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A Partial Replacement of Coarse Aggregate with Recycled Aggregate

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Abstract

This study examines the use of recycled concrete aggregate (RCA) as a partial substitute for natural coarse aggregate in concrete. Replacement levels of 5%, 10%, 30%, 40% and 50% were compared with conventional concrete. Cube compressive strength and cylinder splitting tensile strength were tested after 7, 14 and 28 days of curing. At 28 days, the control mix reached 19.55 MPa in compression, while the RCA mixes recorded 16.20, 15.65, 17.33, 16.88 and 18.22 MPa, respectively. The corresponding splitting tensile strengths were 3.00 MPa for the control and 2.43, 2.34, 2.60, 2.53 and 2.73 MPa for the recycled mixes. Of the replacement levels studied, 50% RCA gave the highest compressive and tensile strengths among the recycled mixes, although neither value exceeded the control. These findings show that recycled aggregate may help reduce the use of natural stone, provided its quality and moisture condition are carefully managed. All numerical results are taken from the original project report.

Keywords: Recycled Concrete Aggregate, Coarse Aggregate Replacement, Compressive Strength, Split Tensile Strength, Sustainable Concrete

1. Introduction

Additional Context

The performance of recycled aggregate depends largely on the concrete from which it was obtained and how it was crushed and processed. Pieces of old mortar often remain attached to the aggregate, making it more absorbent and sometimes more irregular in shape than natural stone. These differences matter when several replacement levels are tested under similar conditions.

Using crushed concrete again can reduce the amount of demolition waste sent for disposal and lower the demand for freshly quarried aggregate. However, the overall environmental and financial benefits also depend on transport, crushing, processing and the requirements of the intended project.

Demolished concrete is a useful source of aggregate for new construction. Recycled concrete aggregate contains natural stone together with hardened cement mortar, which can increase porosity and water absorption. Although reusing this material can conserve natural resources, variations in the recycled material and its moisture content may affect the strength of the new concrete.

In this investigation, conventional concrete was compared with five mixtures containing different amounts of recycled coarse aggregate. All mixtures were assessed at the same curing ages using the mechanical tests reported in the project. The work is limited to laboratory strength measurements and does not represent a full field or durability study.

2. Research Objectives

The study considers how concrete strength develops during curing, how each RCA mixture performs against the natural-aggregate control, and which replacement level gives the best results among those tested. Conclusions are based only on the reported mixtures and test periods.

The main objectives were to examine the materials, prepare concrete with different levels of recycled coarse aggregate, measure compressive and splitting tensile strengths at 7, 14 and 28 days, and identify the strongest recycled-aggregate mixture.

3. Literature Review and Technical Background

Wen, McLean and Willoughby (2015) studied recycled concrete aggregate in new concrete pavements. Their work shows why pavement applications must be assessed against service conditions and performance requirements, rather than strength alone [1].

Adnan, Rahman and Loon (2010) investigated recycled aggregate concrete containing micronized biomass silica. Their findings provide background on the possible influence of fine supplementary materials, although no such material was used in the present tests [2].

Wen and colleagues (2014) evaluated recycled concrete as aggregate for new pavement construction in a transportation-agency report. Their study highlights the importance of material quality and project specifications when demolished concrete is reused [3].

Marinković, Malešev and Ignjatović (2014) compared the life-cycle impacts of concrete made with recycled and natural aggregates. They showed that processing and transportation should be included when evaluating environmental benefits [4].

Soares and colleagues (2014) investigated recycled coarse aggregate obtained from rejected precast concrete. Their research draws attention to the influence of the original concrete and the source of the recycled material [5].

Mukharjee and Barai (2014) studied the combined effects of recycled aggregate and nano-silica on concrete strength and microstructure. Their work suggests ways of improving recycled concrete, but nano-silica was not part of this experiment [6].

Khoshkenari and colleagues (2014) examined how fine recycled concrete aggregate affects compressive and splitting tensile strengths. Although their study concerns fine rather than coarse aggregate, it is relevant to the strength tests considered here [7].

Pedro, de Brito and Evangelista (2014) investigated structural concrete made with recycled aggregates from different sources. Their results emphasize that the origin of the aggregate should be considered before comparing replacement levels [8].

Guerra and colleagues (2014) examined the bond between reinforcing steel and recycled-aggregate concrete. Their work covers an important structural property that was not measured in this study [9].

Uygunoğlu, Topçu and Çelik (2014) explored the use of waste marble and recycled aggregate in self-compacting concrete. Their findings show that fresh-concrete behaviour also matters when recycled materials are introduced [10].

Silva and colleagues (2014) reviewed the composition and properties of recycled aggregates, particularly density, absorption and unwanted constituents. These factors help determine whether recycled material is suitable for concrete production [11].

Etxeberria and colleagues (2007) tested concrete with 0%, 25%, 50% and 100% recycled coarse aggregate. Their work illustrates how replacement level and production methods can influence the final

properties [12].

Xiao and colleagues (2005) investigated the response of recycled-aggregate concrete under uniaxial loading, including its stress–strain behaviour at different replacement levels [13].

Rahal (2007) compared the mechanical properties of concrete containing recycled coarse aggregate with those of conventional concrete, providing useful background for the present strength comparisons [14].

Gómez-Soberón (2002) studied porosity in concrete containing recycled aggregate and showed why the pore structure deserves attention when interpreting its performance [15].

Ferreira and colleagues (2011) examined pre-saturation of recycled coarse aggregate. Their findings underline the importance of controlling aggregate moisture before mixing [16].

Fonseca and colleagues (2011) investigated how curing conditions affect the mechanical performance of concrete made with recycled concrete waste [17].

Evangelista and de Brito (2007) studied concrete containing fine recycled concrete aggregate. Their findings provide related evidence, although the present work replaces coarse aggregate [18].

Poon and colleagues (2007) investigated slump and bleeding in fresh recycled-aggregate concrete. Their work indicates that workability should be examined alongside hardened strength [19].

Xiao and colleagues (2012) reviewed developments in recycled-aggregate concrete research, including its mechanical behaviour and practical limitations [20].

3.1 Material Characteristics

Recycled coarse aggregate commonly carries remnants of old cement paste. This attached mortar can increase water absorption and give the particles a rougher surface than natural aggregate. Both features can affect workability and the water available during cement hydration. The original project recommends keeping RCA close to a saturated-surface-dry condition and comparing several replacement levels.

3.2 Scope and Limitations

The compressive and splitting tensile strengths presented in this paper are the measurements reported in the source project. Although its abstract refers to flexural strength and durability, numerical results for those properties are not available in the results tables. No additional values have therefore been assumed, and the findings should not be taken as proof of suitability for structural design.

4. Materials and Experimental Methodology

Material Selection and Quality Control

Natural coarse aggregate was used in the control mixture, while recycled concrete aggregate replaced part of that coarse fraction in the other mixtures. Cement, sand and water were used throughout. Reliable comparisons depend on consistent batching, mixing, casting, curing and control of aggregate moisture.

The original observation tables record water absorption and impact-test results for aggregates, along with sand bulking and cement-test measurements. The values have been kept as reported. Any unusual entries or units should be checked against the laboratory records before they are used for material acceptance.

The concrete was prepared using cement, fine aggregate, natural coarse aggregate, recycled coarse aggregate and water. The experimental work included aggregate impact and absorption tests, sand bulking, cement consistency and fineness tests, followed by batching, mixing, casting, curing and strength testing.

4.1 Replacement Programme

Table 1: Experimental Replacement Groups

Mix	RCA replacement of coarse aggregate	Test ages (days)
NC	0%	7, 14, 28
5% RCA	5%	7, 14, 28
10% RCA	10%	7, 14, 28
30% RCA	30%	7, 14, 28
40% RCA	40%	7, 14, 28
50% RCA	50%	7, 14, 28

The replacement percentages are those given in the project for substituting recycled coarse aggregate for natural coarse aggregate. Mix quantities and water–cement ratios that were not reported have not been estimated.

4.2 Experimental Sequence

The laboratory work began with collecting and processing waste concrete, followed by aggregate grading and material tests. The ingredients were then batched and mixed, specimens were cast and cured, and their strengths were measured. Careful moisture conditioning was especially important when comparing natural and recycled aggregates.

Table 2: Observations on Water Absorption on Coarse Aggregate

Determination	Trial I	Trial II	Trial III
SSD sample A (g)	2409	2380	2491
Oven-dried sample B (g)	2404	2375	2486
Water absorption (%)	0.208	0.210	0.201
Average water absorption (%)	0.206	--	--

Table 3: Observations on Impact Load Test of Natural Aggregate

Details	Trial 1	Trial 2
Total aggregate weight W1 (source: gm)	0.614	0.616
Passing 2.36 mm sieve W2 (source: gm)	0.054	0.040
Impact value (%)	8.79	6.49
Average impact value (%)	7.64	

Table 4: Observations on Impact Load Test of Recycled Aggregate

Details	Trial 1	Trial 2
Total aggregate weight W1 (source: gm)	0.546	0.586
Passing 2.36 mm sieve W2 (source: gm)	0.066	0.062
Retained after test W3 (source: gm)	0.898	0.524
Impact value (%)	12.08	10.58
Average impact value (%)	11.32	

Table 5: Observations on Water Absorption on Recycled Aggregate

Determination	Trial I	Trial II	Trial III
SSD sample A (g)	2500	2400	2450
Oven-dried sample B (g)	2490	2394	2442
Water absorption (%)	0.401	0.250	0.327
Average water absorption (%)	0.326		

Table 6: Observations on Bulking of Sand

Moisture content (%)	Bulking by volume (%)
2	15
3	20
4	25
5	30
6	26.58

Table 7: Observations and Calculations of Standard Consistency

Trial	Cement (g)	Water (source notation)	Penetration (mm)	Time (source)	Consistency (%)
1	300	26/100	19	0.066	26
2	300	27/100	10	0.083	29
3	300	30/100	6	0.15	30

Table 8: Observations and Calculations on Fineness of Cement

Trial	Cement sample (g)	Retained on 90 µm sieve (g)	Fineness (%)
1	100	4.65	4.65
2	100	8.25	8.25
3	100	7.95	7.95
Average			6.95

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5. Testing Methods and Calculations

Interpretation of Laboratory Tests

Water absorption indicates how much water an aggregate takes up relative to its dry mass. The impact test measures the amount of material broken into smaller particles under repeated blows. Sand bulking describes the increase in apparent sand volume caused by moisture, while consistency and fineness tests help characterize cement.

Concrete strength is calculated from the load carried by the specimen and its dimensions. To make fair comparisons, specimens should be tested at the same curing age and under comparable loading conditions. The reported strengths have been retained without estimating missing failure loads or differences between individual specimens.

5.1 Compressive Strength Test

Concrete cubes were placed in a compression-testing machine and loaded until failure. Compressive strength was calculated by dividing the maximum load by the loaded area and is expressed in N/mm² or

MPa. The project describes tests on 150 mm cubes after 7, 14 and 28 days.

Compressive strength, $f_{(c)} = P / A$ (1)

where P is the maximum compressive load (N) and A is the loaded area (mm^2).

5.2 Splitting Tensile Strength Test

In the splitting tensile test, a cylindrical specimen is loaded across its diameter, producing tensile stresses that cause it to split. The project uses the standard relationship between the failure load and cylinder dimensions.

Splitting tensile strength, $f_{(t)} = 2P / (\pi LD)$ (2)

where P is the maximum applied load (N), L is cylinder length (mm), and D is cylinder diameter (mm).

5.3 Material Characterization

The project includes measurements of water absorption and impact resistance for both natural and recycled aggregates, as well as sand bulking, cement consistency and cement fineness. These tests help explain material behaviour because recycled aggregate may contain more pores and show greater variation than natural stone. The observation tables are reproduced without adding unrecorded results.

5.4 Data Interpretation

Each recycled mixture was compared with the control at the same curing age. The percentage change was calculated as 100 × (RCA strength − control strength) / control strength; a negative result indicates lower strength than the control. Since the source does not give specimen counts or measures of variation, the differences cannot be treated as statistically significant.

6. Experimental Results: Compressive Strength

Strength Development and Relative Performance

At 7 days, compressive strength ranged from 9.44 MPa for the 10% RCA mix to 14.00 MPa for the control. At 14 days, these mixtures reached 11.75 MPa and 17.70 MPa, respectively. Every mixture recorded its highest compressive strength at 28 days, showing the expected gain in strength during curing.

Among the recycled mixtures, the 50% RCA mix achieved 13.00 MPa at 7 days, 16.22 MPa at 14 days and 18.22 MPa at 28 days. Its 28-day strength was about 93.2% of the control value of 19.55 MPa. It was therefore the strongest recycled mix in this experiment, although this does not mean that increasing RCA content always improves strength.

Table 9: Cube Compressive Strength at Different Curing Ages (MPa)

Age	NC	5%	10%	30%	40%	50%
7 days	14.00	10.24	9.44	12.20	11.40	13.00
14 days	17.70	13.50	11.75	15.55	15.11	16.22
28 days	19.55	16.20	15.65	17.33	16.88	18.22

After 28 days, the control concrete reached 19.55 MPa. The mixes containing 5%, 10%, 30%, 40% and 50% RCA recorded 16.20, 15.65, 17.33, 16.88 and 18.22 MPa, respectively. All recycled mixes gained strength with curing, and the 50% RCA mix remained the strongest of the recycled groups at each test age.

Figure 1: Compressive Strength of All Six Mixtures at 7, 14 and 28 Days

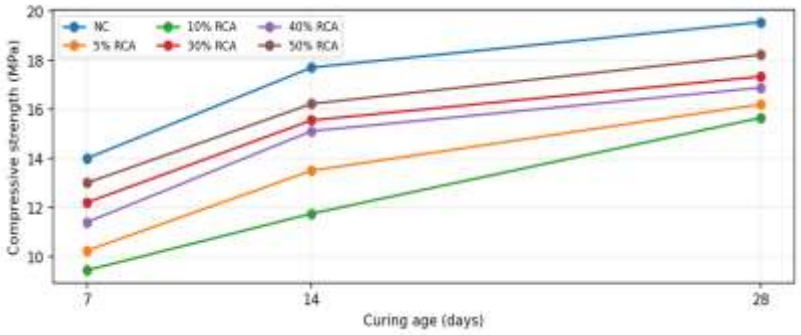
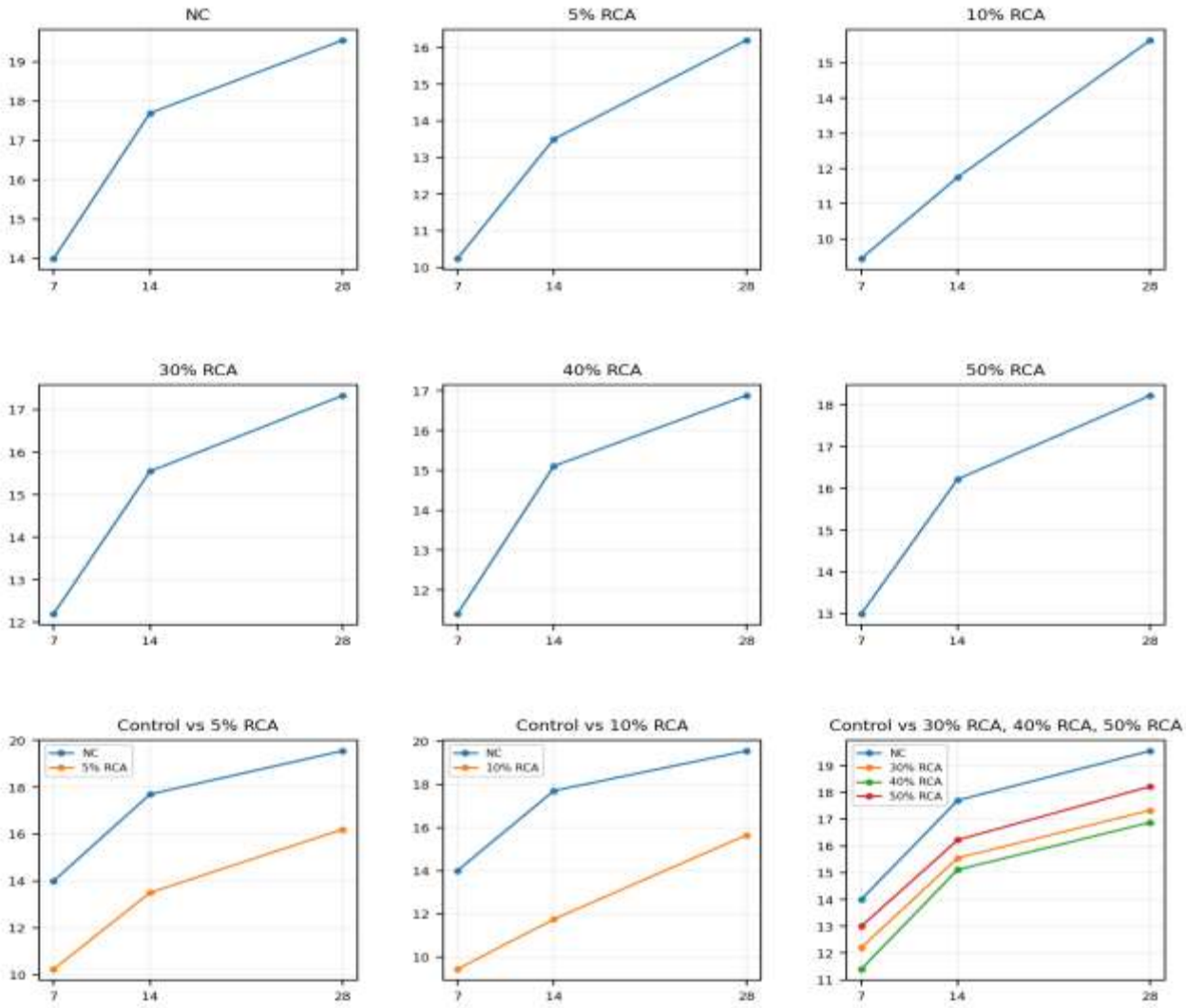


Figure 1 brings together the compressive-strength results for all six mixes. Strength increased with curing time in every case, but the results did not follow a steady upward or downward pattern as the replacement percentage changed.

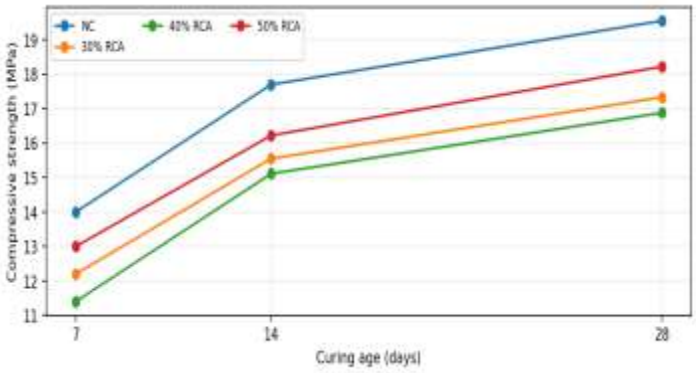
6.1 Compressive Strength Comparisons

Figure 2: Original Compressive-Strength Trends and Selected Mix Comparisons (Nine Graphs)



The 5% and 10% RCA mixes were weaker than the control at all three ages. The 10% mix had the lowest 28-day compressive strength, at 15.65 MPa.

Figure 3: Control Compared with 30%, 40% and 50% RCA



At 28 days, the 30%, 40% and 50% RCA mixes performed better than the 5% and 10% mixes. The 50% mixture reached 18.22 MPa, which was 1.33 MPa below the control.

7. Experimental Results: Splitting Tensile Strength

Tensile Response Across Curing Ages

Splitting tensile strength also increased between 7 and 28 days for every mix. At 7 days, the control reached 2.100 MPa, while the recycled mixtures ranged from 1.410 to 1.950 MPa. By 28 days, the RCA mixes reached 2.340–2.730 MPa, compared with 3.000 MPa for the control.

At 28 days, the 50% RCA mix achieved 91.0% of the control splitting tensile strength. Although the relative ranking was similar to the compressive-strength results, tensile performance must be considered separately because cracking and the bond between aggregate and cement paste can affect it.

Table 10: Splitting Tensile Strength at Different Curing Ages (MPa)

Age	NC	5%	10%	30%	40%	50%
7 days	2.100	1.530	1.410	1.830	1.710	1.950
14 days	2.655	2.025	1.760	2.330	2.260	2.430
28 days	3.000	2.430	2.340	2.600	2.530	2.730

The 28-day splitting tensile strengths of the recycled mixes ranged from 2.34 MPa at 10% RCA to 2.73 MPa at 50% RCA. The control reached 3.00 MPa. Among the RCA mixes, 50% replacement gave the highest splitting tensile strength at each age.

Figure 4: Splitting Tensile Strength of All Six Mixtures

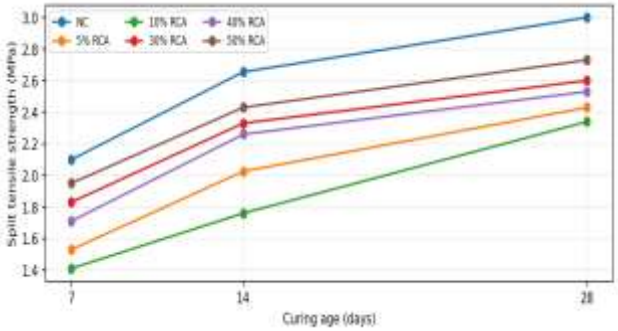
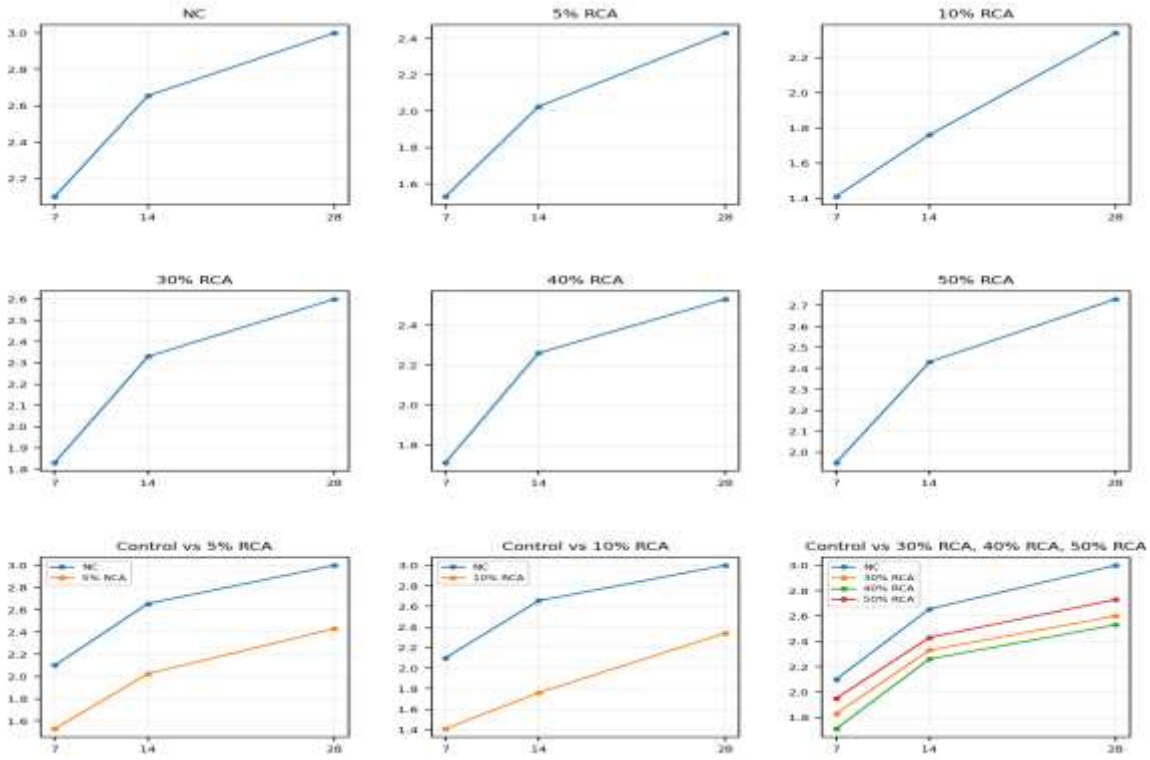


Figure 4 shows the splitting tensile strength of all six mixtures at the three curing ages. Each mixture became stronger with time, while the conventional concrete remained the strongest throughout.

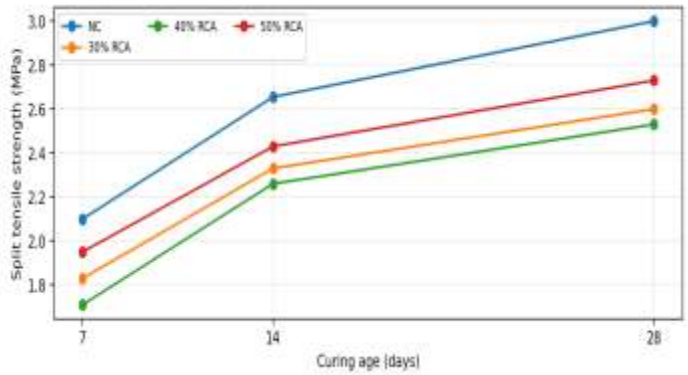
7.1 Splitting Tensile Strength Comparisons

Figure 5: Original Split-Tensile Trends and Selected Mix Comparisons (Nine Graphs)



The 10% RCA mix had the lowest splitting tensile strength at 7, 14 and 28 days. Its 28-day result was 2.34 MPa, compared with 2.43 MPa for 5% RCA and 3.00 MPa for the control.

Figure 6: Control Compared with 30%, 40% and 50% RCA



At 28 days, the 30%, 40% and 50% RCA mixtures reached splitting tensile strengths of 2.60, 2.53 and 2.73 MPa, respectively. The 50% mix came closest to the control, although its strength was still 9% lower.

8. Comparative Discussion

Engineering Interpretation and Limitations

The strength results do not show a simple relationship in which higher RCA content always leads to higher or lower strength. The 10% mix was weaker than the 5% mix, while the 50% mix was stronger than the other recycled groups. Differences in aggregate quality or test variation may have contributed, but the available records do not establish the reason.

Material-test results should be considered alongside compressive and tensile strengths when deciding whether recycled aggregate is suitable for a particular use. More trials, clear mix proportions, workability measurements, durability testing and repeated specimens would be needed before recommending a replacement level for structural concrete.

Table 4: Comparison of 28-Day Strength with Natural Concrete

Mix	Compression (MPa)	Change (%)	Split tensile (MPa)	Change (%)
NC	19.55	+0.0	3.00	+0.0
5% RCA	16.20	-17.1	2.43	-19.0
10% RCA	15.65	-19.9	2.34	-22.0
30% RCA	17.33	-11.4	2.60	-13.3
40% RCA	16.88	-13.7	2.53	-15.7
50% RCA	18.22	-6.8	2.73	-9.0

Increasing the recycled aggregate content did not produce a steady change in strength. Of the recycled mixtures, the 50% RCA mix came closest to the control at 28 days, with compressive strength 6.8% lower and splitting tensile strength 9.0% lower. This makes 50% the best-performing level tested here, not a general optimum for all concrete mixes.

9. Conclusions

Practical Implications and Future Scope

The findings indicate that recycled concrete aggregate can be considered as a way to reuse demolition waste while maintaining useful compressive and tensile strength. The 50% RCA mixture performed best among the recycled mixes at 28 days, although it remained below the control. Further work should examine different aggregate sources, moisture conditions, mix proportions, durability and the demands of specific construction applications.

All six mixtures gained strength from 7 to 28 days. Conventional concrete gave the highest compressive and splitting tensile strengths, while the 50% RCA mix was the strongest recycled mixture at 28 days, reaching 18.22 MPa in compression and 2.73 MPa in splitting tension. Recycled aggregate therefore deserves further investigation as a means of conserving natural resources, but workability, absorption, long-term performance and structural suitability need to be verified. No statistical conclusions are drawn because individual specimen results were not supplied.

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