

Structural Performance of Recycled Concrete Aggregate with Steel Fibre Reinforcement

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Abstract

The increasing demand for sustainable construction materials has stimulated the utilization of recycled concrete aggregate (RCA) in concrete production; however, its application is often constrained by inferior mechanical properties compared to conventional granite-based concrete. This study investigates the structural performance of RCA concrete reinforced with varying steel fibre contents, considering fibre volume fractions of 0%, 0.25%, 0.5%, and 1.0%. Fresh and hardened properties were evaluated through slump, compressive strength, and flexural strength tests. Slump values were first determined to assess workability, followed by strength tests conducted at 7, 14, and 28 days. The results indicate that the control granite concrete mix (gc) exhibited a slump of 83 mm, while the fibre-free recycled aggregate mix (rc) recorded 80 mm. The inclusion of steel fibres resulted in a progressive reduction in workability, with slump values of 72, 60, and 50 mm for mixes r2, r3, and r4, respectively. Compressive strength ranged from 15.90–19.20 MPa at 7 days, 17.12–21.06 MPa at 14 days, and 20.33–26.54 MPa at 28 days, showing improvement with fibre addition. Similarly, flexural strength increased from 4.0–4.6 MPa, 4.7–5.9 MPa, and 5.1–6.4 MPa at 7, 14, and 28 days, respectively. The findings demonstrate that steel fibre reinforcement enhances the mechanical performance of RCA concrete, thereby improving its suitability for structural applications.

Keywords: Recycled Concrete Aggregate, Steel Fibres, Compressive Strength, Flexural Strength, Workability.

Introduction

The growing emphasis on sustainable construction has intensified interest in recycled concrete aggregate (RCA) as an alternative to natural coarse aggregate in structural concrete (Alibeigibeni, *et al.*, 2025). Rapid urbanization and infrastructure renewal generate significant construction and demolition waste, prompting the need for environmentally responsible reuse strategies (De Luca *et al.*, 2021). RCA production reduces landfill demand and conserves natural resources; however, its inherent characteristics, including adhered mortar, higher porosity, and increased water absorption, adversely affect mechanical performance. Consequently, recycled aggregate concrete often exhibits reduced compressive strength, tensile capacity, and stiffness compared with conventional concrete, raising concerns regarding its suitability for structural applications (Wattanapanich *et al.*, 2024). Furthermore, efforts to overcome the mechanical limitations of recycled aggregate concrete have led to increased adoption of fibre reinforcement techniques. Steel fibres are particularly effective due to their high tensile strength and ability to enhance crack resistance within brittle cementitious matrices (Mousavi *et al.*, 2019). When dispersed in concrete, steel fibres bridge microcracks and delay crack propagation, resulting in improved toughness, ductility, and post-cracking behaviour (Akbulut *et al.*, 2025). Recent studies demonstrate that steel fibre inclusion can significantly compensate for strength reductions associated with RCA, thereby improving flexural and tensile performance and promoting more ductile failure modes (Kong *et al.*, 2022).

Additionally, the interaction between RCA and steel fibres introduces complex microstructural mechanisms that influence overall structural performance. The rough surface texture of recycled aggregates may enhance fibre anchorage and mechanical interlock within the cement matrix, potentially improving stress transfer efficiency (Choi *et al.*, 2016). However, weak interfacial transition zones and internal microcracks within RCA can offset these benefits if fibre dosage and mix design are not optimized. Thus, parameters such as

fibre volume fraction, aspect ratio, and aggregate replacement level play critical roles in governing the performance of steel fibre reinforced recycled concrete systems (Balaji *et al.*, 2025). Despite these advancements, a critical problem remains concerning the structural reliability of recycled concrete aggregate in load-bearing elements. Conventional recycled aggregate concrete often exhibits premature cracking, reduced stiffness, and brittle failure behaviour, which undermine confidence in its structural use. Although steel fibres improve crack control and ductility, there is limited agreement on optimal fibre content and its effectiveness across different RCA replacement ratios. Consequently, insufficient linkage between material-level improvements and structural response restricts the development of comprehensive design guidance for steel fibre reinforced recycled concrete aggregate (SFRRCA).

The significance of this study lies in its contribution to sustainable structural engineering by addressing both environmental and performance-related challenges. By systematically evaluating the structural behaviour of recycled concrete aggregate enhanced with steel fibre reinforcement, the research supports the safe and efficient reuse of construction waste in structural applications. Additionally, the findings provide evidence-based insights that can inform mix design optimization and contribute to the evolution of concrete design standards, particularly in contexts where resource conservation and structural safety are equally critical.

Methodology

Sample Collection and Preservation

Recycled concrete aggregate (RCA) was sourced from demolished reinforced concrete elements obtained from building demolition sites, ensuring that the materials were free from deleterious contaminants such as soil, wood, plastics, and asphalt. The collected concrete debris was transported to the laboratory and stored in a dry environment prior to processing. Limestone Portland Cement was used as the binder obtained from a local supplier within the study area, while natural river sand and crushed granite were sourced from local suppliers. Steel fibres were procured from a certified distributor, and potable water suitable for concrete production was used. All constituent materials were properly stored under dry conditions to minimize moisture-induced variability prior to mixing.



Plate 1: Collected Steel Fibres.

Preparation of Materials and Concrete Mixing

The demolished concrete was crushed using a jaw crusher (Model PE 250 × 400, capacity 15 t/h, China) and subsequently sieved with a mechanical sieve shaker (Endecotts EFL2000, United Kingdom) to obtain coarse aggregate sizes comparable to natural granite. The recycled concrete aggregate was preconditioned by moistening followed by surface drying to minimize excessive water absorption during mixing. Concrete production was based on a nominal mix proportion of 1:2:4 cement:sand:coarse aggregate with a water–cement ratio of 0.50, comprising a control mix with natural granite aggregate (Gc), a fibre-free recycled aggregate mix (Rc), and fibre-reinforced recycled aggregate mixes incorporating 0.25% (R2),

0.50% (R3), and 1.00% (R4) steel fibres by volume. Mixing was carried out using a tilting drum mixer (Model JZC350, 350 L capacity, China), with fibres introduced gradually to ensure uniform dispersion. The fresh concrete was subsequently cast into steel moulds and compacted using a vibrating table (Model ZT-96, China) to achieve adequate consolidation.



Plate 2: Concrete Constituent Batching by Weight

Mechanical Tests of Concrete

The mechanical properties of the concrete were evaluated at the Structural Laboratory, University of Ibadan, Oyo State, Nigeria. The tests conducted included the slump test to assess workability, the compressive strength test to determine load-bearing capacity, the tensile strength test to evaluate resistance to cracking under tension, and the flexural strength test to measure the concrete's performance under bending stress.

Slump Test

Fresh concrete workability was assessed using the slump test in accordance with ASTM C143/C143M-20. The test was conducted using a standard slump cone (300 mm height, steel cone) and a tamping rod (16 mm diameter, 600 mm length). The vertical subsidence of the concrete after cone removal was measured immediately to determine consistency, as shown in Plate 3.



Plate 3: Slump Test of concrete samples

Compressive Test

The preparation of concrete specimens prior to the compressive strength test was carried out systematically to ensure accuracy and reliability of results. Cube specimens measuring 150 mm × 150 mm × 150 mm were demoulded after 24 hours of casting and immediately transferred to a curing tank containing clean potable water maintained at room temperature, in accordance with BS EN 12390-2 standards as shown in Plate 3. Curing was continued for 7, 14, and 28 days to allow proper hydration and strength development. Prior to testing, the specimens were lightly surface-dried using a damp cloth to remove excess water and visually inspected for cracks or defects that could affect stress distribution. Each cube was centrally positioned on the compression testing machine (Model YES-2000, 2000 kN capacity, Italy) with alignment and leveling carefully checked to prevent eccentric loading. This methodical preparation ensured consistent application of load and valid evaluation of the structural performance of both fibre-free and steel fibre-reinforced recycled aggregate concrete.



Plate 2: Curing of Concrete samples.



Plate 3: Compressive Test of Concrete samples.

Flexural Strength Test

The flexural strength test was performed to assess the tensile performance and crack resistance of the concrete, which are critical for structural elements subjected to bending. Prism specimens of 100 mm × 100 mm × 500 mm were tested at 7, 14, and 28 days in accordance with ASTM C78/C78M and BS EN 12390-5, using a two-point loading configuration. This test method provides a uniform bending moment over the central region of the specimen, allowing accurate evaluation of flexural behaviour. Specimens were positioned on simple supports with a specified span length, and load was applied steadily until failure as shown in Plate 4. Early-age flexural strength values highlighted the contribution of steel fibres to crack control at low maturity, while later-age results demonstrated improved post-cracking behaviour and

strength retention. The 28-day flexural strength was particularly important in assessing the effectiveness of steel fibres in compensating for the weaker tensile characteristics of recycled aggregate concrete.



Plate 4: Flexural Test of Concrete samples.

Results and Discussion

Slump Test

The slump test results presented in Figure 1 indicate a clear influence of recycled concrete aggregate (RCA) and steel fibre content on the workability of the concrete mixes. The control mix with natural granite aggregate (Gc) exhibited the highest slump value of 83 mm, reflecting good workability for conventional concrete. In comparison, the fibre-free recycled aggregate mix (Rc) showed a slight reduction to 80 mm, which can be attributed to the higher porosity and angular shape of RCA, consistent with observations reported by Guo *et al.* (2018), who noted that recycled aggregates tend to absorb more water and reduce mix flowability. Furthermore, the incorporation of steel fibres caused a progressive decline in slump values with increasing fibre content. The 0.25% fibre mix (R2) recorded a slump of 72 mm, while mixes with 0.50% (R3) and 1.00% (R4) fibres dropped to 60 mm and 50 mm, respectively. This trend reflects the restrictive effect of fibres on particle movement and the increased internal friction within the fresh concrete matrix, a phenomenon also highlighted in the study by Li *et al.* (2025), where higher fibre volumes consistently reduced workability.

These results demonstrate that while recycled aggregate alone has a modest impact on slump, steel fibre reinforcement significantly decreases fresh concrete workability, necessitating adjustments in mixing or the use of water-reducing admixtures for practical application. The findings align with previous research indicating that fibre addition improves post-cracking performance but compromises workability, emphasizing the need for optimized fibre content in structural concrete mixes (Akbulut *et al.*, 2020).

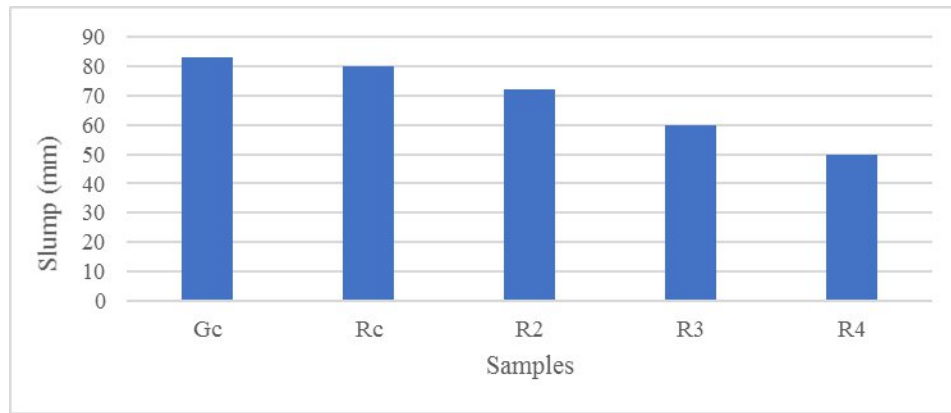


Figure 1: Slump Height of Concrete Samples

Compressive Test

The compressive strength results presented in Figure 2 reveal distinct trends in the performance of recycled concrete aggregate (RCA) with and without steel fibre reinforcement. The control mix with natural granite aggregate (Gc) achieved 7-, 14-, and 28-day strengths of 18.25, 21.65, and 24.96 MPa, respectively, reflecting typical strength development for normal-strength concrete. In contrast, the fibre-free recycled aggregate mix (Rc) recorded lower strengths at all ages, with 28-day strength reaching 20.33 MPa, indicating that the inherent porosity and weaker interfacial transition zone of RCA adversely affected early-age and long-term load-bearing capacity. These observations are consistent with the findings of Morales-Rapallo and Kuchta, (2025), who reported that RCA tends to reduce compressive strength due to residual mortar and higher water absorption.

Furthermore, the incorporation of steel fibres into the recycled aggregate mixes progressively improved compressive strength. The 0.25% fibre mix (R1) achieved 28-day strength of 25.43 MPa, slightly exceeding the control mix, while higher fibre contents of 0.50% (R2) and 1.00% (R3) further increased strength to 25.92 MPa and 26.54 MPa, respectively. This enhancement is attributed to the fibres' ability to bridge microcracks and distribute stresses more effectively within the concrete matrix, which aligns with the results reported by Gao and Wang, (2021), demonstrating that steel fibres can compensate for the weaker properties of recycled aggregates and improve overall compressive performance.

These results indicate that steel fibre reinforcement not only mitigates the strength reduction associated with RCA but can also produce recycled aggregate concrete with compressive performance comparable to or slightly superior to conventional concrete. Consequently, the study confirms that carefully proportioned fibre content is an effective strategy for enhancing structural performance, supporting previous research suggesting that fibre-reinforced recycled concrete can meet normal structural requirements while promoting sustainability (Song *et al.*, 2018).

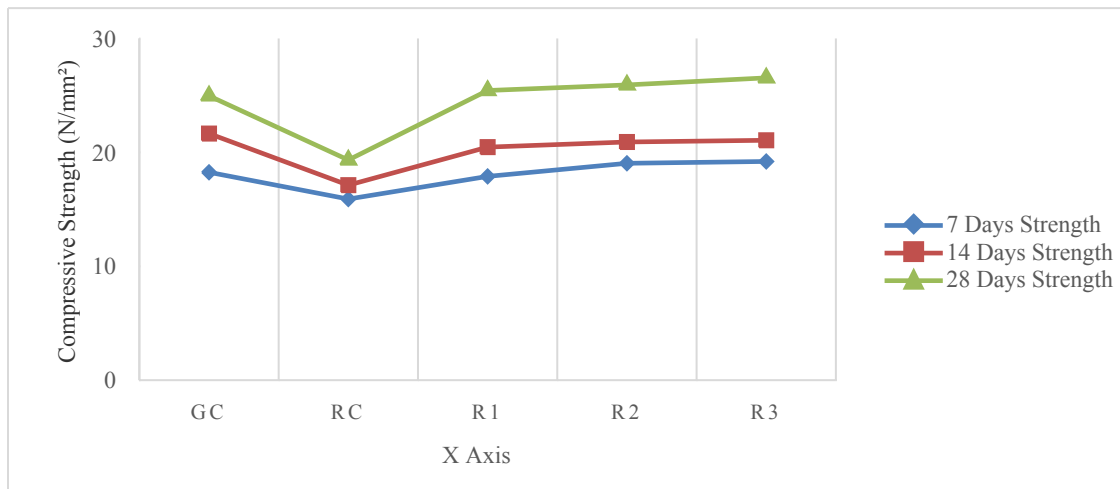


Figure 2: Compressive strength of Samples.

Flexural Strength Test

The flexural strength results summarized in Figure 3 illustrate the effect of recycled concrete aggregate (RCA) and steel fibre reinforcement on the bending (flexural tensile) capacity of concrete. The control mix with granite aggregate (Gc) exhibited 7-, 14-, and 28-day flexural strengths of 4.6, 5.2, and 5.7 MPa, respectively, reflecting typical behaviour for normal-strength concrete under bending. In contrast, the fibre-free RCA mix (Rc) recorded lower values of 4.0, 4.7, and 5.1 MPa at the corresponding curing ages, indicating a reduction in flexural tensile capacity due to the presence of adhered mortar and a weaker interfacial transition zone, as reported by Junior *et al.* (2025). Furthermore, the inclusion of steel fibres progressively enhanced flexural performance. The 0.25% fibre mix (R2) achieved 28-day flexural strength of 5.9 MPa, exceeding the control mix, while higher fibre contents of 0.50% (R3) and 1.00% (R4) further increased strengths to 6.2 MPa and 6.4 MPa, respectively. This improvement is attributed to the fibres' ability to bridge microcracks and delay crack propagation, enhancing post-cracking ductility, a trend similarly reported by Garg *et al.* (2021). These results indicate that steel fibre reinforcement not only compensates for the reduced flexural capacity of RCA but can also improve overall bending performance beyond conventional concrete. Consequently, fibre addition emerges as an effective strategy to enhance tensile and flexural behaviour in recycled aggregate concrete, supporting structural applications while maintaining sustainability objectives (Shahjalal *et al.*, 2021).

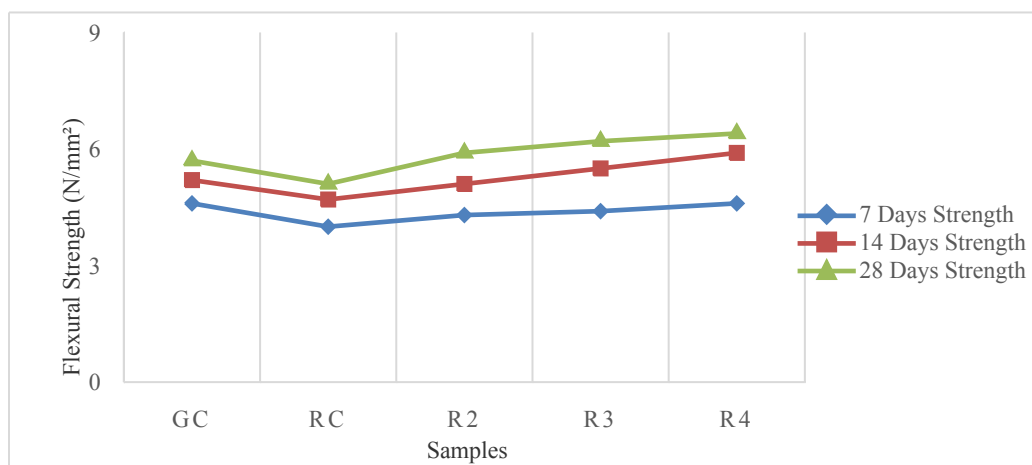


Figure 3: Flexural strength of Samples.

Conclusion

This study shows that recycled concrete aggregate (RCA) reduces both compressive and flexural strengths compared to conventional granite concrete, primarily due to higher porosity and weaker interfacial transition zones. The inclusion of steel fibres effectively improved strength and ductility at all curing ages by bridging microcracks and redistributing stresses, with 28-day results surpassing the control mix. However, workability decreased with higher fibre content due to increased internal friction. The findings indicate that steel fibre reinforced RCA concrete can achieve structural performance comparable to conventional concrete, supporting its use in sustainable construction. Future research should focus on optimizing fibre content, employing admixtures to improve workability, and evaluating long-term durability under varying environmental conditions to ensure reliable structural application of fibre-reinforced RCA concrete.

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