

Optimal Mix Design of M35 grade concrete for Recycled Coarse Aggregate in Concrete

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Concerns about sustainability and the eco sustenance in the field construction are driving the usage of RCA. The use of RCA in concrete mixes gaining popularity due to environmental and sustainability concerns in the construction industry. This study investigates the optimal RCA replacement percentage for maintaining structural integrity while increasing sustainability. The study concentrates on mechanical metrics such strength during compressive force, strength during direct tension, strength during bending readings of rebound number, and UPV. Studies suggest that the best RCA replacement range is 22.5%-25%, after which structural strength degrades.

Keywords: sustainable concrete, recycled coarse aggregate (RCA), optimal replacement, mechanical qualities, and mix design.

1. Introduction

The construction industry is concerned about natural aggregate depletion and environmental sustainability. Using RCA offers an opportunity to lessen environmental impact without compromising on concrete strength and durability remains a significant issue. This study looks at the mechanical properties of RCA-based mixtures to determine the appropriate replacement percentage for high-performance, sustainable concrete. Recycled aggregate concrete (RCA) is an environmentally friendly alternative to standard concrete that improves sustainability by reusing coarse particles from demolished structures. While RCA reduces reliance on natural aggregates, its higher porosity and weaker interfacial bonding may affect strength and durability.

Researchers investigated surface treatments, pozzolanic additives (RHA, silica fume), and

improved mix designs to increase the performance of RCA, making it a viable material for sustainable building. The quality of RCA, residual mortar content, while mix design optimizations all contribute to the unique mechanical qualities of RCA. To assess the mechanical qualities of concrete using coarse recycled concrete aggregates (RCA), Dos Santos et al. (2004) carried out an experiment. Comparing RCA-based concrete to comparable conventional concrete, their study concentrated on concrete mixtures and structural beams. The findings indicate that because of increased porosity and worse interfacial bonding, RCA concrete had somewhat lower compressive strength and modulus of elasticity. However, performance was improved by updated mix designs and surface treatments, which made RCA a good substitute for environmentally friendly building.

The results demonstrate that RCA concrete has lower strength and stiffness than standard mixes due to increased porosity and weaker interfacial bonding. Xiao et al. (2005) investigated the mechanical properties of recycled aggregate concrete (RAC) during uniaxial loading, focusing on compressive strength, modulus of elasticity, and behavior of stress-strain. Their study examined RAC with RCA replacement level 0%, 30%, 50%, 70%, and 100%, and discovered that higher RCA concentration often reduces compressive strength because to weaker interfacial bonding and increased porosity. However, tailored mix designs and surface treatments can mitigate these effects, leading to greater structural performance. The effects of carbonated RCA on the properties and microstructure of RAC were investigated by Lu et al. (2019). Elansary and Ashmawy (2021) conducted an experimental study on the related properties of physical and mechanical for RCA concrete, with an emphasis on its structural performance. Their study compared compressive strength, tensile strength, static modulus of elasticity, and workability in RCA concrete to normal mixes. According to the findings, increasing RCA concentration increases porosity, resulting in decreased strength and durability; however, surface treatments and optimum mix designs can counteract these impacts. The study confirms RCA's potential for sustainable building, assuming adequate aggregate processing and mix adjustments are applied.

(UPV). Enhanced mechanical performance by sniffing the ITZ. A assessment of RCA, covering everything from microstructure to structural performance, was published by Le and Bui (2020). Information from 170 papers was compiled in their analysis, with a focus on important findings about recycling practices, mix proportioning, mechanical properties, durability, and fire resistance. Their goal was to produce low-carbon RAC while maintaining the right amount of strength and durability. The macro- and micro-properties of multi-recycled aggregate concrete (MRAC) were examined by Thomas et al. (2020), who concentrated on the effects of consecutive recycling cycles on mortar content, aggregate dispersion, and porosity. The study measured the volume of cement paste, closed porosity, and limestone aggregate fraction in first, second, and third-generation recycled concrete using computerized microtomography (μ CT). According to their findings, the carbonation treatment the apparent density is increased by 4.8% and 3.2%, while for 5–10 mm RCA decreases the water absorption by 30% and for 10– 20 mm RCA is 22%. Jalilifar and Sajedi (2021) investigated the microstructure of 100% recycled concrete (RC) with recycled coarse concrete aggregates (RCA) using scanning electron microscopy. They found that an increase in RCA content results in increased porosity and microcracks in the interfacial transition zone (ITZ) and hydration products. On the other hand, adding 10% silica fume (SF) significantly reduced holes and thickened the ITZ, improving mechanical performance..

The mechanical and durability properties of fully recycled aggregate concrete (FRAC) containing carbonated recycled fine aggregates (CRFA) were thoroughly investigated experimentally by Jean et al. (2024). Their research aimed to overcome the limitations of untreated recycled fine aggregates to enhance performance in freeze-thaw and chloride-exposed environments.

The strength and durability of recycled aggregate concrete (RAC) with hydrated lime and brick powder (HBr) were examined by Abu Bakr and Singh (2024) study examined compressive strength, water permeability, chloride penetration, and ultrasonic pulse velocity The main focus of RCA research is depicted in Figure 1.

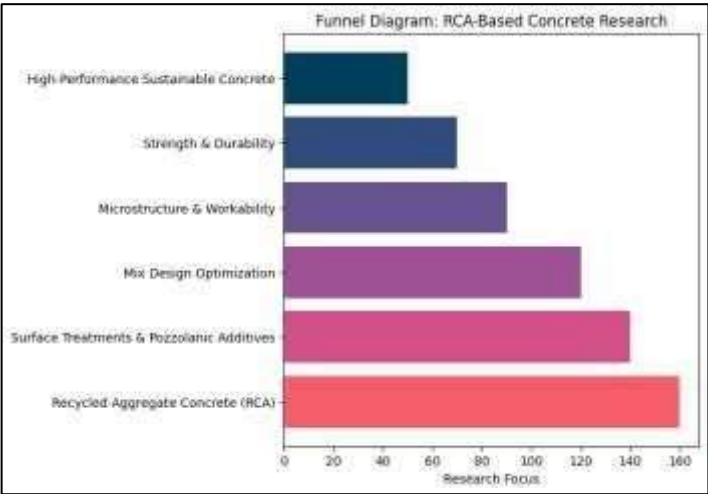


Figure 1

2. Materials and Methodology

In order to obtain the desired goal experimental and Laboratory approach was made on concrete used in this study. Figure 2 shows that various laboratory approaches taken during the study.



Figure 2

2.1 Materials Used

A constant content of cement was kept and RCA at 0%, 20%, 22.5%, 27.5%, 30%, 40%, 50%, 60%. Partially replaced by NCA. Figure 3 shows the various materials used during the experiment.



Figure 3

Cement: 43 Grade OPC which complies with IS 8112:2013 requirements, was utilized in this experimental investigation. The cement was lump-free, fresh, and dry. Two varieties of coarse aggregates were used: recycled coarse aggregates (RCA) from different demolished concrete structures and natural crushed angular aggregates of 20 mm size. To limit the particle size to ≤ 20 mm, the RCA was manually graded.

Fine Aggregates: The fine aggregate used was crushed stone dust, which is clean, well-graded, and classified as Zone II by IS 383:2016.

Coarse Aggregates: NCA and RCA before designing a combination, the physical characteristics of aggregates are evaluated. Natural aggregate, and RCA, are found to have respective temperatures of 21.9°C, and 24.5°C. In accordance with IS 2386 (Part III):1963, water absorption is found to be 1% for natural aggregates, and 5.14% for RCA, Natural aggregates had a 2.71 specific gravity of RCA, and had 2.34 specific gravity. According to the oven-dry method, the moisture content of natural aggregates is 0.78%, and that of RCA was 3.5%. The mechanical characteristics of coarse aggregates are also investigated. According to IS 2386 (Part IV):1963, the crushing values are 18.90% and 24.17%, respectively, whereas the aggregate impact values are 15% for natural aggregates and 17.5% for RCA.

Water: Potable fresh water, ordinary tap water is utilized as the mixing water. To determine its acceptability, a digital pH meter and a TDS meter were used to measure the pH and TDS. The findings showed that the pH is 8.4 and the TDS is 148 mg/L, respectively.

Admixtures: Plasticizers for workability improvement Master Glenium SKY B8777, a high-performance super plasticizer is applied to concrete mixtures to increase their workability & the specific gravity was 1.10.

2.3 Mix Proportions

Mix design of M35 Grade targeted for higher strength with better performance while incorporating sustainable materials. A formulation of mix combinations with % replacement of RCA Concrete mixes were prepared with varying RCA percent replacement (0%, 10%, 20%, 22.5%, 25%, 27.5%, 30%, 40%, 50%, and 60%) mentioned in Table 1 were formulated to evaluate the effect of RCA on fresh and hardened properties of concrete compared with nominal mix concrete.

Table:1 Mix Proportion of various mixes

Nomenclature	RCA (%)	Cement (Kg/m ³)	RCA (Kg/m ³)	Coarse aggregate (Kg/m ³)	Fine aggregate (Kg/m ³)	Water (Kg/m ³)	Admixture (Kg/m ³)	Water cement ratio
RC1	10	375	124.30	1118.70	691	150	3.75	0.40
RC2	20	375	248.60	994.40	691	150	3.75	0.40
RC3	22.50	375	279.67	963.40	691	150	3.75	0.40
RC4	25	375	310.75	933	691	150	3.75	0.40
RC5	27.50	375	341.82	901.20	691	150	3.75	0.40
RC6	30	375	372.90	870.10	691	150	3.75	0.40
RC7	40	375	497.20	745.80	691	150	3.75	0.40
RC8	50	375	621.50	621.50	691	150	3.75	0.40
RC9	60	375	745.80	497.20	691	150	3.75	0.40

2.4 Experimental investigation

2.4.1 Standard specimens were tested for: Fresh Concrete Tests

Various experimental processes by specified in IS code (IS 1199:1959), has done for finding the performance of fresh properties of all mix series. Slump, Compaction Factor, Vee-Bee Consistency, Air Content & Density.

2.4.2 Slump test: For field test measuring of consistency and workability for fresh concrete slump is widely used. identify the ease by which concrete flows and for specific condition for suitability of placing.

2.4.3 Compaction Factor: Especially used for low workable concrete mixes where slump test is

not suitable. for under a standard effort compaction factor provides more precise workability for for desired degree of compaction.

2.4.4 Vee-Bee Consistency: Especially used for very stiff concrete where slump test cannot access accurate workability.

2.4.5 Air content: In fresh mix concrete air voids are measured. Excess air entrainment effects the strength but in international aspects improves durability in cold climate under freeze and thaw condition. In this work Pressure method which is best suitable for normal weight concrete used for finding the air content values as per IS 1199 Part 2:2018 – Section 4.

2.4.6 Density: It is a necessary property of concrete for quality control. Calculation of mix proportion, air content cement factor can accesses by the help and also able to identify the segregation or improper batching. Expressed in kg/m^3 of mass per unit volume.

Figure 4 shows the relation between doses of RCA in Concrete and the fresh properties of concrete

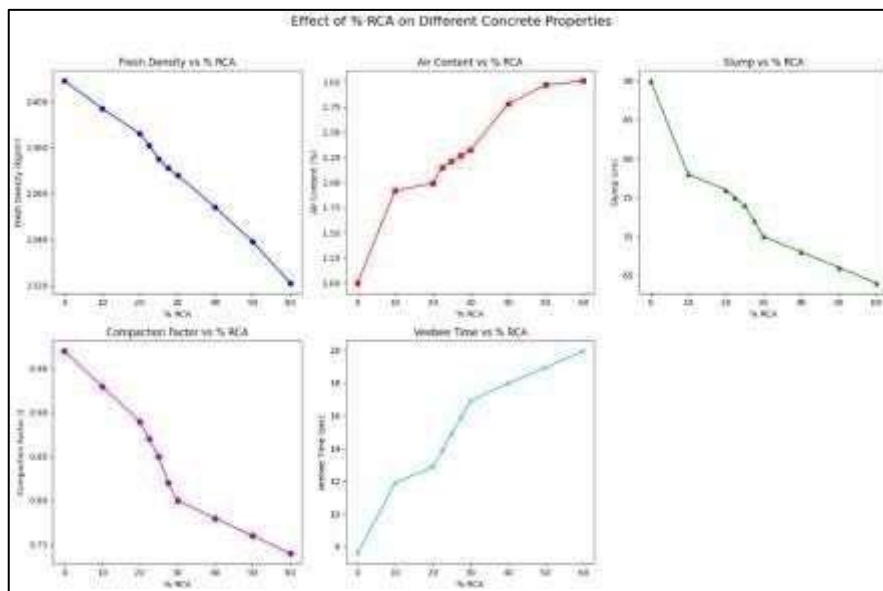


Figure4

2.5 Hardened Concrete Tests

Following test are covered for functioning and strengthen quality of mix series as governing the provision of IS Code. Compressive Strength (7, 28 days – IS 516), Split Tensile Strength (IS 5816), Flexural Strength (IS 516), Rebound Hammer

(with and without 10 kN load – IS 13311 Part2), Ultrasonic Pulse Velocity (UPV – IS 13311 Part 1).

2.5.1 Compressive Strength: Basic and most common test for load bearing capacity of harden concrete for compressive strength it identifies the axial load without resistance of failure. it seems to be necessary for axial design and overall quality control by visual identification. for axial design and quality control it is very crucial without failure resisting the axial load which can be identified by the compressive strength and indicates the overall qualities. 140 no of cubes of size (150mmX150mmX150mm) are casted for obtaining the compressive strength of concrete. Method of tests for compressive strength of Concrete is strictly followed as per (IS 516:1959).

2.5.2 Split Tensile Strength: It is an indirect method for access the direct tensile strength of concrete as per IS516 (Part1/Section-1)2021140 number of cubes of size (150mmX150mmX150mm)are casted for obtaining the splittensile strength. Due to weak in tension its very crucial to find the accuracy in direct tension. This test is widely used for identifying the tensile behavior of concrete.

2.5.3 Flexural Tensile Strength: Very commonly known as modulus of rupture and access the ability of concrete to resist failure during bending. due to bending tensile stress dominates in slab & pavement. The method of testing is strictly followed as per IS516 (Part1/sec1)2021 84 no of beams size (100mmX500mmX100mm) used to determine the flexural strength of mixes.

2.5.4 Rebound Hammer

Indian Standard Code IS 13311(part2):1992 impart for Non destructive Testing of Concrete and it is needed to correlate the rebound values with compressive strength. It is used to evaluate the concrete surface hardness and compressive strength. The rebound valuemeasured against the surface of concreteby the help of hammer loaded with spring.For the variation of quality and uniformity Rebound hammer is very effective and easy for user. Two types of rebound values are illustrated on the sample of 140 cubes before placing for compression testing machinebecause of rebound values obtain from different level without load and under load of dipper level.In realistic the concrete faces both surface stress as well

as dipper core stress. Different rebound value can provide the real scenario of void cracks or weaker bonding with aggregate. Rebound value without load provides curing quality and hardness of surface level. Rebound value with 10 kN load illustrate the condition of dipper core strength and structural stress.

2.5.5 UPV

The Indian Standard IS 13311(part1):1992 recommended the concrete characteristics based on pulse velocity illustrated the uniformity, integrity and quality of concrete by travelling time of ultrasonic wave velocity throughout the material. UPV testing done on the same 140 cubes before compression testing and rebound hammer testing. Results are correlated with compressive.

The figure 5 shows that the effect on mechanical properties of concrete by addition of various doses of RCA.

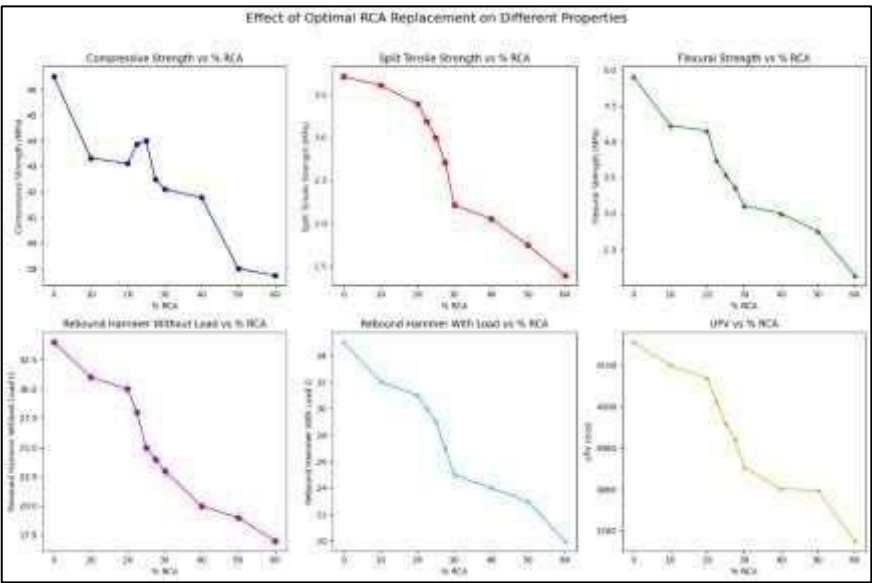


Figure 5

4. Conclusion

1. As the RCA percentage grows, fresh characteristics become less workable, necessitating changes in mix design to account for water absorption.

2. Hardened characteristics gradually diminish, especially in tensile and flexural strength. However, an ideal replacement of 22.5-25% RCA provides balanced mechanical performance. an appropriate RCA replacement range of 22.5%-25% in concrete mixes.
3. This range provides adequate mechanical strength, durability, and sustainability. Beyond 30% RCA replacement reduces strength because to increased porosity and weaker interfacial transition zones.
4. Optimizing RCA content is critical for structural applications, since higher RCA levels result in weaker integrity (UPV and Rebound Hammer values).
5. As a result, an RCA content of 22.5%-25% is recommended for high-performance concrete that promotes eco-friendly building.

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