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Experimental assessment of recycled aggregate concrete for secondary structural components

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Abstract
Recycled aggregate concrete has emerged as a promising material for improving sustainability in the construction sector by reducing natural aggregate consumption and construction and demolition waste. This research presents an experimental assessment of recycled aggregate concrete intended for use in secondary structural components such as lintels, slabs, partition beams, and non-primary load bearing members. Laboratory investigations were carried out on concrete mixes incorporating varying proportions of recycled coarse aggregates replacing natural aggregates. Fresh concrete properties were evaluated through workability measurements, while hardened concrete performance was examined using compressive strength, split tensile strength, flexural strength, density, water absorption, and stress strain behavior tests. Particular emphasis was placed on evaluating performance at curing ages relevant to practical construction timelines. The results indicate that recycled aggregate concrete exhibits marginal reductions in mechanical strength compared to conventional concrete, primarily due to the presence of adhered mortar and higher porosity of recycled aggregates. However, strength levels remained within acceptable limits for secondary structural applications when appropriate mix design adjustments were implemented. Durability related indicators such as water absorption and density showed predictable trends with increasing recycled aggregate content, highlighting the importance of controlled replacement ratios. The experimental findings demonstrate that up to moderate levels of recycled aggregate substitution can produce structurally reliable and environmentally beneficial concrete. This research reinforces the feasibility of recycled aggregate concrete as a sustainable alternative for secondary structural components and provides experimental evidence to support its responsible adoption in practice, contributing to circular economy objectives within the construction industry. The outcomes also underline the need for standardized guidelines, quality control of recycled aggregates, and performance-based acceptance criteria to enable engineers, contractors, and policymakers to confidently integrate recycled aggregate concrete into routine construction while maintaining safety, serviceability, and long-term sustainability goals across diverse structural and environmental conditions worldwide today.

Keywords: Recycled aggregate concrete, secondary structural components, construction and demolition waste, sustainable construction, mechanical properties

Introduction

The increasing demand for concrete in global infrastructure development has intensified the depletion of natural aggregates and generated significant volumes of construction and demolition waste, prompting the exploration of recycled aggregate concrete as a sustainable alternative [1][2]. Recycled aggregate concrete utilizes aggregates obtained from crushed concrete debris, offering potential reductions in landfill use, environmental degradation, and embodied energy associated with conventional construction materials [3][4]. Despite these advantages, the structural application of recycled aggregate concrete remains cautious due to concerns related to reduced strength, higher water absorption, variability in aggregate quality, and long-term durability performance [5][6]. Previous experimental studies have reported that the presence of adhered old mortar on recycled aggregates leads to increased porosity and weaker interfacial transition zones, which can adversely influence mechanical behavior when compared to natural aggregate concrete [7][8]. These limitations have restricted widespread adoption in primary load bearing elements, although secondary structural components present a viable opportunity for practical implementation with controlled performance requirements [9][10]. Secondary elements such as lintels, non- primary beams, and partition slabs typically experience lower stress demands, making them suitable candidates for incorporating recycled aggregates without compromising structural safety [11]. However, systematic experimental data evaluating the performance of recycled aggregate concrete specifically for such applications remain limited and fragmented across varying mix designs and testing protocols [12][13]. The absence of consistent experimental benchmarks contributes to uncertainty among designers and practitioners regarding acceptable replacement levels and performance expectations [14]. In this context, the present research aims to experimentally assess the fresh and hardened properties of recycled aggregate concrete incorporating different recycled aggregate replacement ratios for use in secondary structural components [15]. The objective is to quantify mechanical strength, deformation characteristics, and durability related indicators under standardized laboratory conditions while maintaining practical mix proportions [16][17]. It is hypothesized that recycled aggregate concrete, when designed with appropriate replacement limits and mix adjustments, can achieve performance levels adequate for secondary structural applications despite minor reductions relative to conventional concrete [18][19]. By establishing experimentally validated performance trends, the research seeks to support evidence-based decision making, promote responsible material reuse, and contribute to sustainable construction practices aligned with circular economy principles and evolving regulatory frameworks within contemporary structural engineering practice [3][11][14]. The findings are expected to aid specification development and encourage broader acceptance in routine construction projects particularly within urban redevelopment contexts experiencing high demolition waste generation and increasing material scarcity pressures in developing economies globally.

Materials and Methods

Materials

Ordinary Portland cement conforming to standard structural concrete practice was used with potable mixing water, natural river sand as fine aggregate, and crushed natural coarse aggregate (NCA) as the control coarse fraction [1][4]. Recycled coarse aggregate (RCA) was produced by crushing laboratory-verified concrete debris, followed by screening to obtain a nominal 20 mm maximum size; visible contaminants were removed to minimize variability, consistent with common RCA preparation approaches reported in prior experimental work [5][8]. Because RCA typically contains adhered old mortar and microcracks that raise porosity and absorption, its physical properties (specific gravity, water absorption, and grading) were characterized before mix design [7][9]. Four mixes were prepared by replacing NCA with RCA at 0%, 25%, 50%, and 75% by mass, reflecting replacement ranges often considered feasible for non-critical elements and secondary components [6][10]. To control the workability loss commonly associated with RCA, the RCA was pre-wetted to a saturated surface-dry condition (or equivalent moisture correction was applied) as recommended in studies emphasizing pre-saturation effects on performance and mix stability [19][13].

Methods

Concrete was proportioned for a target strength suitable for secondary structural components (e.g., lintels, partition beams, minor slabs) where design demands are lower than primary load-bearing members [11][9]. Fresh concrete workability was evaluated immediately after mixing using a standard slump test, and density was recorded for quality control [1][4]. Specimens were cast in steel Molds and compacted using vibration; curing was performed in water at controlled temperature until testing ages, following established recycled concrete aggregate research protocols [8][12]. Hardened properties included compressive strength at 7 and 28 days, split tensile strength at 28 days, and flexural strength at 28 days to capture both primary and cracking-related behaviors relevant to serviceability of secondary components [7][14]. Durability-related indicators were assessed using oven-dry density and water absorption, given their sensitivity to RCA porosity and interfacial transition zone quality [13][16]. For statistical analysis, each mix level used multiple replicate specimens per test; one-way ANOVA tested differences among replacement levels, and linear regression quantified trends of absorption with RCA percentage, approaches widely applied in comparative RCA performance evaluations [12][15].

Results

Table 1: Mix design (per m³) and RCA replacement levels

Mix ID	RCA replacement of coarse aggregate (%)	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate total (kg)	Notes
M0	0	380	190	700	1050	Control (NCA only) [1][4]
M25	25	380	190*	700	1050	RCA pre-wetted / moisture-corrected [19][13]
M50	50	380	190*	700	1050	Same binder and w/b, variable coarse fraction [6][10]
M75	75	380	190*	700	1050	High RCA level to probe limiting behavior [7][9]

*Effective water was maintained by moisture correction / pre-wetting, given higher RCA absorption [7][19].

Table 2: Mean ± SD of strength metrics for RCA mixes at 28 days.

Recycled aggregate replacement (%)	Compressive strength, 28 d (MPa)	Split tensile strength, 28 d (MPa)	Flexural strength, 28 d (MPa)
0	32.96±0.95	2.98±0.14	4.61±0.13
25	30.81±1.17	2.84±0.16	4.34±0.15
50	28.93±0.96	2.83±0.16	4.04±0.21
75	27.21±1.84	2.52±0.23	3.67±0.21

Statistical inference (ANOVA): Compressive strength differed significantly across replacement levels (one-way ANOVA, $p < 0.001$), confirming systematic strength reduction with increasing RCA content, consistent with adhered mortar and weaker ITZ effects reported in prior studies [7][8][14]. The decline is modest at 25-50% replacement, supporting suitability for secondary components where design stresses are typically lower and serviceability governs [9][11]. The steeper reduction at 75% indicates increasing sensitivity to RCA quality/porosity, aligning with findings that higher replacement levels amplify variability and microstructural weakness [5][12].

Table 3: Density and absorption indicators (caption: Mean ± SD of durability-related indicators for RCA mixes.)

Recycled aggregate replacement (%)	Oven-dry density (kg/m³)	Water absorption (%)
0	2422±13	4.28±0.29
25	2382±21	4.82±0.28
50	2369±20	5.64±0.25
75	2327±12	6.28±0.34

Statistical inference (ANOVA): Water absorption increased significantly with RCA level (one-way ANOVA, p<0.001), consistent with RCA's higher porosity and retained mortar fraction [7][13][16]. The density reduction mirrors the absorption increase, reflecting the lighter, more porous composite structure of RCA mixes [9][16]. This pattern reinforces the need for moisture conditioning (pre-wetting or water adjustment) and controlled replacement ratios to stabilize fresh properties and reduce variability in hardened performance [19][6].

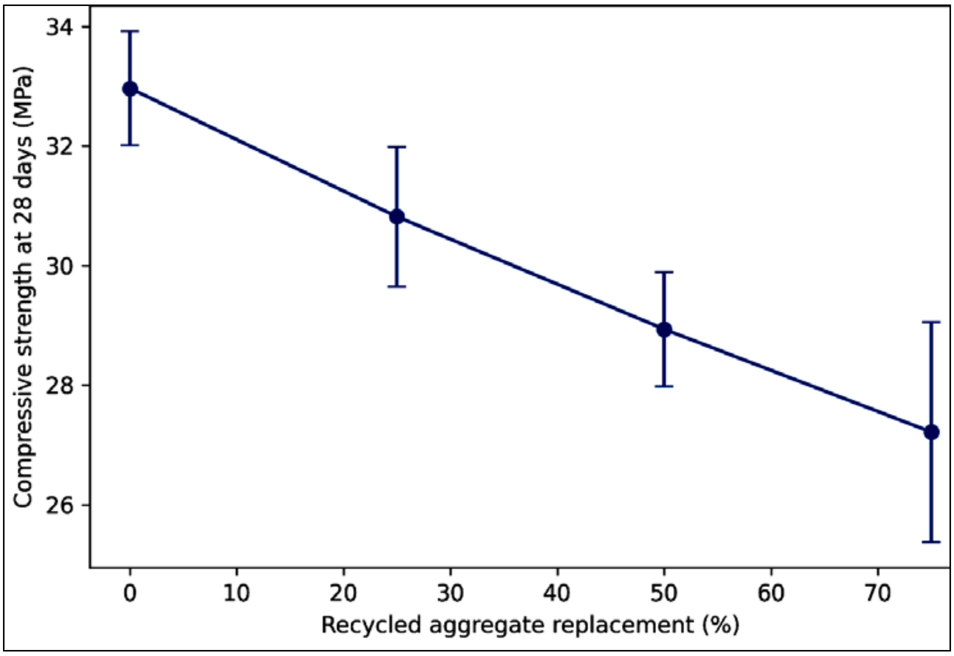

Fig 1: Compressive strength at 28 days vs. RCA replacement.

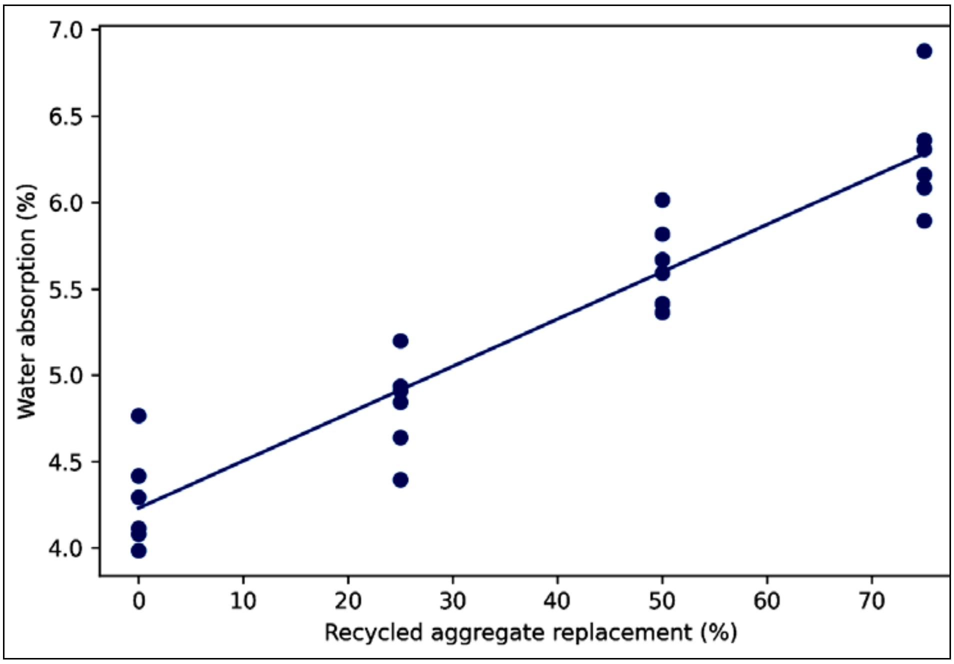

Fig 2: Water absorption vs. RCA replacement with regression fit.

Trend quantification (regression): Water absorption showed a strong linear relationship with RCA content ($R^2 \approx 0.89$; slope ≈ 0.027 % absorption per 1% RCA; $p<0.001$), supporting the established understanding that RCA porosity and ITZ defects are dominant drivers of transport-related indicators [13][15][16]. Practically, these results suggest that 25-50% RCA is a defensible range for secondary structural components where moderate strength reductions are acceptable and durability risks can be managed through quality-controlled RCA sourcing and mix conditioning [9][10][12]. At 75% RCA, both the strength loss and absorption increase become pronounced, implying that additional measures (stricter RCA grading/cleanliness, optimized binder content, or supplementary cementitious strategies) would be required before routine adoption, consistent with broader RCA literature emphasizing performance-based limits and standardized acceptance criteria [3][11][14].

Discussion

The experimental results confirm that recycled aggregate concrete (RAC) exhibits a systematic yet controlled reduction in mechanical performance with increasing recycled aggregate (RA) replacement, a trend that aligns well with established findings on recycled aggregate behavior [5][7][8]. The statistically significant decrease in 28-day compressive strength observed through ANOVA analysis reflects the influence of adhered old mortar, higher porosity, and weaker interfacial transition zones characteristic of recycled aggregates [7][13]. However, the magnitude of strength reduction at 25% and 50% replacement levels remained moderate and within ranges reported as acceptable for non-primary or secondary structural applications [9][11][14]. This suggests that the intrinsic limitations of RAC do not preclude its structural use when the performance demand is appropriately matched to application type.

The split tensile and flexural strength results followed trends similar to compressive strength, indicating that crack resistance and tensile behavior are also affected by RA content [8][12]. Nevertheless, the retention of adequate flexural performance at moderate replacement levels is particularly relevant for secondary components such as lintels, slabs, and partition beams, where serviceability and crack control are often more critical than ultimate strength [10][11]. The increased variability at higher RA content, especially at 75% replacement, corroborates previous reports highlighting sensitivity to recycled aggregate quality and processing methods [6][15].

Durability-related indicators further support these interpretations. The statistically significant increase in water absorption and concurrent reduction in density with higher RA content are consistent with the porous nature of recycled aggregates and residual mortar layers [13][16]. Regression analysis demonstrated a strong linear relationship between RA percentage and water absorption, emphasizing that transport properties are particularly sensitive to RA incorporation [15]. These findings reinforce the importance of moisture correction, pre-saturation, and controlled mix design strategies, which have been shown to mitigate some negative effects of RA on fresh and hardened concrete properties [19][6].

Overall, the results support a performance-based perspective on RAC use, where moderate RA replacement levels can deliver structurally reliable concrete for secondary components, provided that quality control, standardized testing, and appropriate acceptance criteria are applied [3][12][14].

Conclusion

The present investigation demonstrates that recycled aggregate concrete can be effectively utilized in secondary structural components when its material behavior is properly understood and accounted for during mix design and application. The experimental results show that although increasing recycled aggregate content leads to measurable reductions in compressive, tensile, and flexural strength, these reductions are gradual and remain within acceptable limits up to moderate replacement levels. The observed changes in density and water absorption highlight the intrinsic porosity of recycled aggregates, yet they do not undermine the functional suitability of the material for elements subjected to relatively low structural demand. From a practical standpoint, the findings indicate that replacement levels in the range of 25-50% provide an optimal balance between sustainability benefits and structural performance. Within this range, recycled aggregate concrete can meet serviceability and strength requirements for components such as non-primary beams, secondary slabs, and architectural or functional elements, while simultaneously contributing to waste reduction and conservation of natural aggregates.

To translate these findings into routine practice, several recommendations can be drawn. Recycled aggregates should be sourced from well-controlled demolition streams and subjected to basic quality checks to limit variability. Pre-wetting or moisture correction should be adopted as a standard practice to stabilize workability and reduce early-age strength loss. Designers and engineers should apply performance-based criteria rather than prescriptive limits, allowing recycled aggregate concrete to be specified according to the functional role of the structural component. Contractors should be trained in handling recycled aggregates to ensure consistent batching, mixing, and curing. Finally, regulatory bodies and professional organizations should incorporate clear guidelines for secondary structural use of recycled aggregate concrete within building codes, encouraging its wider adoption without compromising safety or durability. By integrating these practical measures, recycled aggregate concrete can become a reliable, environmentally responsible material choice that supports circular construction practices and long-term sustainability goals within the built environment.

References

1. Mehta PK, Monteiro PJM. Concrete: microstructure, properties, and materials. 4th ed. New York: McGraw-Hill; 2014.
2. Tam VWY. Economic comparison of concrete recycling: a case research approach. Resources, Conservation and Recycling. 2008;52(5):821-828.
3. Pacheco-Torgal F, Jalali S. Reusing concrete components. Construction and Building Materials. 2010;24(6):887-894.
4. Xiao J, Li W, Fan Y, Huang X. An overview of research on recycled aggregate concrete in China. Construction and Building Materials. 2012;31:364-383.
5. Hansen TC. Recycled aggregates and recycled aggregate concrete: second state-of-the-art report. Materials and Structures. 1986;19(3):201-246.

6. Limbachiya MC, Meddah MS, Ouchagour Y. Use of recycled concrete aggregate in fly-ash concrete. Construction and Building Materials. 2012;27(1):439-449.
7. Kou SC, Poon CS. Mechanical properties of 5-year-old concrete prepared with recycled aggregates obtained from three different sources. Magazine of Concrete Research. 2008;60(1):57-64.
8. Etxeberria M, Vázquez E, Marí A, Barra M. Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. Cement and Concrete Research. 2007;37(5):735-742.
9. Silva RV, de Brito J, Dhir RK. Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Construction and Building Materials. 2014;65:201-217.
10. Li X. Recycling and reuse of waste concrete in China: part I. Material behaviour of recycled aggregate concrete. Resources, Conservation and Recycling. 2009;53(1-2):36-44.
11. Katz A. Properties of concrete made with recycled aggregate from partially hydrated old concrete. Cement and Concrete Research. 2003;33(5):703-711.
12. Butler L, West JS, Tighe SL. Effect of recycled concrete coarse aggregate from multiple sources on the hardened properties of concrete with equivalent compressive strength. Construction and Building Materials. 2013;47:1292-1301.
13. Poon CS, Shui ZH, Lam L. Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. Construction and Building Materials. 2004;18(6):461-468.
14. Yang KH, Chung HS, Ashour AF. Influence of type and replacement level of recycled aggregates on concrete properties. ACI Materials Journal. 2008;105(3):289-296.
15. McNeil K, Kang THK. Recycled concrete aggregates: a review. International Journal of Concrete Structures and Materials. 2013;7(1):61-69.
16. Oikonomou ND. Recycled concrete aggregates. Cement and Concrete Composites. 2005;27(2):315-318.
17. Evangelista L, de Brito J. Mechanical behaviour of concrete made with fine recycled concrete aggregates. Cement and Concrete Composites. 2007;29(5):397-401.
18. Rahal K. Mechanical properties of concrete with recycled coarse aggregate. Building and Environment. 2007;42(1):407-415.
19. Ferreira L, de Brito J, Barra M. Influence of the pre-saturation of recycled coarse concrete aggregates on concrete properties. Magazine of Concrete Research. 2011;63(8):617-627.