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Performance Evaluation of Recycled Concrete Aggregate as Partial Replacement of Natural Coarse Aggregate in M25, M30, and M35 Concrete

Taba Amang[1]*, Hemant Sood[1]
[1]*Department of Civil Engineering NITTTR Chandigarh Sector 26, Chandigarh*

Abstract: *The increasing generation of construction and demolition (C&D) waste and continued consumption of natural aggregates have created a need for sustainable alternatives in concrete production. This study investigates the utilization of Recycled Concrete Aggregate (RCA) as a partial replacement for Natural Coarse Aggregate (NCA) in M25, M30, and M35 concrete. RCA obtained from a C&D waste processing plant in Chandigarh was incorporated at replacement levels of 0%, 20%, 30%, and 40%. The fresh properties of concrete were evaluated using slump and compacting factor tests, while compressive strength, split tensile strength, and flexural strength were determined at 7 and 28 days. Increasing RCA content generally reduced concrete workability, with slump reductions of approximately 10.6%, 6.5%, and 13.8% for M25, M30, and M35 concrete, respectively, at 40% replacement. The effect of RCA on compressive strength varied with concrete grade. M25 concrete exhibited a notable improvement at moderate replacement, achieving a maximum 28-day compressive strength of 48.27 MPa at 30% RCA compared with 39.37 MPa for the control, representing an increase of approximately 22.6%. In contrast, M30 and M35 concrete showed gradual reductions in compressive strength with increasing RCA content, with reductions of approximately 5.4% and 16.7%, respectively, at 40% replacement. Split tensile and flexural strengths generally decreased as RCA content increased, with more pronounced reductions at higher replacement levels. Considering workability and mechanical properties collectively, RCA replacement in the range of 20–30% provided the most balanced performance under the investigated conditions. The results indicate that controlled partial replacement of NCA with RCA is technically feasible and could contribute to C&D waste utilization and conservation of natural aggregate resources.*

Keywords: *Recycled Concrete Aggregate (RCA); Natural Coarse Aggregate (NCA); Construction and Demolition Waste; Sustainable Concrete; Compressive Strength; Split Tensile Strength; Flexural Strength; Workability.*

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I. Introduction

Concrete is one of the most widely used construction materials, with aggregates comprising approximately 70–80% of its volume. Rapid urbanization and infrastructure development have increased the demand for natural coarse aggregate (NCA), while demolition and reconstruction activities generate substantial construction and demolition (C&D) waste[1–3]. The continued extraction of natural aggregates can deplete finite resources and contribute to environmental degradation. Recycled Concrete Aggregate (RCA), produced by crushing, cleaning, and grading demolished concrete, offers a potential solution to both challenges. Its use in new concrete can reduce C&D waste disposal and decrease dependence on natural aggregates, supporting resource conservation and circular construction practices[4–7]. However, RCA is not equivalent to NCA because its particles contain adhered cement mortar, which generally increases porosity and water absorption while reducing density. These characteristics can affect concrete workability, strength, and durability. Increasing RCA content may reduce workability and mechanical performance because of its higher absorption, angularity, rough texture, adhered mortar, and crushing-induced microcracks. However, the extent of these effects depends on the RCA source and quality, replacement level, concrete grade, mix proportions, aggregate grading, and curing conditions. Previous studies have reported satisfactory performance at low and moderate replacement levels, although higher percentages often reduce workability and strength[8–11]. The literature therefore does not establish a universally applicable optimum RCA replacement level. Furthermore, many studies have focused on a single concrete grade or evaluated only compressive strength. Comparative investigations involving identical RCA replacement levels across different concrete grades and assessing both fresh and hardened properties remain limited. A comprehensive evaluation of workability, compressive strength, split tensile strength, and flexural strength is therefore necessary to determine the practical suitability of RCA concrete. The present study investigates RCA as a partial replacement for NCA in M25, M30, and M35 concrete[12–14]. RCA obtained from a C&D waste processing plant in Chandigarh is used at replacement levels of 0%, 20%, 30%, and 40%. Fresh properties are evaluated through slump and compacting factor tests, while hardened properties are assessed through compressive, split tensile, and flexural strength tests at 7 and 28 days. The objective is to identify a practical RCA replacement level that balances engineering performance with environmental benefits. The findings are expected to support the controlled use of locally available RCA, reduce C&D waste, and conserve natural aggregate resources[15–17].

II. Materials and Methodology

2.1 Experimental Programme

An experimental investigation was conducted to evaluate the influence of Recycled Concrete Aggregate (RCA) as a partial replacement for Natural Coarse Aggregate (NCA) in M25, M30, and M35 grades of concrete. For each grade, a control mixture containing 100% NCA was prepared and compared with concrete containing 20%, 30%, and 40% RCA replacement. The experimental programme comprised material characterization, concrete mix proportioning, preparation and curing of specimens, and testing of fresh and hardened concrete properties[18–20].

The control mixes were designed using the Bureau of Indian Standards (BIS) method. RCA was subsequently introduced by replacing the corresponding proportion of NCA while maintaining the principal mix-design parameters for each concrete grade. The fresh properties were assessed using slump and compacting factor tests. Mechanical performance was evaluated by compressive strength, split tensile strength, and flexural strength tests at curing ages of 7 and 28 days. The same general preparation, compaction, curing, and testing procedures were maintained for the control and RCA mixtures to provide a consistent basis for comparison.

2.2 Materials

2.2.1 Cement

Ordinary Portland Cement (OPC), 43 Grade, manufactured by UltraTech Cement, was used as the binder throughout the investigation. The cement conformed to IS 8112. The same type and source of cement were maintained for all concrete mixtures to minimize variations arising from the cementitious material.

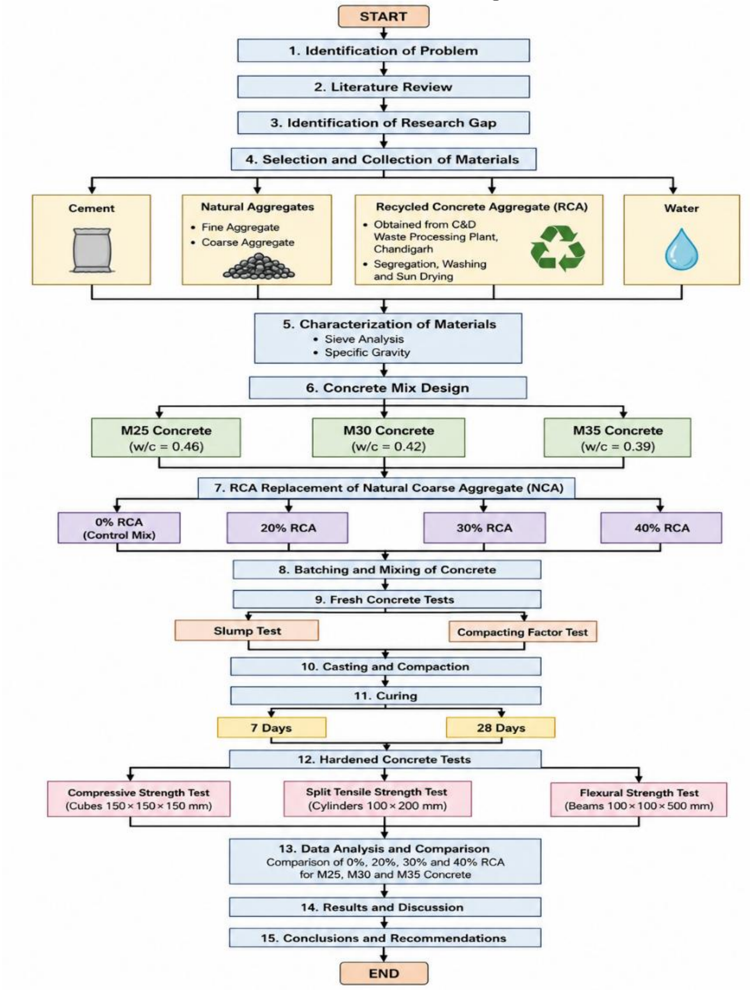

Figure 1: Methodology adopted for this research study

2.2.2 Fine Aggregate

Locally available natural river sand conforming to IS 383:2016 was used as the fine aggregate. Sieve analysis indicated that the sand corresponded to Grading Zone III[21–23]. Its experimentally determined specific gravity was approximately 2.60.

2.2.3 Natural Coarse Aggregate

Natural coarse aggregate was used as the primary coarse aggregate in the control mixtures. It consisted of 10 mm and 20 mm nominal-size fractions, which were blended in a 1:2 proportion, respectively. The particle-size distribution was determined by sieve analysis before concrete preparation. The specific gravity adopted for the coarse aggregate during mix design was 2.70.

2.2.4 Recycled Concrete Aggregate

The RCA used in this investigation was obtained from the Construction and Demolition (C&D) Waste Processing Plant, Chandigarh. The as-received material contained unwanted constituents, including ferrous materials, brick fragments, marble and tile pieces, wood, and other foreign matter. These materials were manually removed before use. The RCA was subsequently washed with clean water to remove adhering dust and loose particles and then sun-dried before characterization and concrete preparation.

Sieve analysis was performed on a representative 2000 g RCA sample. Based on IS 383:2016, the recycled aggregate was classified as 20 mm graded aggregate. Its experimentally determined specific gravity was approximately 2.40.

2.2.5 Water and Chemical Admixture

Clean potable tap water was used for both concrete mixing and specimen curing. The water was maintained in accordance with the requirements of IS 456:2000, and the same source was used throughout the experimental programme.

Auramix 200, a high-performance superplasticizer, was used as the chemical admixture. The admixture was employed to provide water reduction and maintain the required workability without increasing the water content. The thesis reports that the product conforms to IS 9103 and was used consistently for M25, M30, and M35 concrete.

2.3 Concrete Mix Design

Concrete mixes were proportioned using the BIS method in accordance with IS 10262:2009 and IS 456:2000, with aggregate requirements considered according to IS 383:2016. Three characteristic compressive strength grades—M25, M30, and M35—were investigated. The corresponding target mean compressive strengths were 31.60, 38.25, and 43.25 MPa, respectively. Water–cement ratios of 0.46, 0.42, and 0.39 were adopted for M25, M30, and M35 concrete, respectively.

Table 1: The final control mix quantities reported in the experimental programme

Material/Parameter	M25	M30	M35
Characteristic strength (MPa)	25	30	35
Target mean strength (MPa)	31.6	38.25	43.25
Water–cement ratio	0.46	0.42	0.39
Cement (kg/m³)	375	385	400
Fine aggregate (kg/m³)	637.71	630.15	619.73
Coarse aggregate (kg/m³)	1219.12	1247.899	1260.47
Water (kg/m³)	172.5	161.7	156

2.4 RCA Replacement Levels

For each concrete grade, NCA was replaced by RCA at 0%, 20%, 30%, and 40%. The 0% RCA mixture served as the control, while the remaining mixtures represented progressively increasing levels of recycled aggregate incorporation. Thus, the experimental matrix consisted of four RCA levels for each of the three concrete grades.

Table 2: The replacement scheme

RCA replacement (%)	NCA (%)	RCA (%)
0	100	0
20	80	20
30	70	30
40	60	40

This experimental range was selected to assess moderate RCA replacement levels and determine whether a practical balance between natural aggregate conservation and concrete performance could be achieved.

2.5 Mixing and Specimen Preparation

All constituent materials were measured by weight according to the respective mix proportions. Cement, fine aggregate, NCA, RCA, water, and chemical admixture were mixed using a rotary concrete mixer until a uniform and homogeneous mixture was obtained. The same general mixing procedure was followed for the control and RCA-containing mixtures.

Before casting, the moulds were cleaned, tightened, and coated internally with a thin layer of mould oil. Fresh concrete was placed in the moulds in layers of approximately 50 mm and compacted using a vibrating table. Excessive vibration was avoided to minimize segregation. After compaction, the specimen surfaces were levelled and finished using a trowel.

Different specimen geometries were prepared according to the mechanical property being evaluated:

- Cubes of **150 × 150 × 150 mm** for compressive strength;
- Cylinders of **100 mm diameter × 200 mm height** for split tensile strength; and
- Beams of **150 × 150 × 700 mm** for flexural strength.

Each specimen was identified according to concrete grade, RCA replacement percentage, and testing age.

2.6 Curing

Following casting, the specimens were maintained under moist conditions for approximately 24 h to allow initial hardening. They were subsequently demoulded, appropriately marked, and completely submerged in clean water until the designated testing ages of 7 and 28 days. The curing water was maintained at approximately **27 ± 2 °C**. Before mechanical testing, the specimens were removed from the curing tank and tested in saturated surface-dry condition.

2.7 Testing of Fresh Concrete

The effect of RCA replacement on the fresh properties of concrete was evaluated through the slump and compacting factor tests. These tests were performed for M25, M30, and M35 mixtures containing different RCA percentages.

2.7.1 Slump Test

The slump test was used to determine the consistency and workability of freshly prepared concrete. The test was conducted following IS 1199 procedures. Changes in slump with increasing RCA content were used to assess the influence of recycled aggregate on the mobility and consistency of fresh concrete.

2.7.2 Compacting Factor Test

The compacting factor test was also conducted to provide an additional assessment of concrete workability. Its inclusion was particularly relevant because the rough texture and relatively high water absorption of RCA could alter the degree of compaction attainable under a given amount of applied effort. The fresh-concrete testing programme followed IS 1199:2018.

2.8 Testing of Hardened Concrete

The mechanical performance of the control and RCA concrete was evaluated through compressive strength, split tensile strength, and flexural strength. Tests were conducted at **7 and 28 days** to examine both early-age and later-age strength development.

2.8.1 Compressive Strength

Compressive strength was determined using 150 mm concrete cubes. After the specified curing period, the specimens were removed from the curing tank and tested under compression. The measured failure load was used to determine compressive strength from the applied load and loaded cross-sectional area. Results obtained for RCA mixtures were subsequently compared with the corresponding control concrete for each grade.

2.8.2 Split Tensile Strength

Split tensile strength was determined using cylindrical specimens measuring 100 mm in diameter and 200 mm in height. The specimens were subjected to diametrical compressive loading until failure. The results were used to examine the influence of increasing RCA replacement on the tensile behaviour of M25, M30, and M35 concrete.

2.8.3 Flexural Strength

Flexural strength was evaluated using beam specimens measuring 150 × 150 × 700 mm. The specimens were tested after 7 and 28 days of curing to assess the effect of RCA replacement on the flexural behaviour of the concrete.

2.9 Experimental Comparison

For each concrete grade, the measured fresh and hardened properties of the 20%, 30%, and 40% RCA mixtures were compared with those of the corresponding 0% RCA control. Comparisons were made across both replacement percentage and concrete grade. This approach allowed the influence of increasing RCA content to be evaluated systematically and provided the basis for identifying a replacement range capable of maintaining satisfactory engineering performance while reducing the consumption of natural coarse aggregate.

III. Results and Discussion

The effects of replacing natural coarse aggregate with recycled concrete aggregate (RCA) were evaluated for M25, M30, and M35 concrete. The mixtures contained 0%, 20%, 30%, and 40% RCA. Fresh properties were assessed using slump and compacting factor tests, while compressive, split tensile, and flexural strengths were measured at 7 and 28 days.

3.1 Workability

Increasing RCA content progressively reduced the workability of all concrete grades. In M25 concrete, slump decreased from 66 mm for the control mixture to 59 mm at 40% RCA. Similarly, slump decreased from 46 to 43 mm for M30 and from 29 to 25 mm for M35. The compacting factor also declined, from 0.92 to 0.89 for M25, 0.89 to 0.85 for M30, and 0.83 to 0.78 for M35.

The reduction in workability is attributed to the porous adhered mortar, angular shape, rough texture, and higher water absorption of RCA. These characteristics increase interparticle friction and reduce the amount of free water available for flow. Workability also decreased with increasing concrete grade because of the lower water–cement ratios used for M30 and M35 concrete. The combined results from the slump and compacting factor tests confirm that higher RCA contents require careful control of water demand and admixture dosage.

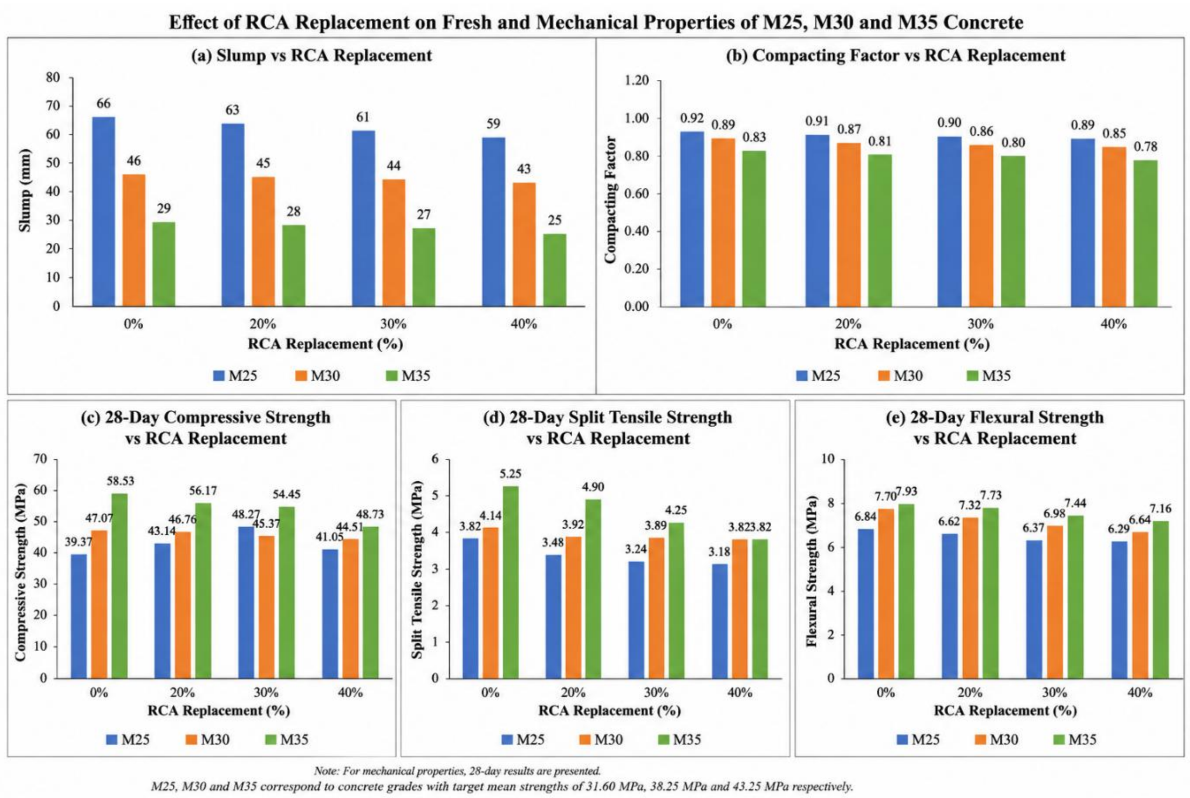

Figure 2: Effect of Replacement on Fresh and Mechanical Properties of M25. M30 and M35

3.2 Compressive Strength

The 28-day compressive strength was higher than the 7-day strength for all mixtures, confirming continued hydration and strength development. However, the influence of RCA varied with concrete grade.

For M25 concrete, the 7-day strength changed only slightly, decreasing from 34.10 MPa for the control to 33.38 MPa at 40% RCA. At 28 days, strength increased from 39.37 MPa for the control to 43.14 MPa at 20% RCA and reached a maximum of 48.27 MPa at 30% RCA. This represented an increase of approximately 22.6%. At 40% RCA, the strength decreased to 41.05 MPa but remained slightly higher than that of the control. The improvement at 30% RCA may be related to favourable particle packing, surface roughness, and improved mechanical interlocking. At higher replacement, the weaker adhered mortar and additional interfaces may have reduced the strength benefit. M30 concrete showed a gradual reduction in compressive strength with increasing RCA. The 28-day strength decreased from 47.07 MPa for the control to 46.76, 45.37, and 44.51 MPa at 20%, 30%, and 40% RCA, respectively. These reductions were relatively small, indicating that moderate RCA replacement can be used in M30 concrete without substantial loss of compressive strength. M35 concrete was more sensitive to RCA replacement. Its 28-day strength decreased from 58.53 MPa for the control to 56.17 MPa at 20%, 54.45 MPa at 30%, and 48.73 MPa at 40% RCA. The reduction at 40% replacement was approximately 16.7%. This behaviour may be associated with the greater influence of porous adhered mortar and weaker interfacial transition zones at higher RCA contents. Overall, M25 showed an improvement at moderate RCA replacement, whereas M30 and M35 exhibited progressive strength reductions. These results indicate that the optimum RCA content depends on the concrete grade and should not be considered universal.

3.3 Split Tensile Strength

Split tensile strength generally decreased as RCA content increased. For M25 concrete, the 28-day strength decreased from 3.82 MPa for the control to 3.18 MPa at 40% RCA, representing a reduction of approximately 16.8%. M30 concrete showed better strength retention, with a decrease from 4.14 to 3.82 MPa, or approximately 7.7%. The greatest reduction occurred in M35 concrete, where the 28-day strength decreased from 5.25 MPa to 3.82 MPa at 40% RCA, corresponding to a reduction of approximately 27.2%. The reduction in tensile strength can be attributed to the weaker adhered mortar and the presence of additional interfacial transition zones in RCA concrete. These regions can act as locations for crack initiation and propagation, particularly at higher replacement levels. The results indicate that tensile performance is more sensitive to RCA content than compressive strength, especially in higher-grade concrete.

3.4 Flexural Strength

Flexural strength also generally decreased with increasing RCA content. For M25 concrete, the 28-day strength decreased from 6.84 MPa for the control to 6.29 MPa at 40% RCA, representing an approximately 8.0% reduction. In M30 concrete, the corresponding strength decreased from 7.70 to 6.64 MPa, with the most noticeable reduction occurring at 40% RCA. M35 concrete showed a decrease from 7.93 to 7.16 MPa, equivalent to approximately 9.7%. The reduction in flexural strength is likely related to the weaker bond between RCA particles and the surrounding cement paste. Although the rough surface of RCA may improve mechanical interlocking, the adhered mortar and internal defects can reduce resistance to crack development under flexural loading.

3.5 Overall Performance

The results demonstrate that RCA replacement consistently reduces workability, while its effect on mechanical properties depends on the concrete grade and replacement level. M25 concrete containing 30% RCA achieved the highest 28-day compressive strength, whereas M30 maintained comparatively stable performance across the replacement range. M35 concrete showed greater sensitivity, particularly at 40% RCA. Split tensile and flexural strengths generally decreased with increasing RCA content, even when compressive strength was maintained or improved. Therefore, the suitability of RCA should be assessed using multiple performance indicators rather than compressive strength alone. Considering workability and all measured mechanical properties, RCA replacement levels of 20–30% provided the most balanced performance under the conditions of this study. At 40% replacement, reductions became more pronounced, particularly in the tensile and compressive strengths of M35 concrete. The findings confirm that moderate RCA replacement is technically feasible, but the appropriate level should be selected according to the concrete grade and performance requirements of the intended application.

IV. Conclusion

This study evaluated RCA as a partial replacement for NCA in M25, M30, and M35 concrete at replacement levels of 0%, 20%, 30%, and 40%. Increasing RCA content reduced workability because of its rough surface, adhered mortar, higher porosity, and greater water absorption. At 40% RCA, slump decreased by approximately 10.6%, 6.5%, and 13.8% for M25, M30, and M35 concrete, respectively. The effect on compressive strength depended on concrete grade. M25 concrete achieved its highest 28-day strength of 48.27 MPa at 30% RCA, compared with 39.37 MPa for the control. M30 showed only a gradual reduction, while M35 experienced a more significant decrease at higher replacement levels. Split tensile and flexural strengths generally decreased with increasing RCA content, particularly at 40% replacement. Therefore, these properties should be considered along with compressive strength when selecting the replacement level. Overall, 20–30% RCA provided the most balanced performance. Specifically, 30% RCA was most favourable for M25 concrete, whereas higher replacement levels, especially in M35 concrete, caused greater reductions in mechanical performance. RCA can therefore be used effectively as a partial NCA replacement, provided that its quality, concrete grade, and application requirements are carefully considered.

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