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Strength and Quality Assessment of Concrete with Recycled Coarse Aggregate As Partial Replacement of Coarse Aggregate

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Abstract

The continuous demand for concrete places substantial strain on natural aggregate resources and simultaneously generates vast quantities of construction waste. Addressing these challenges, In this study, the practical application of recycled coarse aggregate (RCA), derived from concrete debris, as a partial replacement for natural coarse aggregate (NCA) in new concrete. Multiple concrete mixes were prepared, incorporating varying proportions of RCA. To ensure optimal workability, a super plasticizer was added to all formulations. These concretes were then extensively tested for their compressive, split tensile and flexural strengths at different curing periods. Furthermore, the internal quality of the concrete was assessed using a non-destructive method. Our findings demonstrate the influence of RCA content on concrete's performance properties, offering valuable insights for developing more sustainable construction materials.

Keywords: RCA, Mechanical properties, UPV, Super plasticizer, Sustainable concrete

Introduction

Concrete is used everywhere in modern construction, but its production puts a heavy strain on natural resources especially coarse aggregates [18-27]. As cities grow, this demand keeps rising, while waste from old buildings and structures piles up. Most of this debris goes to landfills, but it can actually be reused in new concrete. Recycled coarse aggregates (RCA) offer a way to ease both the resource crisis and the waste problem. This study explores how partial replacement of natural aggregates with RCA affects the strength and quality of concrete. Zega & Di Maio (2011) [1] highlighted that the origin and type of parent concrete significantly affect the mechanical properties of RCA-based concrete. Ajdukiewicz & Kliszczewicz (2002) [2] observed that high-performance concrete incorporating RCA exhibited only slight strength reductions, remaining within acceptable structural margins. Malesev et al. (2010) [3] confirmed that RCA can be successfully used in structural concrete, provided that the replacement levels are optimized and the material is clean. Rahal (2007) [4] found that while compressive strength decreased slightly with RCA use, tensile and flexural strengths were less affected, especially at lower replacement ratios. Amnon Katz (2003) [5] showed that using RCA from partially hydrated concrete resulted in slightly lower strength, but the mixes retained good long-term performance characteristics. Silva et al. (2017) [6] reviewed extensive research and found that RCA typically causes less than 15% strength loss, especially when water-cement ratios are properly controlled. Nachimuthu B. et al. (2024) [7] examined the mechanical properties of concrete using 25% and 50% RCA replacement and incorporated PCE-type superplasticizer. Corinaldesi (2010) [8] demonstrated that RCA concrete retained comparable elasticity and strength when mixed with high-performance cement binders. Evangelista & de Brito (2007) [9] pointed out that using fine RCA can lead to more pronounced strength reductions than coarse RCA, making coarse fractions more suitable for structural use. Fathifazl et al. (2009) [10] proposed a mix design method that adjusts for the adhered mortar in RCA, helping align strength outcomes with those of conventional concrete. Ann et al. (2008) [11] reported that incorporating pozzolanic materials such as fly ash improved the resistance of RCA concrete to chloride ingress and enhanced its durability. Olorunsogo & Padayachee (2002) [12] found that although RCA concrete showed reduced durability indices, using supplementary cementitious materials helped mitigate these effects. Ismail & Ramli (2017) [13] demonstrated that surface-treating RCA improved both the compressive strength and water resistance of the concrete. K.K. Sagoe-Crentsil et.al. (2021) [14], stated that the mechanical quality of RCA is lower than that of NCA due to the presence of old mortor and impurities. Tam et al. (2005) [15] introduced a two-stage mixing approach that enhanced the interfacial transition zone (ITZ) between old and new paste in RCA concrete, improving microstructural integrity. Medina et al. (2014) [16] warned that RCA containing brick or ceramic fragments (i.e., mixed recycled aggregates) showed weaker performance than pure concrete-based RCA. Thomas et al. (2013) [17] concluded that despite lower long-term durability compared to conventional concrete, RCA mixes can meet service-life requirements with proper mix adjustments.

2. Materials and mix proportions

2.1 Physical properties of the materials

The materials used in this study include Ordinary Portland Cement (OPC) with a specific gravity of 3.15 and density of 1.55 kg/cm³, along with fly ash having a specific gravity of 2.15. Natural sand conforming to Zone-II grading as per IS 383-1970 was used as fine aggregate, with a specific gravity of 2.37. For coarse aggregates, both natural coarse aggregate (NCA) and recycled coarse aggregate (RCA) were employed, with particle sizes ranging from 10 mm to 20 mm. The NCA had an aggregate impact value of 15.74%, specific gravity of 2.8, bulk density of 1.46 g/cm³, and fineness modulus of 7.3, while RCA showed an aggregate impact value of 15.56%, specific gravity of 2.7, bulk density of 1.42 g/cm³, and fineness modulus of 7.238. Water absorption for NCA and RCA was 1.27% and 3.36%, respectively, indicating higher porosity in RCA. To enhance the workability of concrete mixes containing recycled aggregates, a polycarboxylate ether (PCE)-based superplasticizer was added at an optimized dosage to maintain desired slump and flow without compromising mechanical properties.

Figure.1 Coarse aggregates for the study (a) NCA,(b) RCA

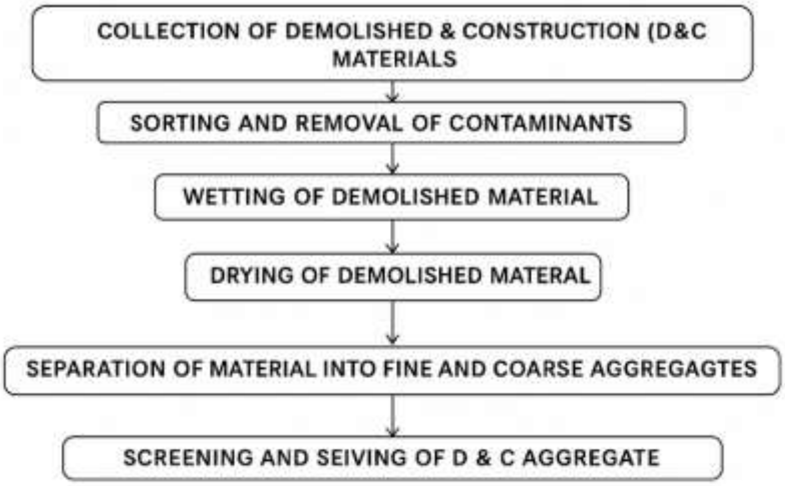

Figure: 2.Recycling process of the demolished & construction aggregate.

2.2 Mix proportions

Mix design was prepared in the ratio of 1:1.44:2.40 as per IS 10262:2019. Natural coarse aggregates were replaced with the 0%RCAis taken as mix1, replacement of NCA with RCA of 12.5% is taken as mix2, replacement of NCA with RCA of 25% taken as Mix3 and mix containing NCA-50% , RCA-50% taken as Mix4.To counter the higher water absorption rate in RCA, 1%superplasticizer by weight of cement is used.10% of is used Fly ash to the weight of cement.

Table 1. Details of the composition of mixes designed as per Kg/Cu.m

Sl.No	Mix id	C	Fly ash	FA	20 mm	12 mm	W	S.P
1	RA0%	355.5	39.5	645.7	748.33	498.89	169.85	3.95
2	RA12.5%	355.5	39.5	645.7	654.78	436.52	169.85	3.95
3	RA25%	355.5	39.5	645.7	561.24	374.16	169.85	3.95
4	RA50%	355.5	39.5	645.7	374.16	249.44	169.85	3.95

3. Casting and curing of concrete

All materials were maintained at ambient room temperature prior to use. Before casting, the inner surfaces of the moulds were thoroughly cleaned and uniformly coated with oil to prevent adhesion and ensure smooth demoulding. Aggregates, cementitious binders, water, and the superplasticizer were measured and thoroughly combined in a pan mixer, as per IS 12119:1987, with a total mixing duration of approximately 7 to 10 minutes to achieve a homogeneous blend. Fresh concrete from each mix was poured into respective moulds in layers. Each layer was compacted using vibration to eliminate entrapped air and achieve uniform compaction. The excess concrete was then leveled off to ensure even surfaces. After casting, the moulded specimens were left undisturbed at room temperature for 24 hours for initial setting. Subsequently, the demoulded samples were placed in a curing tank containing clean water and maintained under standard curing conditions for specified durations of 7 and 28 days.After completion of the respective curing periods, the hardened concrete specimens were subjected to a series of mechanical and non-destructive tests to evaluate their compressive strength, split tensile strength, flexural strength, and ultrasonic pulse velocity (UPV).

4. Results and discussions

To evaluate the effect of recycled coarse aggregate (RCA) on compressive strength (CMS), 100mm concrete cubes were tested at 7 and 28 days. From Fig-3a, the results clearly demonstrate that 12.5% RCA replacement (RA12.5%) consistently outperformed the other mixes. At 7 days, RA12.5% achieved 21 MPa, which is 31.25% higher than the control mix (RA0%) at 16 MPa. At 28 days, the strength increased to 35.5 MPa, which is 16.4% more than the control's 30.5 MPa. This improvement could be attributed to the internal curing effect and enhanced particle packing at lower RCA content. However, when RCA content was increased to 25% and 50%, the compressive strength decreased significantly. RA25% recorded 20 MPa at 7 days (a 4.8% drop from RA12.5%) and 33.5 MPa at 28 days (a 5.6% decrease from RA12.5%). RA50%, with 11 MPa at 7 days and 22 MPa at 28 days, showed the steepest decline—47.6% and 38% lower, respectively, than RA12.5%. These results clearly suggest that while a small RCA addition enhances early and later strength, higher percentages reduce concrete performance due to increased porosity and weak interfacial bonding.

The split tensile strength (STS) results at 28 days also followed a similar trend (Fig- 3b). The highest value was observed for RA25% at 2.35 MPa, slightly exceeding both the control (RA0% at 2.16 MPa) and RA12.5% (2.03 MPa). This indicates that a moderate amount of RCA might not adversely affect tensile strength and, in some cases, may enhance it due to improved stress distribution. However, RA50% showed a reduction to 2.04 MPa, which is nearly the same as RA12.5% but 13.2% lower than RA25%. These fluctuations indicate that RCA's influence on tensile strength is non-linear and could depend on particle quality and bonding efficiency in the matrix

Flexural strength (FTS) was measured at 28 days to evaluate bending resistance (Fig-3c). The mix with 12.5% RCA (3.70 MPa) exhibited the highest flexural strength, showing an increase of 24.2% over the control mix (RA0% at 2.98 MPa). This suggests that limited RCA inclusion can enhance concrete ductility and crack resistance. With increased RCA content, performance declined: RA25% had 3.33 MPa (a 10% decrease from RA12.5%), while RA50% dropped to 3.00 MPa, a 19% reduction compared to RA12.5%. These results align with expectations that excessive RCA may disrupt load transfer mechanisms due to weaker old ITZ (interfacial transition zones).

The Ultrasonic Pulse Velocity (UPV) results, shown in Fig-3d, reflect the internal quality and density of concrete mixes with varying RCA content. At 7 days, the mix with 12.5% RCA (RA12.5%) achieved the highest velocity at 4950 m/s, which is 12.1% higher than the control mix (RA0%) at 4415 m/s. At 28 days, RA12.5% again led with 5190 m/s, showing a 5.5% increase over the control's 4920 m/s. However, as the RCA content increased beyond 12.5%, UPV values declined. RA25% recorded 4367 m/s at 7 days and 5105 m/s at 28 days, while RA50% showed the lowest velocities of 4202 m/s and 5051 m/s, respectively. Compared to RA12.5%, RA50% showed reductions of 15.1% (7 days) and 2.7% (28 days). Despite the downward trend at higher RCA levels, all values remained above 4000 m/s, indicating that internal concrete quality remained acceptable across all mixes. These results suggest that 12.5% RCA enhances internal compactness, while higher percentages gradually compromise it due to increased porosity and weaker bonding.

Table.2 Test results

Mix Id	Compressive strength , MPa		Split tensile strength, Mpa	Flexure strength, Mpa	UPV, m/s	
	7 Days	28 days	28 Days	28 days	7 days	28 days
RA0%	16	30.50	2.16	2.98	4415	4920
RA12.5%	21	35.50	2.03	3.70	4950	5190
RA25%	20	33.50	2.35	3.33	4367	5105
RA50%	11	22.00	2.04	3.00	4202	5051

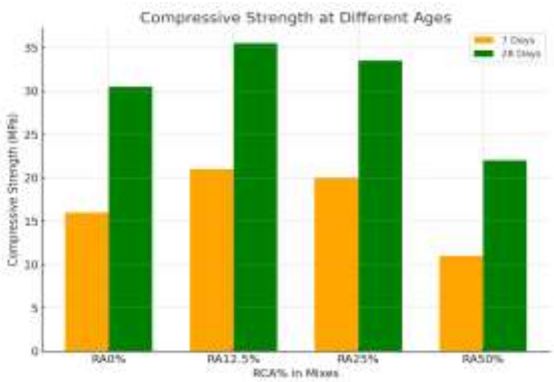

Fig-3a

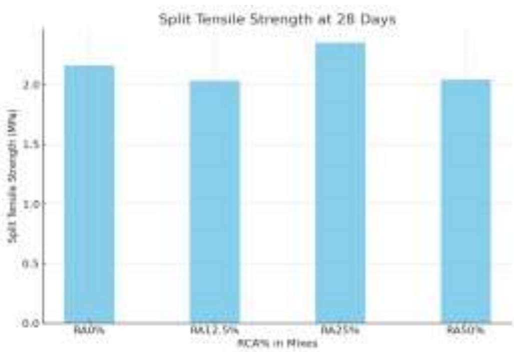

Fig-3b

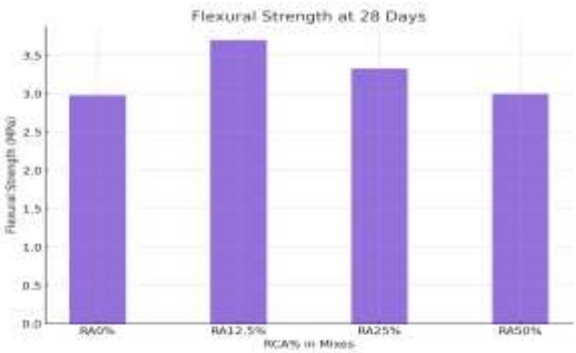

Fig-3c

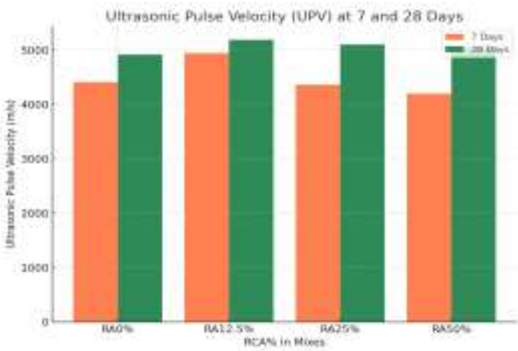

Fig-3d

Figure.3. Mechanical properties of mixes: (a) CMS, (b) STS, (C) FTS, (d) UPV

5. Conclusions

This experimental investigation was carried out to study the influence of varying percentages of recycled coarse aggregates (RCA) on the mechanical and durability-related properties of concrete. The replacement levels considered were 0%, 12.5%, 25%, and 50%, and the behavior of each mix was evaluated through compressive strength, split tensile strength, flexural strength, and ultrasonic pulse velocity (UPV) at different curing periods.

The compressive strength of concrete improved significantly when 12.5% of natural aggregates were replaced with RCA. This mix outperformed all others, including the control mix, at both early and later curing ages. The improvement suggests that a small quantity of RCA can positively contribute to concrete's load-bearing capacity, possibly due to improved internal moisture retention. However, increasing RCA content beyond 12.5% led to a steady decline in compressive strength. Mixes with 25% and especially 50% RCA showed a marked reduction, indicating that higher quantities of recycled material weaken the compactness and strength development of concrete.

Split tensile strength results followed a similar trend to compressive strength. The 12.5% RCA mix showed performance close to the control mix, indicating that lower levels of RCA do not negatively impact tensile behavior. Interestingly, the 25% RCA mix produced the highest tensile strength in some cases, suggesting that moderate RCA content may help distribute stresses more effectively. However, the tensile strength dropped again at 50% replacement, which shows that higher RCA levels reduce the mix's ability to resist tension and control crack formation.

Flexural strength was highest for the 12.5% RCA mix, slightly exceeding the strength of the control mix. This suggests that concrete with a small amount of RCA has good bending resistance and can effectively resist flexural stresses. As RCA content increased, flexural strength steadily decreased. At 25% and 50% replacement, a significant reduction in bending capacity was observed. These results indicate that higher RCA content weakens the overall cohesiveness of the concrete under flexural loads.

UPV testing revealed that the 12.5% RCA mix had the highest pulse velocity values among all mixes, including the control. This indicates better internal quality and compactness. As RCA content increased to 25% and 50%, the UPV values declined, suggesting the presence of more voids and less uniform internal structure. However, all mixes recorded UPV values within acceptable limits, meaning that despite some reduction in density, the concrete remained structurally sound.

To expand upon these findings, future research should focus on long-term performance evaluation of RCA-based concrete under varied environmental conditions such as freeze-thaw exposure, sulfate attack, and carbonation. Additionally, advanced treatments or beneficiation methods for RCA (such as surface coating, thermal treatment, or pre-saturation) may help mitigate performance losses at higher replacement levels. Further exploration into the combined use of RCA with supplementary cementitious materials (SCMs) like fly ash, silica fume, or GGBS could also enhance durability and broaden the applicability of recycled aggregates in high-performance concrete.

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