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Mechanical and Durability Assessment of Concrete with partial and full replacement of coarse aggregate from C&D waste

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Abstract : The escalating volume of construction and demolition (C&D) waste globally presents critical environmental and logistical challenges. Concurrently, the construction sector's heavy reliance on Natural Coarse Aggregate (NCA) leads to the depletion of natural reserves. In response, this thesis, titled "Towards Sustainable Construction: Mechanical and Durability Assessment of Concrete with Partial and Full Replacement of Coarse Aggregate from C&D Waste," investigates the feasibility of integrating Recycled Coarse Aggregate (RCA) derived from C&D waste as a sustainable alternative. The study systematically assesses the mechanical behaviour, durability characteristics, and overall performance of concrete incorporating RCA at replacement levels of 0% (control), 20%, 40%, 60%, 80%, and 100% by weight, using an M30 grade mix design. The results showed that concrete performance was adversely impacted by RCA's intrinsic characteristics, particularly its increased porosity and adhering mortar. Because RCA absorbed mixing water and lowered the amount of free water available for lubrication, workability steadily declined as RCA concentration increased. All mechanical strength decreased as replacement increased, with the 28-day compressive strength for the 100% RCA mix falling from 38.5 MPa to 27.2 MPa, a 29.4% decrease from the control mix. Because of higher permeability and a poorer Interfacial Transition Zone (ITZ), durability worsened proportionately to RCA concentration; water absorption rose by 92.8% in the 100% RCA combination, and resistance to freeze-thaw and acid attack dramatically decreased.
Keywords: RCA, NCA, C&D, Durability, ITZ, Compressive strength.

I. Introduction

The rapid pace of urbanization and infrastructure development has significantly increased the generation of construction and demolition (C&D) waste, posing substantial environmental, economic, and logistical challenges worldwide. Conventional disposal practices not only exhaust valuable land resources but also contribute to pollution and ecological degradation. At the same time, the construction sector continues to rely heavily on natural aggregates, the extraction of which leads to depletion of natural reserves, habitat disruption, and an elevated carbon footprint. In response, the use of recycled aggregates derived from C&D waste has emerged as a promising strategy to promote circular economy principles and reduce environmental impacts. This thesis, titled "Towards Sustainable Construction: Mechanical and Durability Assessment of Concrete with Partial and Full Replacement of Coarse Aggregate from C&D Waste," investigates the feasibility of integrating recycled coarse aggregates into concrete as a sustainable alternative to conventional aggregates. The study critically examines the mechanical behavior, durability characteristics, and overall performance of concrete incorporating varying levels of C&D waste, thereby providing insights into its potential for structural and non-structural applications. By evaluating both partial and full replacement scenarios, the research aims to advance sustainable construction practices, mitigate waste generation, and support the transition toward environmentally responsible material utilization in the construction industry. In recent decades, construction technology and building materials have undergone significant advancements. The emergence of high-performance materials, blended cement, and supplementary cementitious components has transformed the design and construction of structures. Innovations in concrete durability, along with enhanced reinforcing materials such as fiber-reinforced steel, have enabled the creation of thinner and more efficient structural elements.

The building sector uses a lot of natural resources and is a major contributor to environmental deterioration and carbon emissions worldwide. Construction and demolition (C&D) waste creation has expanded concurrently with rising urbanization, posing problems for waste management, resource depletion, and landfill scarcity. A sustainable way to lessen the environmental impact of building operations is through the use of recycled coarse aggregate (RCA), which is made from processed construction and demolition debris.

However, RCA's efficacy in concrete is affected by adherent mortar, increased porosity, and microcracks. The mechanical and durability behavior of M30 grade concrete with RCA at different replacement levels is examined in this study. The goal of the study is to determine the ideal replacement percentages that strike a compromise between structural performance and sustainability.

II. LITERATURE REVIEW Numerous international research show that RCA's intrinsic qualities impact the properties of concrete. Researchers like Silva et al. and Poon et al. discovered that RCA decreases mechanical strength and increases water absorption. According to Kou & Poon, RCA concrete is less durable when exposed to harsh environments. Nonetheless, a number of studies attest to the viability of employing up to 40% RCA without appreciably impairing structural performance. The research emphasizes the necessity of a methodical assessment across various exposure situations and RCA percentages.

Yousaf M al (2025) The mechanical performance of reinforced concrete (RC) beams using recycled brick aggregates (RBA) as a sustainable substitute for natural aggregates (NA) is assessed in this study. Four concrete mixes were tested: two hybrid mixes of fine and coarse aggregates, 100% NA, and 100% RBA. While beams incorporating coarse brick aggregates showed a more pronounced reduction in shear strength, with values dropping to 53.0 kN, the highest shear strength (71 kN) was observed in mixes using brick fine aggregates and natural coarse aggregates, nearly matching the 70.8 kN of the 100 % NA mix. In contrast to NA mixes, 100% RBA mixes showed a 16% decrease in MOR and a 24% decrease in compressive strength.

S. Tejas P. Dinakar (2024) The carbon footprint that the cement production process leaves on the environment is decreased by using higher percentages of industrial by-products. Additionally, recycled aggregates or recycled concrete coarse aggregates are being utilized as an alternative to natural aggregates due to the fast-increasing demand for natural aggregates. However, research on the use of 100% recycled concrete aggregates and composite cement (fly ash and slag as blending components) is lacking. The current investigation concludes that, for reducing w/c from 0.7 to 0.3, the created concrete made of 100% RCA and composite cement displays compressive strength between 25 MPa and 60 MPa. Additionally, a well-designed mix with thick aggregate grading guarantees that this concrete meets all durability criteria and exhibits very little carbonation.

P Anand et al.(2023) The creation of aerated concrete (AC) blocks is thoroughly examined in this work, with an emphasis on how different binders and additives affect the blocks' mechanical and durability characteristics. Flyash (FA), glass powder (GLP), and ground granulated blast furnace slag (GGBS) are the binders. Additionally, in the absence of aluminum powder, individual binders such as cement, lime, gypsum powder, FA, GLP, and GGBS were utilized. Alternatively, the alkaline solution used in the design of AC blocks was made by combining Na_2SiO_3 and NaOH at a ratio of (Na_2SiO_3/NaOH = 1.5). Heat curing was carried out using an accelerated curing tank. In separate batches, 50% construction and demolition waste (C&D) waste was substituted for FA or GLP and GGBS.

S. V Devi et al. (2021) These days, sustainability is a major problem since we utilize a lot of natural resources to make things like concrete. We must effectively handle the growing demand for aggregates and the depletion of natural resources. However, construction and demolition (C&D) trash, which makes up over 30% of India's solid waste stream, is neglected and loses its potential for recycling. This study, which includes a number of aggregate tests to compare Recycled Aggregate (RA) and Natural Aggregate (NA), presented the most significant research findings over the previous several years about the material features of recycled aggregate. Fresh and cured concrete that was partially replaced with recovered concrete aggregate waste from lab-tested concrete samples was the subject of an experimental program.

Rui Vasco Silva (2014) The paper investigates the factors influencing the physical, chemical, mechanical, permeation, and compositional properties of recycled aggregates sourced from construction and demolition waste intended for concrete production. It is based on a systematic, rather than narrative, literature review of 236 publications published over a period of 38 years from 1977 to 2014. Classifications according to their pollutants and composition have been researched. A performance-based categorization is suggested, primarily for usage in concrete building, after the data were statistically analyzed collectively. The findings made it possible to develop a useful method for evaluating the quality of recycled aggregates, which may be utilized to create concrete with consistent performance.

Ashraf M. Wagih (2013) This study explores the feasibility of using recycled concrete aggregate (RCA) in place of natural coarse aggregate (NA) in structural concrete. Eight groups of fifty different concrete mixtures were cast. Groups were created to investigate the effects of silica fume, cement dosage, superplasticizer usage, and the quality and content of recycled coarse aggregates. Compressive strength, splitting strength, and elastic modulus tests were performed. The findings demonstrated that the concrete debris may be recycled and utilized to make concrete with qualities appropriate for the majority of structural concrete applications in Egypt. When compared to natural aggregate concrete (NAC), the qualities of recycled aggregate concrete (RAC) composed of 100% RCA were significantly reduced, while the properties of RAC composed of a combination of 75% NA and 25% RCA did not significantly alter.

III. MATERIALS & METHODOLOGY The materials and experimental approach utilized to examine the mechanical and durability performance of M30 concrete using Recycled Coarse Aggregate (RCA) derived from Construction and Demolition (C&D) waste are described in this chapter. The approach was created to methodically assess concrete's performance at different RCA substitution levels for natural coarse aggregates.

3.1 Materials

3.1.1 Cement

Throughout the investigation, Portland Pozzolana Cement (PPC) that complies with IS 1489 (Part 1): 2015 was utilized.

Because fly ash may partially replace clinkers, PPC has better workability, long-term strength, increased durability, and environmental benefits. The cement demonstrated:

Table 1 Physical requirements of cement

S. NO	Experiment of the Cement	Results
1	Fineness (Specific Surface Area) Kg/m^2	320
2	Soundness (Le-Chatelier) mm	6
3	Specific Gravity	3.05
4	Initial Setting Time in minutes	29

Table 2 Physical requirements of FA

S. No.	Experiment of Natural Sand	Result
1	Specific gravity of the fine aggrega	2.64
2	Water absorption of fine aggrega	0.9
3	Fineness modulus	1.81
4	ılk density of fine aggregate Kg/cu	1650
5	Grading Zone	Zone II

3.1.2 Aggregate Fine

As fine aggregate, locally accessible river sand (Zone II) that complies with IS 383:2016 was utilized.

3.1.3 NCA, or natural coarse aggregate

The control aggregate was made of crushed stone aggregates with a nominal size of 20 mm that complied with IS 383:2016.

3.1.4 RCA, or recycled coarse aggregate

RCA came from crushed concrete debris found in processed construction and demolition (C&D) waste.

Following mechanical crushing and screening, natural aggregate was substituted with RCA in percentages of 20%, 40%, 60%, 80%, and 100% after passing through a 20 mm sieve. To adjust for excessive absorption, pre-soaking was done.

Table 3 Physical requirements of CA

S. No.	Characteristics	Value obtained
1	Specific gravity	2.78
2	Abrasion value (%)	21.4
3	Impact value (%)	16.7
4	Water absorption (%)	0.31
5	Crushing value (%)	16.7
6	Shape	Angular and rounded

3.1.5 Water

In accordance with IS 456:2000, clean drinkable water devoid of organic debris, oils, and salts was utilized for mixing and curing.

3.1.6 Superplasticizer

To improve workability, a Polycarboxylate Ether (PCE)-based superplasticizer (PC-200) was utilized, particularly for higher RCA mixtures where high porosity increases water consumption.

3.2 Proportions of Mix

Six distinct RCA replacement levels were used in the preparation of concrete mixes:

Table 4 Details the Material Quantities Per Cubic Meter

Samples	w/c Ratio	Cement Kg/m^3	Water Kg/m^3	FA Kg/m^3	NCA Kg/m^3	RCA Kg/m^3	Superplasticizers (%)
NCAC	0.45	427	192	684	1081	0	1.2
RCAC20	0.45	427	192	684	864.8	216.2	1.2
RCAC40	0.45	427	192	684	648.6	432.4	1.2
RCAC60	0.45	427	192	684	432.4	648.6	1.2
RCAC80	0.45	427	192	684	216.2	864.8	1.2
RCAC100	0.45	427	192	684	0	1081	1.2

According to IS 10262:2019, all mixes were created for M30 grade while keeping the water-to-cement ratio constant.

3.3 Methods of Experimentation-There are three parts to the methodology:

3.3.1 Material Preparation

RCA Procedures

- A jaw crusher was used to smash C&D trash.
- 20 mm aggregates were obtained by screening the materials.
- Foreign elements, dust, and wood fragments were carefully eliminated.
- Aggregates were cleaned and dried in an oven.
- To reduce the impact of excessive absorption, pre-soaking was carried out.

Batching-According to the mix design, each material was weighed (by mass). For RCA, moisture correction was used.

3.3.2 The Casting Process

Combining- Cement, fine aggregate, and coarse aggregate (NCA + RCA) are mixed dry. Water and superplasticizer are added gradually and mixing consistently until a homogenous mixture is achieved.

Casting

- Fresh concrete was poured into molds (cubes, cylinders, prisms).
- Compaction performed using a table vibrator.
- Surfaces were finished using a trowel.

Curing

- Specimens were demolded after 24 hours.
- All samples were water-cured for 7 or 28 days.

3.3.3 Methods of Testing

Tests of Fresh Concrete- carried out in accordance with IS 1199:1959:

1. The Slump Test
2. Test for Compaction Factor
3. Test for Flow Table

These experiments evaluated the changes in workability brought on by an increase in RCA content.

Mechanical Examinations-carried out in accordance with IS 516:1959

1. Compressive Strength Test (150 x 150 x 150 mm cube)
2. Split Tensile Strength Test (150 x 300 mm cylinder)
3. Test of Flexural Strength (beam: 100 x 100 x 500 mm)

Tests for Durability

1. Test of Water Absorption- determines the RCA concrete's pore structure and permeability.
2. Test for Freeze-Thaw- evaluates degradation during repeated freezing and thawing.
3. Test for Acid Resistance to assess the following, specimens were submerged in diluted sulfuric acid (H_2SO_4).

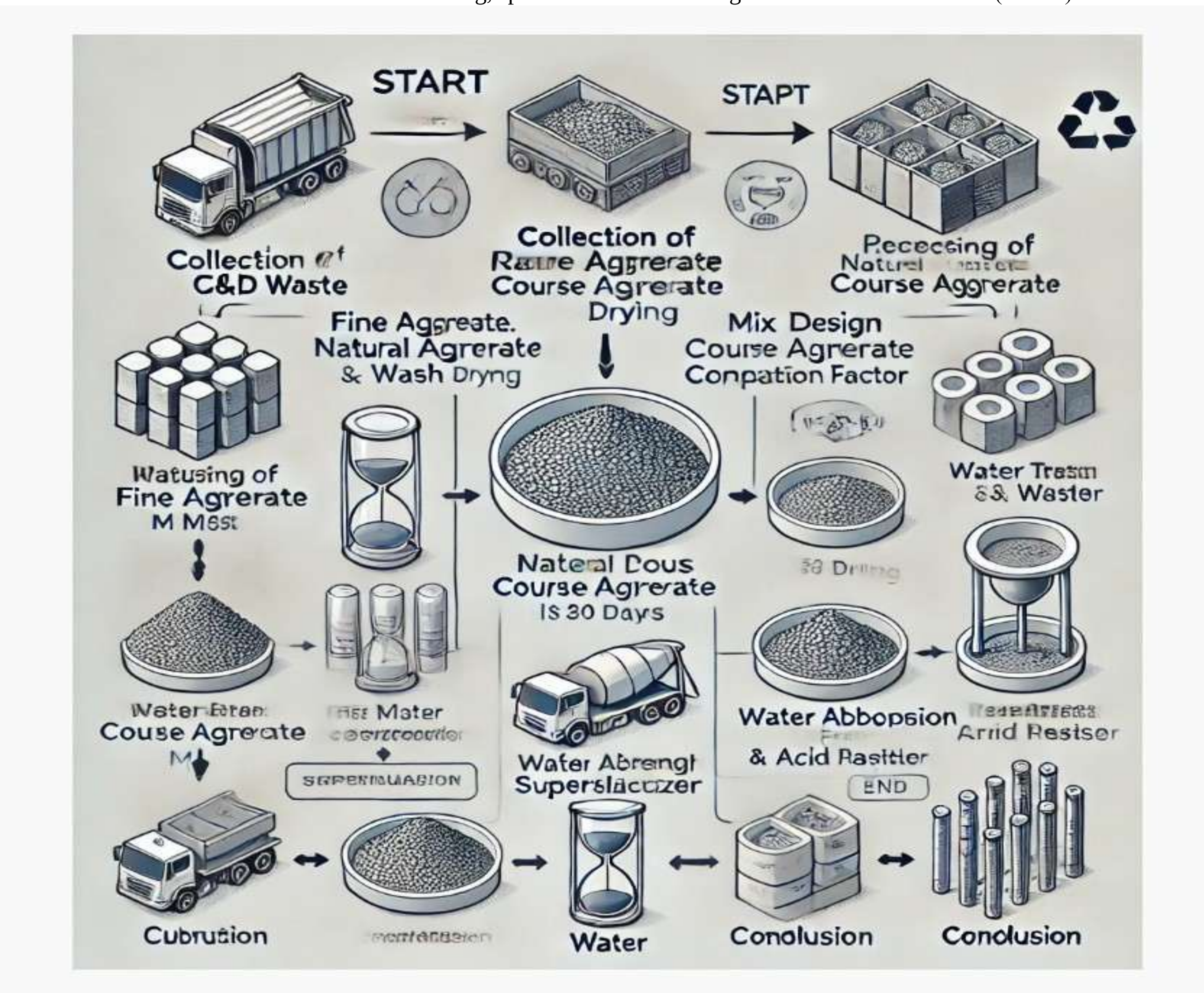

Fig. 1 Flow Chart of Methodology

IV. RESULTS AND DISCUSSION

Slump Test

- Greater water absorption of RCA: RCA is more porous than natural coarse aggregate (NCA) and contains leftover mortar. Slump-flow falls when RCA% rises because it absorbs mixing water, which reduces the amount of free water available for flow.
- Particle form and surface texture: Compared to rounded, smooth natural aggregate, RCA particles are frequently more angular and rougher, which increases internal friction in the mix and decreases flowability.

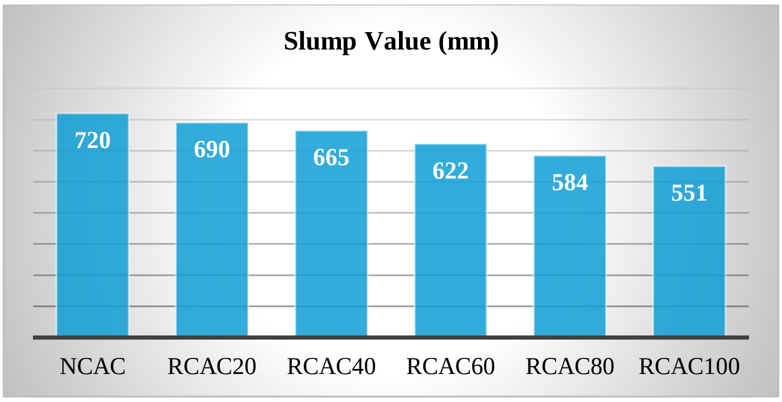

Fig. 2 Slump value test

- Fines and adhered mortar: In order to attain the same flow, RCA adds more fine material and attached mortar, which raises the paste demand (more binder/water or superplasticizer required).
- Heterogeneous RCA surfaces provide varying interfacial transition zones (ITZs), which can reduce spread diameter by lowering particle lubrication.
- Segregation and blocking tendency: The mix may become sticky at moderate or high RCA levels, which might decrease spread and raise the possibility of blockage in crowded environments.

Compaction Factor Test

- Increased water absorption of RCA: Compared to natural coarse aggregate (NCA), RCA is more porous and contains adherent mortar. RCA absorbs some of the mixing water, which lowers the amount of free water available for lubrication and, consequently, the CF.
- Rougher particle surface and angularity: RCA particles are generally rougher and more angular; higher inter-particle friction makes rearrangement under compaction more difficult, which lowers the compaction factor.
- Increased fines and adherent mortar: If the paste content is constant, the mix gets stiffer and compaction is more difficult. Additional fines from RCA raise the paste requirement for the same flowability.

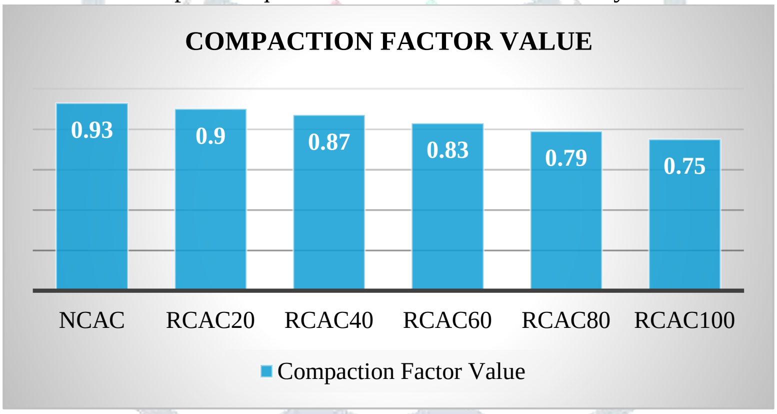

Fig. 3 Compaction factor test

- Reduced unit weight and bulkiness: RCA frequently has irregular forms and reduced particle density, which alter packing, creating more voids and reducing the effectiveness of mechanical compaction.
- Heterogeneous grading/ITZ variability: Particle sliding is lessened and consolidation is hampered by uneven surfaces and varied ITZ (new mortar-to-old mortar connections).
- Potentially increased internal friction and blocking: The mix may become sticky or prone to internal choking around reinforcement with greater RCA levels, which would further reduce CF.

Flow Table Test

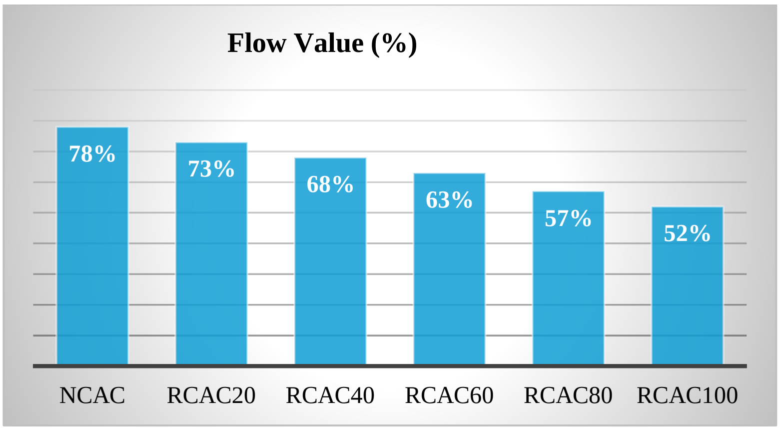

Fig. 4 Flow table test

- RCA's Water Absorption- Compared to natural coarse aggregate, RCA is more permeable because it includes attached old mortar. It reduces effective free water by absorbing some of the mixing water, which results in less spread during the flow test.
- Increased Adhered Mortar Fines Content- Micro fines and loose mortar are present in RCA. Because of the increased surface area caused by these extra particles, more paste is needed for lubricating. Concrete with less paste is harsher and less workable;
- As RCA% increases, flow percentage decreases.
- Poor Packing and Increased Heterogeneity- Increased RCA content Particle packing is disrupted by uneven particle shapes, which increase voids and internal resistance. Flow drastically drops after 60% RCA and mix gets harsh.
- The maximum flow value is seen in the control mix (0% RCA), indicating that natural aggregates offer superior workability. For workable concrete, mixes with 20–40% RCA stay within an acceptable performance range. Workability is noticeably reduced in mixes containing 60% or more, necessitating adjustments:

Compressive Test

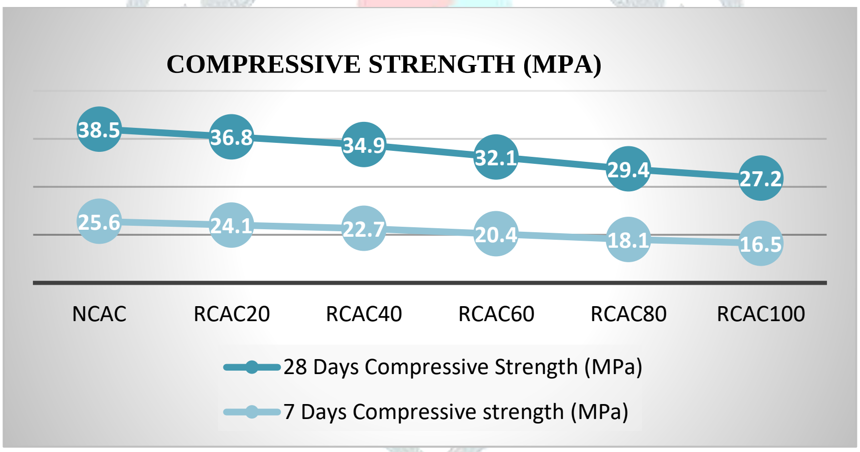

Fig. 5 Comparison of 7 days & 28 days Compressive Strength test

- The normal 7-day strength of M30 concrete (≈65–70% of 28-day strength) is demonstrated by the control mix (0% RCA).
- Because there is little microstructure disturbance, 20% RCA nevertheless has acceptable early strength. 40% RCA exhibits a moderate decrease because of reduced mortar adhesion and greater absorption.
- 60–100% RCA mixtures exhibit a notable decrease because RCA raises the effective w/c ratio by absorbing more water. Aggregate quality is decreased by a weak old mortar layer. ITZ gets increasingly microcracked and porous.
- Partial RCA replacement is possible without significant performance loss, as seen by the slight strength decreases seen in 20%–40% RCA mixes that nevertheless reach near-target levels.
- 60% and above exhibit steadily decreasing strengths, indicating the greater impact of porous RCA.
- The 100% RCA mix shows the biggest decrease because of the combined impacts of: poorly adhering mortar, poor mortar-aggregate bond, increased absorption of water and internal flaws.

Split Tensile Test

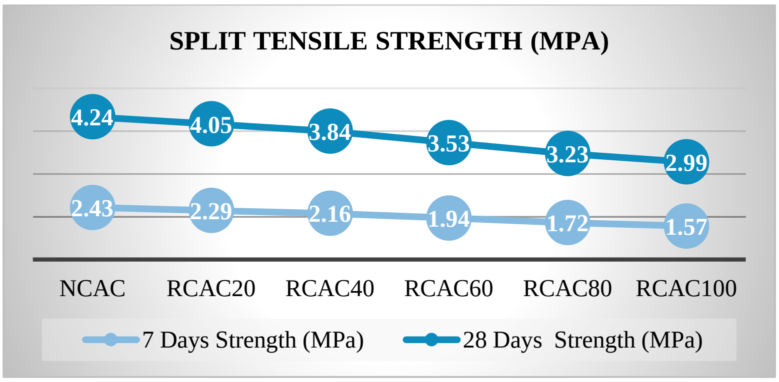

Fig. 6 Comparison of 7 days & 28 days split tensile strength test

- Overall trend: As RCA replacement rises, split tensile strength falls. This is in line with published research on RCA concrete and reflects the decrease in compressive strength.
- Weak adherent mortar: Old mortar used by RCA is porous and less durable than natural aggregate, resulting in weak areas that reduce tensile strength.
- Poorer ITZ (interfacial transition zone): Under tensile stress, fractures start and spread more easily because the link between the new cement matrix and RCA is often poorer than with natural aggregate.
- Increased porosity and microcracks: RCA's internal flaws and increased absorption cause the concrete to have more voids and crack-initiation sites, which lowers tensile resistance.
- Particle form and packing: Under tensile loading, irregular, angular RCA particles and inadequate packing raise stress concentrations and reduce split tensile values.
- Partial replacement (≤40%): With the right mix changes (e.g., SP dose, pre-soaking RCA), small reductions (≈<10%) are frequently acceptable for many non-critical structural applications.
- Higher replacements (≥60%): Greater decreases in tensile capacity necessitate design/mixture changes or prudence for elements (such as slabs and beams) where tensile performance or crack management is crucial.

Flexural Test

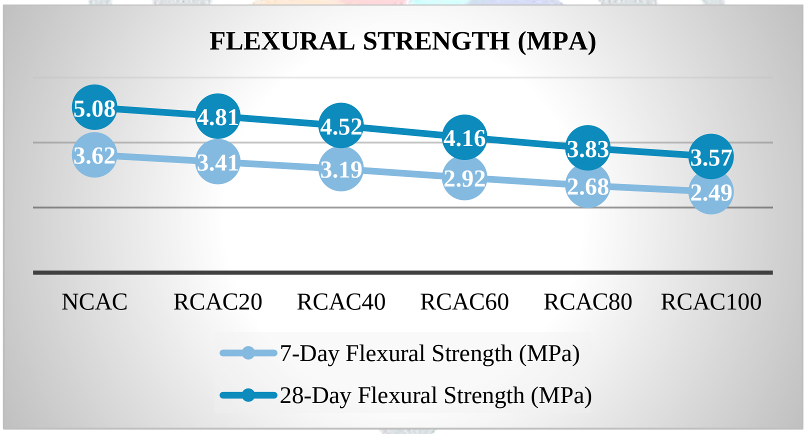

Fig.7 Comparison of 7 days & 28 days flexural strength test

As the percentage of RCA rises from 0% to 100%, the flexural strength data show a steady decline. The following variables account for this tendency, which is in line with previous studies on recycled aggregate concrete:

- Inadequately Adhered Mortar on RCA- Compared to natural aggregates, RCA contains leftover old mortar from earlier concrete projects, which is more porous and microcracked. This lowers the tensile and flexural load-carrying capacity, where the failure process is dominated by fracture initiation and propagation.
- Enhanced Absorption of Water- Because of its porous nature, RCA absorbs more water. Increased water absorption leads to a greater effective w/c ratio, weaker cement paste, and less flexural strength.
- Zone of Inferior Interfacial Transition (ITZ)- Early microcracking, decreased cohesiveness between aggregate and paste, and decreased flexural resistance result from the ITZ becoming more porous and discontinuous as the RCA concentration rises.
- Increased Replacement Rates (60–100%) Boost the Reduction- Reduced aggregate strength, a weaker link, and more heterogeneity all have a major impact on the concrete matrix at 60–100% RCA. Flexural strength declines more sharply as a result.
- RCA may partially substitute natural aggregates without significantly compromising flexural behaviour, facilitating sustainable construction, as evidenced by the minor reduction seen when substituting up to 20% RCA

Water Absorption Test

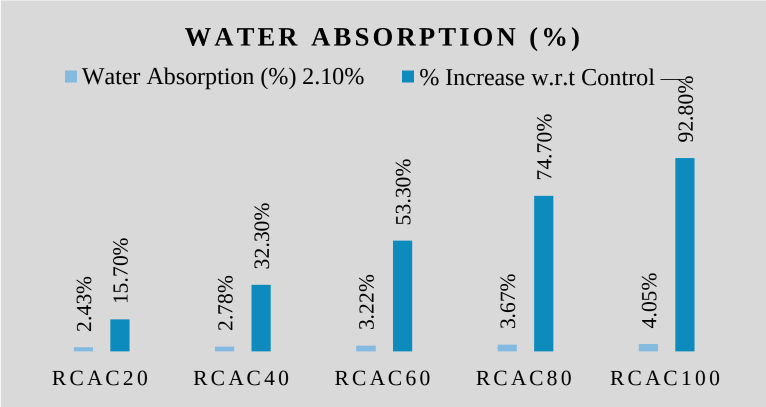

Fig.8 Comparison of water absorption and increment with control concrete

- The findings of the water absorption test unequivocally demonstrate that as the proportion of recycled coarse aggregate (RCA) in the concrete mix rises, so does water absorption. Because of the intrinsic qualities of RCA, this behaviour is both predicted and supported by science.
- Porous Old adhering mortar, microcracks, and a larger void content are characteristics of RCA. These elements improve RCA's ability to absorb water, increasing concrete's total absorption.
- The Interfacial Transition Zone (ITZ) around RCA particles is less dense, more porous, and microcracked. This leads to increased water intrusion, particularly at higher replacement levels (60–100%).
- More Effective Water–Cement Ratio: As a result of RCA absorbing more mixed water, the real effective water–cement ratio rises, resulting in larger capillary holes, a less dense microstructure, and more water absorption.
- The Impact of Increased RCA Content Because the concrete is nearly entirely made of recycled aggregates, which results in significant surface roughness, a greater adherent mortar content, and an uneven interior structure, water absorption increases dramatically at 80–100% RCA.
- Lower Levels of Replacement (0–20%) Perform more effectively increase in water absorption with 20% replacement is modest and yet falls within permissible bounds for structural concrete. This encourages the use of sustainable partial replacement techniques.

Freeze Thaw Test

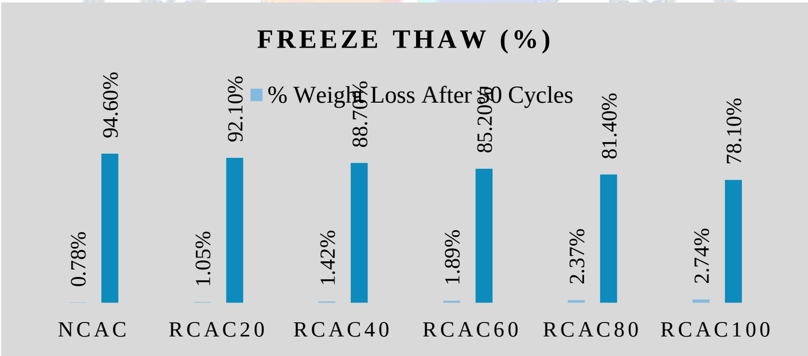

Fig. 9 Comparison of weight loss and residual compressive strength

The freeze-thaw results show that as the amount of recycled coarse aggregate (RCA) rises from 0% to 100%, durability gradually decreases. The basic physical characteristics of RCA and its impact on the microstructure of concrete are closely related to this tendency.

- RCA with a higher porosity has more interior voids, microcracks, and attached old mortar.
- Weak Interfacial Transition Zone (ITZ): Rough, uneven surfaces and glued mortar weaken the connection between cement paste and RCA. Under freeze-thaw cycles, microcracks spread more quickly and cracks start earlier.
- Reduction in Density and Matrix Integrity with higher RCA replacement concrete becomes less dense, higher permeability allows more water and freeze–thaw action becomes more aggressive. Hence, mixes with 60–100% RCA show significant deterioration.
- Low Replacement Levels (0–20%) Perform Acceptably at 20% RCA replacement the old mortar content is limited the microstructural densification from fresh cement paste offsets RCA weaknesses.
- High RCA Levels (80–100%) Show Sharp Decline at higher RCA percentages weak aggregate skeleton, high moisture retention and inferior ITZ. Following freeze-thaw cycles, these variables result in the greatest weight loss and the lowest strength retention.

Acid Resistance Test

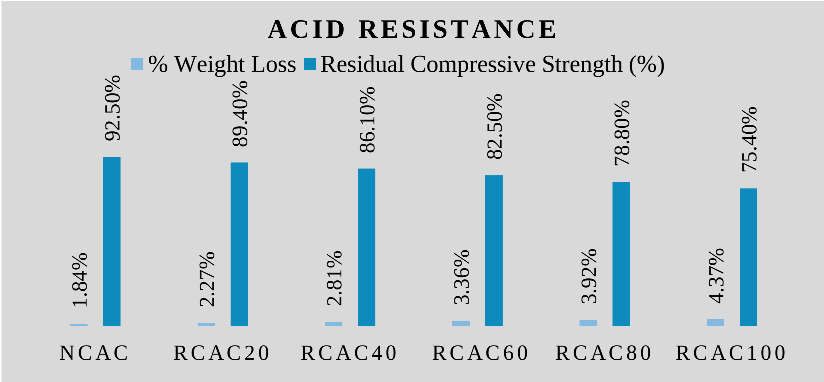

Fig. 10 Comparison of weight loss and residual compressive strength

The acid resistance results show a similar trend: acid attack gets more severe as the amount of RCA rises, as seen by increased weight loss and decreased residual compressive strength. The properties of regenerated aggregates and the chemistry of acid attack provide scientific justification for this behaviour.

- Causes of Porous Adhered Mortar Increased Penetration of Acid Adhered mortar from old concrete, which is weaker and more porous than natural aggregates, is present in RCA. These holes facilitate the breakdown of calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrates (C–S–H) by making it easier for acid to enter. As a result, mixtures with higher RCA levels exhibit more mass loss.
- Less dense RCA-based concrete has a weaker Interfacial Transition Zone (ITZ) that speeds up chemical attack because of uneven RCA surfaces, leftover mortar, and greater ratio of effective water to cement. These weak areas are first attacked by acids, which decrease cohesiveness and residual compressive strength.
- Hydrochloric and sulfuric acids dissolve Cement Hydrates Acids react with Ca $(OH)_2$ to create soluble salts and with C–S–H to decrease binding strength. Because RCA maintains more free water and offers more channels for acid diffusion, this chemical breakdown proceeds more quickly in RCA mixtures.
- Replacement Levels and Their Effects: low replacement (0–20%), little degradation, reasonable acid resistance, and the possibility of sustainable partial replacement. High Replacement (80–100%) is caused by high water absorption and porosity, rapid acid-induced degradation, and severe loss of structural integrity; Moderate Replacement (40–60%) is caused by an increase in porosity and a notable but controllable strength loss.

V. CONCLUSION

The study demonstrates that RCA derived from C&D waste can be effectively utilized in M30 grade concrete to promote sustainable construction practices. Fresh concrete workability decreases with higher RCA content, and mechanical strength exhibits a gradual reduction due to elevated porosity and weaker ITZ. Durability performance also declines with increasing RCA, especially in aggressive environments. However, 20–40% RCA replacement achieves a favorable balance between sustainability and performance, retaining acceptable strength and durability. Full replacement (100% RCA) is feasible for non-structural applications. Utilizing RCA reduces environmental impact, preserves natural aggregates, and supports circular economy principles in construction.

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