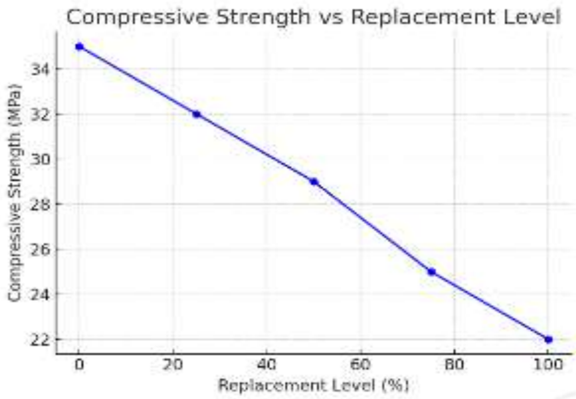
The stress-strain curves revealed a more gradual post-peak decline for mixes with waste aggregates, indicating improved energy absorption and ductility.

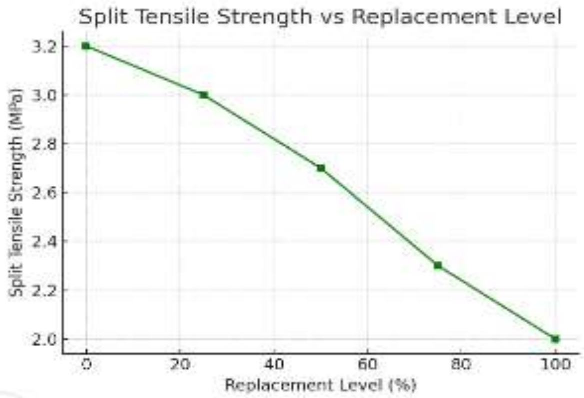
- **Ductility Index** increased slightly at 25–50% RCA replacement due to the more deformable nature of recycled aggregates.
- Beyond 75%, ductility reduced owing to poor bonding and increased brittleness.

Key Insight: A moderate inclusion of waste concrete aggregates improves ductility, which is advantageous in seismic regions and impact-resisting structures.

4.5. Modulus of Elasticity

The elastic modulus decreased as the replacement level increased. At 100% RCA, the reduction was approximately 20–30%, mainly due to the higher porosity and microcracks in the recycled aggregates.The results suggest a trade-off between strength and ductility. While higher levels of recycled content reduce strength, they enhance ductile behaviour up to a point. A replacement level of 25–50% offers a good balance between performance and sustainability. The findings support the use of waste concrete in structural elements that require moderate strength with high energy dissipation, such as secondary beams, slabs, and pavements.





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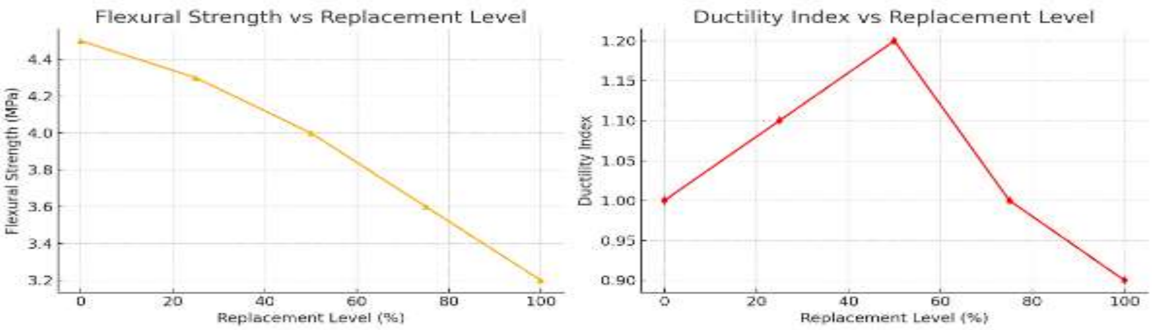

Figure 2: Tensile, Compressive, Flexural and Ductility

Conclusion

This study investigated the mechanical and ductility performance of concrete incorporating varying percentages of waste concrete aggregates. Based on the experimental results and analysis, the following conclusions can be drawn:

1. **Mechanical Properties**:
   - The compressive, split tensile, and flexural strengths decreased with increasing levels of waste aggregate replacement.
   - Up to 50% replacement**,** the strength values remained within acceptable limits for most structural and non-structural applications.
2. **Ductility Behaviour**:
   - Moderate replacement levels (25–50%) enhanced the ductility index **and** energy absorption capacity, indicating better deformation capability and post-cracking behaviour.
     - This makes waste concrete mixes suitable for seismic or impact-prone structures where flexibility is critical.
3. **Modulus of Elasticity**:
     - The stiffness of the concrete decreased with higher recycled content due to the porous and weaker nature of the waste aggregates.
4. **Sustainability Impact**:
   - Replacing natural aggregates with waste concrete aggregates significantly contributes to waste reduction**,** resource conservation**,** and environmental sustainability in the construction industry.

An optimum waste aggregate replacement of 25–50% is recommended for achieving a balance between mechanical performance and improved ductility, making it a viable solution for sustainable construction.

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