

Fresh, physical, and mechanical performance of concrete incorporating pre-soaked recycled coarse aggregate derived from construction and demolition waste: Experimental evaluation and linear regression analysis

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Article Info	Abstract
Article History: Received 04 Sept 2026 Accepted 28 Sept 2026 Keywords: Recycled coarse aggregate; Construction and demolition waste; Compressive strength; Workability; Water absorption; Statistical analysis	Construction and demolition waste can partially substitute natural aggregate when processed as recycled coarse aggregate (RCA), although adhered mortar is associated with higher porosity and may reduce concrete performance. This study evaluates RCA produced from demolition waste collected in Tikrit, Iraq, at 0%, 20%, 40%, 60%, and 80% replacement of natural coarse aggregate by mass. All RCA mixtures used the same 48 h water-conditioning protocol to obtain a saturated surface-dry state. At a constant w/c ratio of 0.48, slump, 28-day water absorption and density, and compressive, flexural, and splitting tensile strengths at 7 and 28 days were measured. Slump decreased from 83 to 53 mm, water absorption increased from $3.97 \pm 0.45\%$ to $7.53 \pm 0.49\%$, and density decreased from 2.394 ± 0.070 to 2.268 ± 0.020 g/cm³. At 28 days, compressive strength decreased from 31.13 ± 0.35 to 22.80 ± 0.40 MPa; RCA20 and RCA40 retained 96.5% and 91.3% of control strength, respectively. At 7 days, compressive strength decreased from 22.40 ± 0.56 to 13.93 ± 2.05 MPa as RCA replacement increased from 0% to 80%, with the 7-day/28-day strength ratio declining from 72.0% to 61.1%. Inferential analysis confirmed significant replacement-level effects for water absorption and several strength responses, while regressions incorporating within-mixture variability remained statistically significant. Within the investigated mixtures, 20–40% RCA provided the most favorable measured balance between reducing natural coarse-aggregate use and retaining 91–97% of the control 28-day compressive strength; however, structural and durability applications require additional verification.

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1. Introduction

Urban development increases both the demand for natural aggregate and the quantity of construction and demolition waste (CDW). Recycling demolished concrete as aggregate can divert waste from disposal and conserve primary resources, thereby supporting circular use of construction materials [1,2].

Recycled concrete aggregate differs from natural aggregate because particles commonly retain old cement mortar. The adhered mortar produces a rougher surface, lower density, and higher porosity and water absorption, which can alter workability and mechanical response [3-5]. Recycled aggregate concrete also contains multiple interfacial regions: the original interface between old mortar and the parent natural aggregate and the new interface formed between the recycled particle and new cement paste. These dual interfacial transition zones (ITZs), together with pre-existing microcracks in the attached mortar, are frequently identified in the literature as potential

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weak paths under loading; however, direct attribution of the present results to these mechanisms requires microstructural evidence. Recent reviews consistently show that RCA performance depends on source-concrete quality, adhered-mortar content, processing, replacement level, conditioning, and curing [6,7]. Improvement strategies reported in the literature include water pre-saturation, mechanical or thermal removal of old mortar, acid treatment, pozzolanic or cementitious slurry coating, polymer or mineral surface treatments, and accelerated carbonation [7-10]. These methods act differently: pre-saturation primarily controls short-term moisture exchange during mixing, whereas coating and carbonation treatments can densify accessible pores or modify the new/old ITZ. Comparative studies therefore caution against treating a single conditioning method as universally beneficial, because effectiveness depends on RCA quality and treatment conditions [8-10].

In the present work, 48 h water pre-soaking was used only as a fixed aggregate-conditioning protocol to obtain a saturated surface-dry (SSD) condition before batching; it was not an independent treatment variable because no untreated-RCA control was included. Region-specific evidence remains relevant because demolition sources and aggregate quality vary. Iraqi studies have demonstrated the feasibility of using CDW-derived aggregates in concrete and masonry [13,14], but published characterization specific to Tikrit remains limited. This study therefore reports measured physical and chemical indices of locally collected RCA together with concrete performance across a broad partial-replacement range.

It was hypothesized that moderate RCA replacement would preserve most of the control concrete strength while higher replacement levels would increasingly reflect the lower density, higher absorption, and weaker mechanical indices of the recycled particles. The objectives were to: (i) quantify changes in fresh, physical, and 7/28-day mechanical properties; (ii) evaluate whether replacement level produces statistically significant differences using one-way ANOVA and Tukey HSD; (iii) reassess linear trends while incorporating within-mixture variability; and (iv) identify a practical replacement range that reduces natural-coarse-aggregate demand without overstating structural applicability. The contribution is therefore a combined engineering and statistical assessment of locally sourced RCA under a controlled conditioning and curing regime, together with explicit definition of the study's experimental and methodological limitations.

2. Materials and Methods

2.1 Materials

Ordinary Portland cement (Type I) complying with Iraqi Specification No. 5 (1984) was used. The reported cement properties were a specific gravity of 3.15, Blaine fineness of 3280 cm²/g, initial setting time of 110 min, final setting time of 255 min, and 7-day compressive strength of 33.8 MPa. The chemical composition of the Type I Portland cement used in the concrete mixtures is summarized in Table 1. Natural river sand and crushed natural coarse aggregate complied with Iraqi Specification No. 45 (1984). The natural coarse aggregate had a nominal maximum size of 25 mm. For the natural fine aggregate, the measured bulk, SSD, and apparent specific gravities were 2.63, 2.67, and 2.73, respectively, and water absorption was 1.52%. Potable tap water was used for mixing and curing.

RCA was produced from concrete debris collected from demolished buildings in Tikrit. Reinforcing steel, wood, plaster, soil, and other visible contaminants were removed manually. The concrete debris was crushed with a laboratory jaw crusher, washed, and sieved to the required coarse-aggregate size range. The parent-concrete strength and quantitative adhered-mortar content were not recorded. Before batching, RCA was immersed in clean water for 48 h, then drained and surface-dried until no visible free water remained. The 3.21% absorption value reported in Table 2 is the aggregate absorption determined by the ASTM C127 test procedure and is distinct from the separate 48 h conditioning step. Initial RCA moisture content immediately before pre-soaking was not preserved in the archived records. Figure 1 documents the principal preparation, casting, and testing stages.

Table 1. Chemical composition of type I Portland cement

Oxide composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O + K ₂ O	LOI	Insoluble material
content (%)	20.32	4.06	3.67	60.12	2.04	2.03	0.24	2.95	1.18



Figure 1. Experimental program: (a) crushing concrete debris; (b) processed RCA; (c) slump measurement; (d) cast specimens; (e) compression testing; and (f) flexural testing. Photographs supplied by the author

Table 2. Physical properties of natural fine, natural *coarse*, and recycled coarse aggregates used in this study

Property	Natural Fine Aggregate	Natural Coarse Aggregate	Recycled Coarse Aggregate	Relevant Specification
Bulk specific gravity	2.63	2.55	2.18	ASTM C128/ASTM C127
SSD specific gravity	2.67	2.56	2.25	ASTM C128/ASTM C127
Apparent specific gravity	2.73	2.58	2.34	ASTM C128/ASTM C127
Water absorption (%)	1.52	0.39	3.21	ASTM C128/ASTM C127
Aggregate impact value (%)	—	13.66	16.58	BS 812
Aggregate crushing value (%)	—	14.53	16.2	BS 812
Los Angeles abrasion (%)	—	17.5	20.85	ASTM C131

Note: ASTM C128 was used for the natural fine aggregate, while ASTM C127 was used for the natural and recycled coarse aggregates.

The physical properties of the natural fine aggregate, natural coarse aggregate, and recycled coarse aggregate are presented in Table 2. The natural fine aggregate data complete the basic material characterization, while the RCA exhibited lower specific gravity and higher water absorption than the natural coarse aggregate. The higher impact, crushing, and Los Angeles abrasion indices of RCA indicate comparatively lower resistance to the corresponding aggregate tests. These aggregate-scale indicators are used here as descriptive material characteristics rather than as direct proof of any particular microstructural failure mechanism. The chemical composition of the recycled concrete aggregate (RCA) used in this study is presented in Table 3.

Table 3. Chemical composition of recycled concrete aggregate (RCA)

Chemical oxide	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O + K ₂ O	LOI
RCA (%)	60.78	4.55	3.15	16.34	1.25	0.95	0.24	11.03

2.2 Mixture Proportions and Variables

Five mixtures were prepared by replacing natural coarse aggregate with RCA at 0%, 20%, 40%, 60%, and 80% by mass. Cement, fine aggregate, nominal total coarse-aggregate mass, mixing water, and the water-to-cement ratio were held constant (Table 4). Because RCA had a lower SSD specific gravity (2.25) than natural coarse aggregate (2.56), equal-mass substitution increased the absolute coarse-aggregate volume as RCA content increased; consequently, the mortar-to-aggregate volume ratio was not strictly constant. This mass-based approach reflects the original experimental design and is now explicitly recognized when interpreting the results. The program was designed to examine progressive partial replacement, with 80% selected as the upper bound; 100% replacement was outside the predefined experimental matrix. All RCA mixtures used the same 48 h water-conditioning protocol, so the study cannot isolate the benefit of pre-soaking relative to untreated RCA. The reported mixture record contains no chemical admixture; therefore, no superplasticizer is included in Table 4. The nominal mixing-water content was 144 kg/m³ (w/c = 0.48), and the 48-h water-conditioning step was intended to limit immediate water exchange, although effective free-water changes during mixing were not independently measured.

Table 4. Concrete mixture proportions (kg/m³)

Mix	RCA (%)	Cement	Fine agg.	Natural coarse agg.	RCA	Water	w/c
RCA0	0	300	890	1150	0	144	0.48
RCA20	20	300	890	920	230	144	0.48
RCA40	40	300	890	690	460	144	0.48
RCA60	60	300	890	460	690	144	0.48
RCA80	80	300	890	230	920	144	0.48

2.3 Specimen Preparation and Testing

Dry constituents were blended in a laboratory rotary mixer for approximately 2–3 min before water was added gradually. After water addition, mixing continued for approximately 3–4 min. Fresh concrete was then placed in steel molds in three layers and compacted on a vibrating table. Specimens were demolded after 24 h and water-cured under laboratory conditions at approximately 22.5°C until testing. For every replacement level, three specimens were tested for each applicable property and age. Six cubes, six prisms, and six cylinders were produced per mixture, giving 90 hardened specimens in total. In addition, three separate 150-mm cubes were prepared for each mixture at 28 days for water absorption and density measurements in accordance with ASTM C642. Thus, the total number of hardened specimens prepared for the experimental program was 105. A summary of specimen types, dimensions, ages, and test

standards is provided in Table 5. For the ASTM C293 flexural test on 100 × 100 × 400 mm prisms, a center-point loading configuration was used with a 300 mm clear span and a single load applied at the mid-span of the prism specimens. Splitting tensile strength was determined on 100 × 200 mm cylinders (L/D = 2) using the ASTM C496 expression based on the actual specimen length and diameter; no separate size-effect coefficient was applied.

Table 5. Specimens and test methods reported in the experimental program

Property	Specimen	Dimensions	Age (days)	Reported method
Slump	Fresh concrete	—	—	ASTM C143
Water absorption	Cube	150 × 150 × 150 mm	28	ASTM C642
Density	Cube	150 × 150 × 150 mm	28	Gravimetric measurement
Compressive strength	Cube	150 × 150 × 150 mm	7, 28	BS EN 12390-3
Flexural strength	Prism	100 × 100 × 400 mm	7, 28	ASTM C293
Splitting tensile strength	Cylinder	100 × 200 mm	7, 28	ASTM C496

2.4 Statistical Treatment

For each hardened property, the arithmetic mean, sample standard deviation (SD), and coefficient of variation ($CV = 100SD/\text{mean}$) were calculated from three replicate measurements. One-way ANOVA was performed for the five replacement levels using three replicate measurements per mixture; when the omnibus test was significant ($p < 0.05$), Tukey HSD comparisons were computed using the pooled within-group mean square. Slump was reported as one fresh-concrete measurement per mixture, so no SD or inferential group test is claimed for slump. Ordinary least-squares regression was also recalculated using all 15 individual replicate observations for each hardened property: the fitted slope and intercept are identical to those obtained from equal-size group-mean regression, but residual variance and R^2 incorporate the reported within-group variation. Slope p-values and 95% confidence intervals are reported. These inferential results should still be interpreted cautiously because $n = 3$ per mixture provides limited power for assessing distributional assumptions.

3. Results

3.1 Fresh and Physical Properties

Slump decreased monotonically from 83 mm for RCA0 to 53 mm for RCA80, a 36.1% reduction; because slump was recorded once per mixture, this trend is descriptive only. Water absorption increased from $3.97 \pm 0.45\%$ to $7.53 \pm 0.49\%$, corresponding to an 89.7% increase relative to the control. One-way ANOVA indicated a significant replacement-level effect on water absorption ($F(4,10) = 30.92$, $p < 0.001$), with several Tukey HSD pairwise differences becoming significant from 40% RCA upward (Table 8). Density decreased by 5.3%, from 2.394 ± 0.070 to 2.268 ± 0.020 g/cm³; the five-group ANOVA was not significant at $\alpha = 0.05$ ($F(4,10) = 2.66$, $p = 0.096$), although the prespecified linear trend remained significant. These fresh and physical trends are summarized in Figure 2 and Table 6, while regression metrics are reported in Table 7.

3.2 Mechanical Properties

All mixtures gained strength between 7 and 28 days. At 28 days, compressive strength decreased from 31.13 ± 0.35 MPa for RCA0 to 22.80 ± 0.40 MPa for RCA80, a reduction of 26.8%; RCA20 and RCA40 retained 96.5% and 91.3% of the control value. One-way ANOVA confirmed a significant replacement-level effect on 28-day compressive strength ($F(4,10) = 30.86$, $p < 0.001$), and Tukey HSD showed significant differences mainly in comparisons involving the 60% and 80% RCA mixtures (Table 8). The 7-day/28-day compressive-strength ratio declined progressively from

72.0% (RCA0) to 69.3%, 66.5%, 62.3%, and 61.1% for RCA20, RCA40, RCA60, and RCA80, respectively. This pattern indicates slower early-to-later strength development as RCA content increased; within the limits of the dataset, this may reflect greater heterogeneity and moisture redistribution associated with adhered mortar rather than a directly measured change in hydration kinetics. Figure 3 illustrates the compressive-strength development at 7 and 28 days, and the complete mechanical results are listed in Table 6.

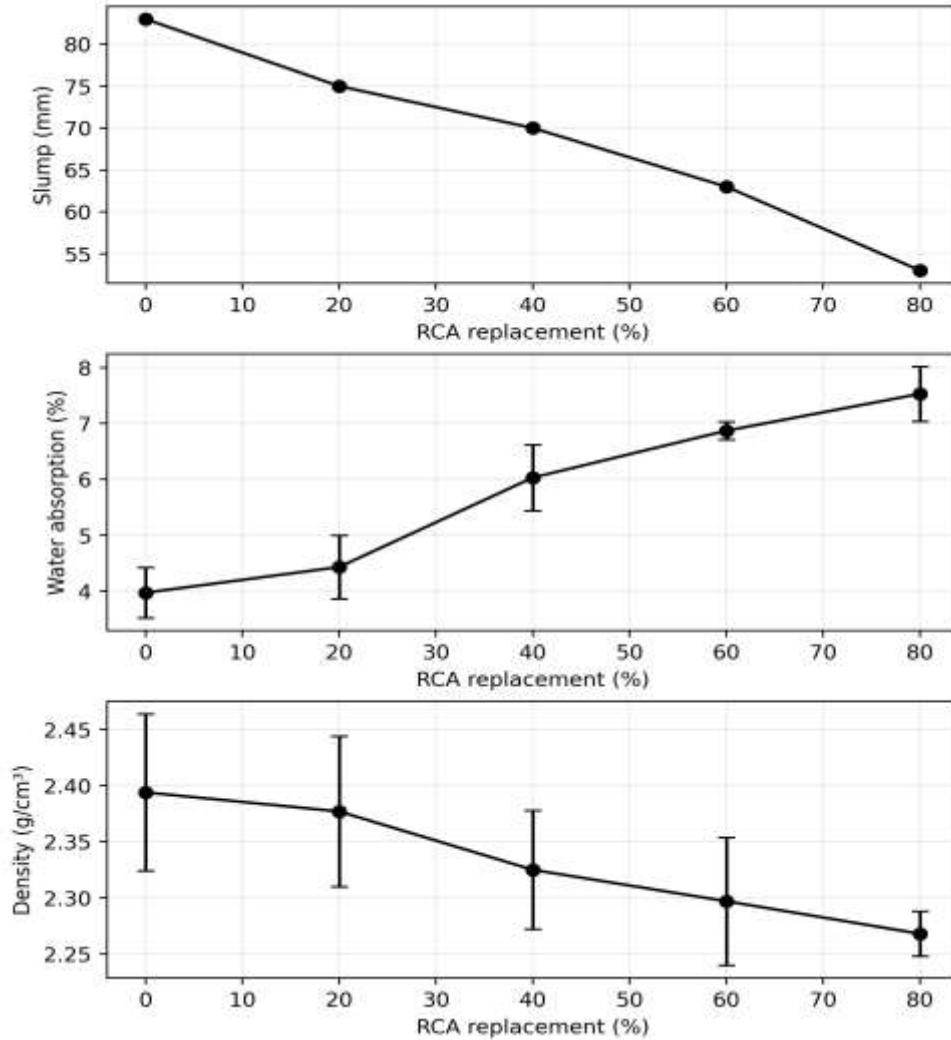


Figure 2. Effect of RCA replacement on slump, 28-day water absorption, and 28-day density. Error bars show ± 1 sample SD where replicate measurements were available ($n = 3$)

At 28 days, flexural strength decreased from 4.60 ± 0.26 to 3.45 ± 0.22 MPa (25.0%), while splitting tensile strength decreased from 3.30 ± 0.20 to 2.20 ± 0.10 MPa (33.3%). The five-group ANOVA was significant for 28-day flexural strength ($F(4,10) = 5.25$, $p = 0.015$) and 28-day splitting tensile strength ($F(4,10) = 26.72$, $p < 0.001$), but not for the corresponding 7-day flexural ($p = 0.066$) or splitting ($p = 0.318$) datasets. Figures 4 and 5 show the flexural and splitting-tensile trends. The 28-day splitting-to-compressive-strength ratio declined from 0.106 for RCA0 to 0.096 for RCA80, supporting greater proportional sensitivity of tensile behavior at high RCA contents. No outlier-removal procedure was applied to the reported data. The high 7-day CVs for RCA0 splitting strength (36.8%) and RCA60 flexural strength (31.7%) are retained transparently and interpreted as evidence of limited early-age repeatability rather than selectively excluding observations. Table 7 reports regressions recalculated with within-mixture variance, and Table 8 summarizes ANOVA/Tukey results. Representative post-test fracture patterns are provided in Figure 6. The visible cracks and fractured surfaces confirm macroscopic failure across the tested specimen types; however, they do not by themselves distinguish cracking through old mortar, new paste, RCA particles, or the individual interfacial transition zones.

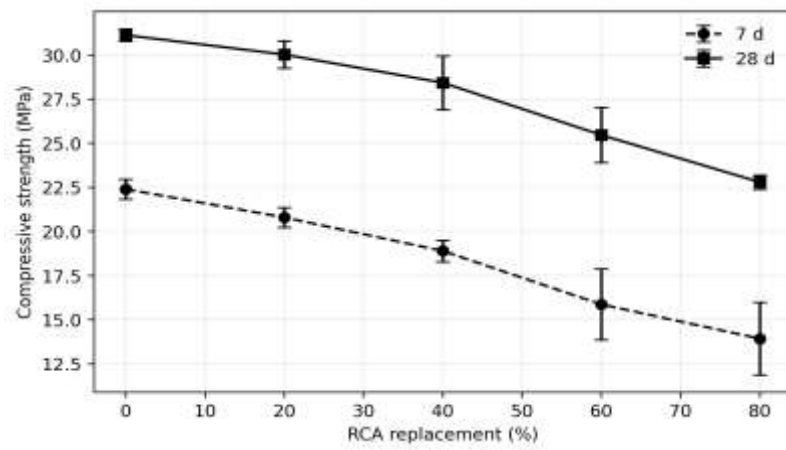


Figure 3. Compressive strength at 7 and 28 days. Error bars show ± 1 sample SD (n = 3)

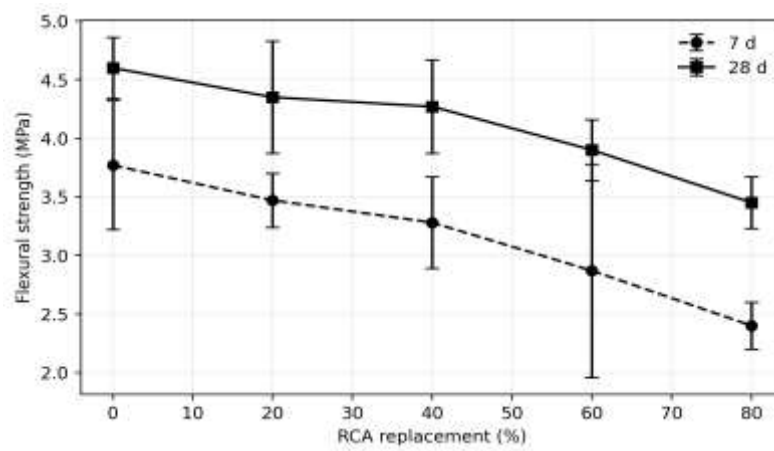


Figure 4. Flexural strength at 7 and 28 days. Error bars show ± 1 sample SD (n = 3)

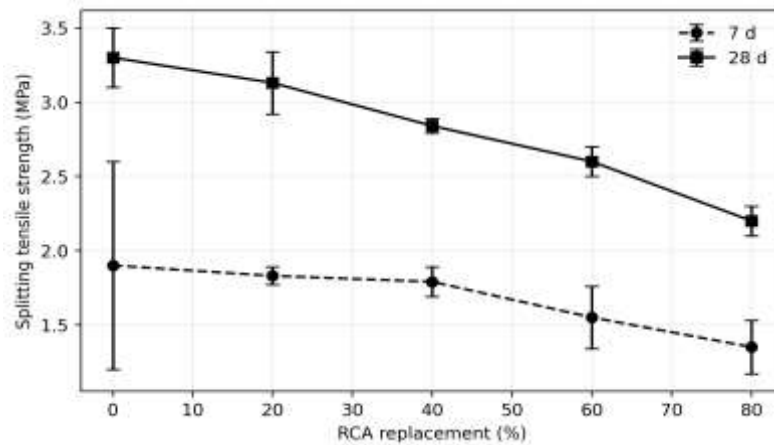


Figure 5. Splitting tensile strength at 7 and 28 days. Error bars show ± 1 sample SD (n = 3)



(a) Flexural failure of prisms (b) Representative fractured cubes (c) Splitting-tensile cracking, RCA 0-80%

Figure 6. Representative post-test failure patterns: (a) flexural cracking of prism specimens, (b) fractured cube specimens, and (c) splitting-tensile cracking of cylinders containing 0-80% RCA. The photographs document macroscopic failure only and are not used as direct microstructural evidence of ITZ behavior

Table 6. Experimental results (mean $\pm$ sample SD; n = 3 for hardened properties; slump = one measurement per mixture)

Mix	Slump (mm)	Abs. 28 d (%)	Density 28 d (g/cm ³)	Comp. 7 d (MPa)	Comp. 28 d (MPa)	Flex. 7 d (MPa)	Flex. 28 d (MPa)	Split. 7 d (MPa)	Split. 28 d (MPa)
RCA0	83	3.97 $\pm$ 0.45	2.394 $\pm$ 0.070	22.40 $\pm$ 0.56	31.13 $\pm$ 0.35	3.77 $\pm$ 0.55	4.60 $\pm$ 0.26	1.90 $\pm$ 0.70	3.30 $\pm$ 0.20
RCA20	75	4.43 $\pm$ 0.57	2.377 $\pm$ 0.067	20.80 $\pm$ 0.56	30.03 $\pm$ 0.78	3.47 $\pm$ 0.23	4.35 $\pm$ 0.48	1.83 $\pm$ 0.06	3.13 $\pm$ 0.21
RCA40	70	6.03 $\pm$ 0.59	2.325 $\pm$ 0.053	18.90 $\pm$ 0.61	28.43 $\pm$ 1.53	3.28 $\pm$ 0.39	4.27 $\pm$ 0.40	1.79 $\pm$ 0.10	2.84 $\pm$ 0.05
RCA60	63	6.87 $\pm$ 0.16	2.297 $\pm$ 0.057	15.87 $\pm$ 2.01	25.47 $\pm$ 1.56	2.87 $\pm$ 0.91	3.90 $\pm$ 0.26	1.55 $\pm$ 0.21	2.60 $\pm$ 0.10
RCA80	53	7.53 $\pm$ 0.49	2.268 $\pm$ 0.020	13.93 $\pm$ 2.05	22.80 $\pm$ 0.40	2.40 $\pm$ 0.20	3.45 $\pm$ 0.22	1.35 $\pm$ 0.18	2.20 $\pm$ 0.10

Table 7. Linear regression of hardened-property responses on RCA replacement percentage, incorporating within-mixture variance (N = 15)

Response	Intercept	Slope per 1% RCA	R ²	Slope p-value	95% CI low	95% CI high
Water absorption, 28 d (%)	3.8540	0.04780	0.899	<0.001	0.03818	0.05742
Density, 28 d (g/cm ³)	2.3986	-0.00166	0.506	0.003	-0.00264	-0.00068
Compressive strength, 7 d (MPa)	22.7540	-0.10935	0.877	<0.001	-0.13391	-0.08479
Compressive strength, 28 d (MPa)	31.8160	-0.10610	0.893	<0.001	-0.12807	-0.08413
Flexural strength, 7 d (MPa)	3.8260	-0.01670	0.541	0.002	-0.02591	-0.00749
Flexural strength, 28 d (MPa)	4.6640	-0.01375	0.638	<0.001	-0.01996	-0.00754
Splitting strength, 7 d (MPa)	1.9600	-0.00690	0.320	0.028	-0.01293	-0.00087
Splitting strength, 28 d (MPa)	3.3600	-0.01365	0.897	<0.001	-0.01642	-0.01088

Table 8. One-way ANOVA and significant Tukey HSD pairwise comparisons for hardened properties (n = 3 per replacement level)

Response	F(4,10)	ANOVA p	Significant Tukey pairs (p < 0.05)
Water absorption, 28 d (%)	30.92	<0.001	0-40%, 0-60%, 0-80%, 20-40%, 20-60%, 20-80%, 40-80%
Density, 28 d (g/cm ³)	2.66	0.096	None
Compressive strength, 7 d (MPa)	19.63	<0.001	0-60%, 0-80%, 20-60%, 20-80%, 40-80%
Compressive strength, 28 d (MPa)	30.86	<0.001	0-60%, 0-80%, 20-60%, 20-80%, 40-60%, 40-80%
Flexural strength, 7 d (MPa)	3.12	0.066	None
Flexural strength, 28 d (MPa)	5.25	0.015	0-80%
Splitting strength, 7 d (MPa)	1.35	0.318	None
Splitting strength, 28 d (MPa)	26.72	<0.001	0-40%, 0-60%, 0-80%, 20-60%, 20-80%, 40-80%, 60-80%

4. Discussion

The continuous slump loss with increasing RCA content is consistent with the rough texture, angularity, and attached mortar of recycled particles reported in the literature [1,2,7]. Because the aggregates were conditioned to SSD, immediate absorption of mixing water was reduced as a confounding factor; nevertheless, SSD conditioning does not remove surface friction or particle-shape effects. The present results therefore do not demonstrate that pre-soaking improved workability relative to dry RCA. At higher replacement levels, a slump of 53 mm may also be restrictive for some placement or pumping conditions. Future mixture optimization should evaluate high-range water-reducing admixtures or rheology-based adjustments while maintaining the target effective w/c ratio. The macroscopic fracture photographs in Figure 6 are compatible with heterogeneous crack paths in the RCA-containing specimens, but no SEM, XRD, MIP, or other microstructural method was performed; accordingly, dual-ITZ weakness and crack-path selection are discussed only as literature-supported possible mechanisms rather than directly observed causes.

The concurrent rise in absorption and decrease in density are consistent with a progressively more porous concrete system as RCA content increased, in agreement with prior RCA studies [5,15]. However, water absorption should not be interpreted as a direct cause of strength loss. Instead, the higher RCA crushing, impact, and abrasion indices in Table 2, attached old mortar, and associated particle heterogeneity are parallel material characteristics that can contribute to both higher absorption and lower strength. The RCA chemical composition in Table 3 provides source characterization: SiO₂ is associated mainly with mineral aggregate, whereas CaO and the measured loss on ignition are compatible with cementitious/carbonated constituents and mineral phases. Without XRD, TGA, or microstructural imaging, these chemical results cannot identify the dominant strength-loss mechanism.

The limited compressive-strength loss at 20-40% RCA and the larger reductions at 60-80% agree with the general replacement-level trend reported for recycled aggregate concrete [16]. Tensile-related properties were proportionally more sensitive at high replacement. A plausible explanation from the literature is that the old mortar-natural aggregate interface and the newly formed paste-RCA interface create dual ITZs where local heterogeneity may facilitate crack initiation [3,8]. In this study, however, SEM, XRD, MIP, and systematic post-failure fracture-plane imaging were not performed; ITZ weakening and microcrack propagation are therefore presented only as literature-supported possible mechanisms, not as directly observed causes.

The high early-age CV values in two groups further indicate that local heterogeneity or casting/testing variability may have influenced the 7-day response, and no observations were removed as outliers. Among the tested mixtures, 20-40% RCA provided the most favorable balance between reducing natural coarse-aggregate consumption and retaining 91-97% of control 28-day compressive strength. This is an engineering performance observation, not a blanket recommendation for structural members. Modulus of elasticity, reinforcement-concrete bond, shrinkage, creep, chloride transport, carbonation resistance, and other durability indicators were not measured. Accordingly, structural use must be verified against the applicable design and exposure requirements using project-specific testing. In the Tikrit/Iraq context, the results nevertheless support further development of controlled CDW sorting and RCA production for applications in which the measured strength and exposure requirements can be demonstrated. The significant linear trends in Table 7 may serve as preliminary within-range prediction tools for the investigated material source, but they should not be extrapolated to other RCA sources or beyond 0-80% replacement. Natural fine-aggregate specific gravity and absorption were available and are reported in Table 2; however, unit weight and fineness modulus were not included in the supplied quantitative dataset and therefore were not invented or inferred.

4.1 Limitations and Future Work

The study used one RCA source, one water-to-cement ratio, and three replicate specimens per hardened-property group. Basic RCA absorption and specific-gravity indices were reported in Table 2, but parent-concrete strength, quantitative adhered-mortar content, unit weight and fineness modulus of the fine aggregate, full aggregate gradation curves, initial RCA moisture content, records of effective free-water changes during mixing were not preserved in the archived dataset. The absence of an untreated-RCA series prevents direct quantification of any benefit from 48 h pre-soaking. Slump was measured once per mixture, limiting uncertainty analysis for fresh workability. Systematic post-failure photographs and microstructural analyses (SEM/XRD/MIP) were not available, so proposed ITZ and crack-path mechanisms remain literature-based interpretations. Long-term durability indicators, modulus of elasticity, bond strength, shrinkage, and creep were not measured. Future work should use larger replication, explicitly separated physical-test specimens, 100% RCA as a boundary condition, untreated and alternative-treatment controls, and treatments such as acid washing, cementitious/pozzolanic slurry coating, or accelerated carbonation [8-10]. These extensions should be combined with durability and microstructural characterization before broad structural recommendations are made.

5. Conclusions

This study demonstrates that progressively replacing natural coarse aggregate with locally sourced recycled coarse aggregate (RCA) changes fresh, physical, and mechanical behavior in a systematic but property-dependent manner. The decline in slump with increasing RCA content confirms that bringing RCA to an SSD condition does not eliminate the workability consequences associated with particle roughness, angularity, and attached mortar. At the same time, the increase in water absorption and reduction in density show that the recycled aggregate introduces a more porous and heterogeneous constituent into the concrete. These physical changes occurred alongside reductions in compressive, flexural, and splitting tensile strengths, with tensile-related behavior showing greater proportional sensitivity at high replacement levels. The decreasing 7-day/28-day compressive-strength ratio from 72.0% in the control to 61.1% at 80% RCA further indicates that high RCA contents were associated with slower early-to-later strength development under the investigated curing regime. The statistical analysis strengthens these observations while also qualifying them. One-way ANOVA identified significant replacement-level effects for water absorption, 7- and 28-day compressive strength, 28-day flexural strength, and 28-day splitting tensile strength, whereas density and some 7-day tensile-related responses did not reach the 0.05 level with only three replicates per group. The regression models should be viewed as source-specific descriptive or preliminary predictive relationships rather than universal design equations.

Within the tested range, 20-40% RCA provided the most favorable measured compromise: these mixtures replaced a meaningful fraction of natural coarse aggregate while retaining approximately 91-97% of the control 28-day compressive strength. This finding has practical relevance for construction and demolition waste management in Tikrit and similar regional contexts, where controlled recovery of concrete debris could reduce landfill disposal and demand for virgin aggregate. However, the study does not establish that 20-40% RCA is automatically suitable for all structural exposure classes. Modulus of elasticity, bond, creep, shrinkage, chloride transport, carbonation resistance, and other durability indicators were not evaluated, and no untreated-RCA control was available to isolate the effect of the 48-h pre-soaking protocol. Consequently, field or structural adoption should be supported by project-specific performance and durability verification. Overall, the results support moderate RCA incorporation as a technically promising pathway for resource conservation while clearly defining the additional evidence needed before broader structural implementation.

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