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Experimental Investigation of Combined Recycled Fine and Coarse Aggregate Replacement in Concrete

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Abstract: This study experimentally investigates the feasibility of replacing natural fine and coarse aggregates with recycled concrete aggregates (RCA) in M25 concrete. A control mixture and four recycled aggregate mixtures containing 10%, 20%, 30% and 40% combined replacement were produced using a design procedure based on IS 10262:2019. Fresh-state performance was evaluated by slump, while hardened-concrete performance was assessed using 7- and 28-day compressive strength, 28-day split tensile strength, and 28-day flexural strength. The control mixture exhibited a slump of 75 mm and a 28-day compressive strength of 32.8 MPa. At 10% and 20% RCA replacement, the compressive strengths remained close to the control value, at 32.5 and 31.8 MPa, respectively. Beyond 20%, the reduction became pronounced, reaching 28.1 MPa at 30% and 24.4 MPa at 40% replacement. Similar trends were obtained for split tensile and flexural strengths. The 20% mixture maintained a slump of 75 mm and achieved split tensile strength of 3.05 MPa and flexural strength of 3.70 MPa at 28 days. Although the 10% mixture produced marginally higher mechanical properties, 20% was identified as the optimum replacement level investigated because it enabled greater utilization of recycled aggregate without a loss of control-level slump and with satisfactory mechanical performance. The findings indicate that controlled combined replacement of natural fine and coarse aggregates can provide a technically viable route for incorporating processed C&D concrete waste into M25 concrete.
Keywords: recycled concrete aggregate; recycled fine aggregate; recycled coarse aggregate; fresh and mechanical properties; construction and demolition waste in concrete.

I. INTRODUCTION

Concrete is the most widely used construction material due to its versatility, strength, durability, and relatively economical production [1]. However, the large-scale consumption of natural aggregates and the increasing generation of construction and demolition (C&D) waste have created significant environmental concerns [2-5]. Excessive quarrying of natural aggregates contributes to resource depletion, landscape degradation, energy consumption, and associated carbon emissions, while disposal of C&D waste places additional pressure on landfills. Recycling concrete waste into recycled concrete aggregate (RCA) and recycled fine aggregate (RFA) provides a potential circular approach for reducing waste generation and conserving natural resources.

Recycled aggregates differ from natural aggregates because crushing of parent concrete leaves adhered old mortar on the aggregate particles. This residual mortar generally results in higher porosity, water absorption, and lower density, which can adversely affect workability and mechanical properties as the replacement level increases. Previous studies [6-10] have reported that moderate replacement levels can provide satisfactory concrete performance, whereas higher replacement levels may lead to greater reductions in strength and workability. Proper aggregate processing, moisture conditioning, mix proportioning, and quality control are therefore essential for producing reliable recycled aggregate concrete. In addition to recycled aggregates, the incorporation of supplementary and alternative construction materials, such as fly ash [11], ground granulated blast-furnace slag, silica fume, and geopolymer-based binders, has gained attention for reducing the environmental impact of conventional cement-based construction [12-20]. Such materials can reduce dependence on Portland cement, utilize industrial by-products, and potentially lower embodied carbon and waste generation. These approaches support the broader transition towards resource-efficient and sustainable construction materials.

Most previous investigations have focused on recycled fine or coarse aggregates individually, while comparatively limited studies have examined their simultaneous replacement. Combined replacement may increase the utilization of C&D waste but can also significantly affect workability, strength, and durability due to interactions between recycled fine and coarse fractions. Therefore, systematic optimization of the combined RFA and RCA replacement is required to strike an appropriate balance between environmental benefits [21-22] and engineering performance.

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Accordingly, the present study investigates M25 concrete incorporating combined recycled fine and coarse aggregates at replacement levels of 0%, 10%, 20%, 30%, and 40%. The study evaluates their effects on workability, compressive strength, split tensile strength, and flexural strength, to identify an optimum replacement level that provides satisfactory mechanical performance while improving resource conservation and reducing the environmental burden associated with conventional concrete production.

II. MATERIALS AND EXPERIMENTAL PROGRAMME

A. Constituent Materials

Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112:2013 was used. The reported specific gravity, standard consistency, initial setting time, and final setting time were 3.15, 31%, 78 min, and 547 min, respectively. Natural river sand conforming to Zone II of IS 383:2016 was used as fine aggregate; its specific gravity, water absorption, and fineness modulus were 2.65, 1.20%, and 2.66, respectively. Natural crushed angular coarse aggregate of 20 mm nominal maximum size had a specific gravity of 2.70, water absorption of 0.80%, and aggregate impact value of 18%.

The recycled fine and coarse aggregates were produced from processed construction and demolition concrete waste. The waste was sorted to remove reinforcement and visible contaminants, crushed, screened, and washed before use. The recycled fine aggregate had a reported specific gravity of 2.40 and water absorption of approximately 3.5% (the thesis property table reports 4.5%; this manuscript retains the narrative value for the experimental discussion). The recycled coarse aggregate had a specific gravity of 2.50, a water absorption of 3.0%, and an aggregate impact value of 26%. The higher absorption and lower density of the recycled aggregates, compared with natural aggregates, were considered during mix preparation.

Material	Property	Value
Cement	Specific gravity	3.15
Cement	Standard consistency	31%
Natural fine aggregate	Specific gravity	2.65
Natural fine aggregate	Water absorption	1.20%
Natural fine aggregate	Fineness modulus	2.66
Natural coarse aggregate	Specific gravity	2.70
Natural coarse aggregate	Water absorption	0.80%
Natural coarse aggregate	Impact value	18%
Recycled fine aggregate	Specific gravity	2.40
Recycled fine aggregate	Water absorption	3.5%*
Recycled coarse aggregate	Specific gravity	2.50
Recycled coarse aggregate	Water absorption	3.0%
Recycled coarse aggregate	Impact value	26%

**The source thesis contains 3.5% in the narrative and 4.5% in its property table; this discrepancy should be resolved from the laboratory record before journal submission.*

B. Mix design

M25 concrete was proportioned in accordance with IS 10262:2019. The target mean strength was taken as 31.6 MPa, and a water-to-cement ratio of 0.45 was adopted. The design used 20 mm nominal maximum size aggregate, Zone II fine aggregate, and a target slump of 75 mm. The calculated cement and effective water contents were 427 and 192 kg/m³, respectively. The control mixture contained 649.5 kg/m³ natural fine aggregate and 1126.8 kg/m³ natural coarse aggregate. Recycled aggregate replacement was introduced on an equivalent absolute volume basis to keep aggregate volume comparable across mixtures.

Mix	RCA replacement	Cement	Water	Natural FA	Recycled FA	Natural CA	Recycled CA
M0	0%	427	192	649.5	0	1126.8	0
M1	10%	427	192	584.6	58.8	1014.1	104.3
M2	20%	427	192	519.7	117.6	901.4	208.7
M3	30%	427	192	454.7	176.4	788.8	313.0
M4	40%	427	192	389.8	235.2	676.1	417.3

C. Specimen preparation and testing

Concrete constituents were batched by mass. The aggregates and cement were initially dry-mixed for approximately 2 min, followed by the gradual addition of water. Additional water required to compensate for aggregate absorption was incorporated during mixing. Separate batches were produced for the control and four RCA replacement levels. Fresh concrete was tested immediately for slump in accordance with IS 1199:1959.

Cube specimens of 150 × 150 × 150 mm were cast for compressive strength, cylinders of 100 × 200 mm for split tensile strength, and beams of 100 × 100 × 500 mm for flexural strength. Three cubes were tested at 7 days and three at 28 days for each mixture; three cylinders and three beams were tested at 28 days for each mixture. Specimens were demoulded after approximately 24 h and cured in water at 27 ± 2 °C until the specified testing age. Compressive strength was determined according to IS 516, split tensile strength according to IS 5816:1999, and flexural strength according to IS 516.

III. RESULTS AND DISCUSSION

A. Workability

Mix	RCA (%)	Slump (mm)	Change from M0
M0	0	75	0.0%
M1	10	78	+4.0%
M2	20	75	0.0%
M3	30	65	−13.3%
M4	40	50	−33.3%

The Control concrete produced a slump of 75 mm. A small increase to 78 mm occurred at 10% replacement, followed by a return to 75 mm at 20%. The reduction became clear at higher RCA contents: 65 mm at 30% RCA and 50 mm at 40% RCA. This pattern indicates a threshold beyond which the absorption and surface characteristics of the recycled aggregates have a dominant influence on fresh concrete. The recycled particles contain adhered mortar and have rougher surfaces than the natural aggregates, increasing water demand and reducing the free water available for lubrication. Thus, the 20% mixture retained the same measured slump as the control despite containing recycled fine and coarse aggregates.

B. Compressive strength

Mix	RCA (%)	7-day (MPa)	28-day (MPa)	28-day change vs M0
M0	0	23.5	32.8	0.0%
M1	10	23.4	32.5	−0.9%
M2	20	23.2	31.8	−3.0%
M3	30	19.5	28.1	−14.3%
M4	40	17.8	24.4	−25.6%

Compressive strength exhibited a two-stage response to RCA content. Up to 20% replacement, the decrease was small: the 28-day value reduced from 32.8 MPa for M0 to 32.5 MPa for M1 and 31.8 MPa for M2. In contrast, the 30% and 40% mixtures reached only 28.1 and 24.4 MPa, corresponding to reductions of approximately 14.3% and 25.6% relative to the control. The 7-day results show the same transition, with only marginal changes up to 20%, but marked reductions at 30% and 40%.

The observed trend is consistent with the physical characteristics of the recycled aggregate. The adhered mortar introduces additional porous zones and produces a less dense aggregate particle than natural stone. With increasing RCA content, the volume of these recycled particles and associated interfacial regions increases, making the concrete more sensitive to moisture conditions and bond quality. The results nevertheless show that the M2 mixture exceeded the M25 characteristic strength level at 28 days.

C. Split Tensile Strength

Mix	RCA (%)	28-day split tensile (MPa)	Change vs M0
M0	0	3.25	0.0%
M1	10	3.18	−2.2%
M2	20	3.05	−6.2%
M3	30	2.61	−19.7%
M4	40	2.52	−22.5%

Split tensile strength decreased progressively with RCA content. The control value of 3.25 MPa reduced only slightly to 3.18 MPa at 10% and 3.05 MPa at 20%. At 30% and 40%, the values decreased to 2.61 and 2.52 MPa, respectively. The comparatively greater sensitivity of tensile performance is expected because splitting failure is strongly governed by crack initiation, aggregate-paste bond, and the integrity of the interfacial transition zone. The presence of adhered mortar and increased porosity can therefore influence tensile performance more strongly than compressive response at moderate replacement levels.

D. Flexural Strength

Mix	RCA (%)	28-day flexural (MPa)	Change vs M0
M0	0	4.20	0.0%
M1	10	3.90	−7.1%
M2	20	3.70	−11.9%
M3	30	3.20	−23.8%
M4	40	2.90	−31.0%

Flexural strength followed the same overall pattern. The control mixture reached 4.20 MPa, while M1 and M2 remained at 3.90 and 3.70 MPa, respectively. The decrease became more substantial at 30% and 40%, with values of 3.20 and 2.90 MPa, respectively. Since flexural performance depends on tensile stress transfer and crack propagation through the matrix, the weaker or more porous interfacial regions associated with recycled aggregate can contribute to earlier crack development as RCA content increases.

E. Integrated Performance and Optimization

Mix	RCA	Slump (mm)	28-d compressive (MPa)	Split tensile (MPa)	Flexural (MPa)	Assessment
M0	0%	75	32.8	3.25	4.20	Control
M1	10%	78	32.5	3.18	3.90	Satisfactory
M2	20%	75	31.8	3.05	3.70	Optimum
M3	30%	65	28.1	2.61	3.20	Significant reduction
M4	40%	50	24.4	2.52	2.90	Lowest performance

The optimization criterion was not defined as the mixture with the absolute maximum strength; instead, the study sought the most useful balance among workability, mechanical performance,, and increased use of recycled aggregate. On that basis, M2 (20% combined replacement) was selected. M1 has slightly higher measured strengths than M2, but the 20% mixture doubles the recycled aggregate replacement relative to M1 while retaining the control-level slump and 31.8 MPa 28-day compressive strength. In contrast, the transition from 20% to 30% results in a much larger deterioration: slump decreases by 10 mm and compressive strength decreases by 3.7 MPa. The 40% mixture shows an even stronger penalty in both fresh and hardened properties.

From a practical perspective, the results therefore indicate that 20% is a performance-balanced replacement level for the materials, mix proportions, and curing conditions investigated. This conclusion is intentionally limited to the tested system; it should not be interpreted as a universal maximum RCA content for all M25 concretes or all sources of recycled aggregate.

IV. PRACTICAL IMPLICATIONS

The results suggest that the quality and moisture condition of RCA should be treated as primary mix-design variables. At higher replacement levels, pre-conditioning or controlled moisture adjustment can reduce the loss of workability. Water-reducing admixtures may also be considered where a lower effective water content is required. Equally important is the removal of reinforcement, brick, wood, glass, soil, and other contaminants during recycling. The present findings support the use of processed RCA at controlled replacement levels, particularly where the objective is to reduce natural aggregate consumption without substantially compromising M25 mechanical performance.

However, the present experimental programme did not quantify life-cycle environmental benefits, economic savings, or long-term durability. Accordingly, the sustainability implications are demonstrated through aggregate substitution and waste utilization, whereas quantitative claims regarding carbon reduction, cost savings, or service-life improvement require further investigation.

V. LIMITATIONS AND FUTURE RESEARCH

The study was limited to M25 concrete and five combined replacement levels. The exact optimum around 20% was not refined using smaller increments. The individual effects of recycled fine and recycled coarse aggregate were not isolated, and a single fine-to-coarse replacement proportion was used. RCA was obtained from a limited source, so source-to-source variation was not assessed. The experimental programme focused on workability and mechanical properties; durability parameters, such as permeability, chloride resistance, sulphate resistance, carbonation, and water absorption, were not measured. Long-term performance and the effects of admixtures or aggregate-treatment techniques were also outside the scope.

Future work should therefore investigate replacement levels around 20% at finer intervals, separate the contributions of recycled fine and coarse aggregates, evaluate different fine-to-coarse RCA ratios, and assess pre-soaking, moisture conditioning, and chemical admixtures. Durability, life-cycle assessment, and economic analysis should be incorporated to establish the broader sustainability value of recycled aggregate concrete.

VI. CONCLUSIONS

1) Combined replacement of natural fine and coarse aggregates with processed RCA influenced both workability and hardened concrete properties.
2) Slump was 75, 78, 75, 65, and 50 mm at 0%, 10%, 20%, 30%, and 40% replacement, respectively; the principal workability loss occurred beyond 20%.
3) 28-day compressive strength was 32.8, 32.5, 31.8, 28.1, and 24.4 MPa for 0-40% RCA, respectively. The reduction was limited to 20% but became pronounced at higher concentrations.
4) 28-day split tensile strength reduced from 3.25 MPa for the control to 3.05 MPa at 20%, 2.61 MPa at 30%, and 2.52 MPa at 40%.
5) 28-day flexural strength reduced from 4.20 MPa for the control to 3.70 MPa at 20%, 3.20 MPa at 30%, and 2.90 MPa at 40%.
6) Although the 10% mixture showed slightly higher mechanical properties than the 20% mixture, the 20% mixture was selected as optimum because it enabled greater RCA utilization while retaining a 75 mm slump and satisfactory mechanical performance.
7) Under the tested materials, mix proportions, and curing conditions, 20% combined RCA replacement is the recommended performance-balanced level for the investigated M25 concrete.

VII. DECLARATIONS

Funding: No external funding information was reported in the source thesis.

Conflict of interest: The authors should confirm and declare any actual conflicts before submission.

Author contributions: Ranveer Singh – experimental investigation, data analysis, and manuscript preparation; Hemant Sood – supervision and technical guidance; Himmi Gupta – technical review and manuscript editing.

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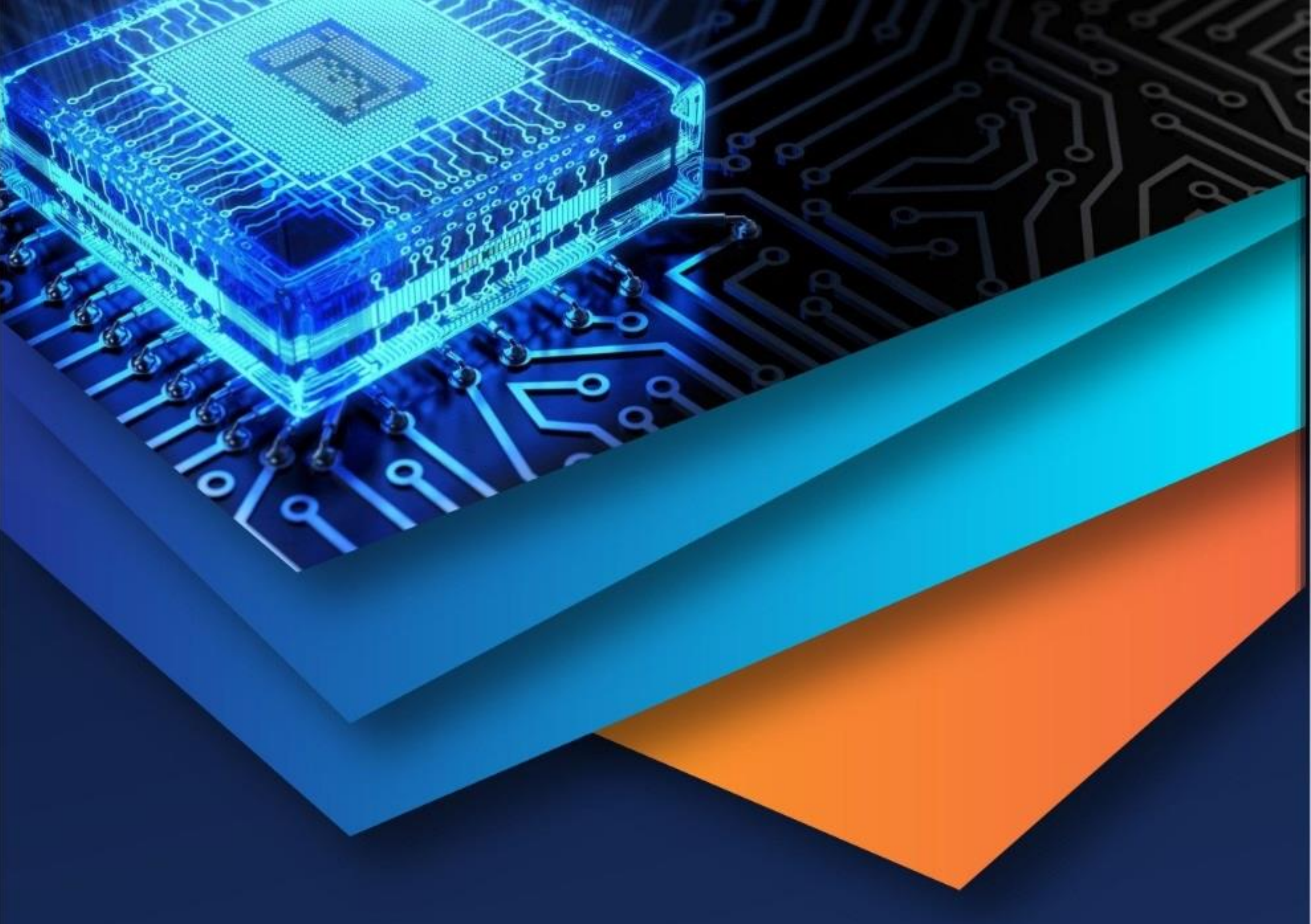

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