



IMPROVING COMPRESSIVE STRENGTH OF ECO-FRIENDLY CONCRETE USING TREATED DEMOLITION WASTE

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Abstract : Rapid urbanization in developing countries has led to significant generation of construction and demolition (C&D) waste, particularly from building demolition, creating serious environmental and disposal challenges. This study investigates the sustainable utilization of demolished concrete as partial replacement of natural coarse aggregate in M25 grade concrete. Recycled coarse aggregate was incorporated at replacement levels of 25% and 50%, and the mechanical performance was evaluated through compressive strength tests at 7, 14, and 28 days. The results were compared with conventional concrete to assess structural feasibility. The novelty of this work lies in optimizing replacement levels for strength performance while promoting circular economy principles and reducing dependency on natural aggregates in structural-grade concrete applications.

Keywords - Recycled coarse Aggregate, Compressive Strength, Tensile strength, Flexural strength.

I. INTRODUCTION

The rapid growth of urbanization, industrialization, and infrastructure development across developing countries has significantly increased the generation of construction and demolition (C&D) waste. Among various waste streams, demolition waste constitutes the largest fraction, particularly from residential and commercial buildings reaching the end of their service life. It is estimated that demolition of permanent structures generates approximately 300 kg/m² of waste, while semi-permanent buildings can generate up to 500 kg/m². With increasing redevelopment activities and replacement of old infrastructure, the volume of such waste continues to rise exponentially. The improper disposal of this material poses serious environmental concerns, including land degradation, dust pollution, groundwater contamination, and excessive demand for landfill space. At the same time, the construction industry is one of the largest consumers of natural resources. Concrete, being the most widely used construction material globally, depends heavily on natural aggregates, which constitute nearly 60–75% of its total volume. The continuous extraction of natural coarse aggregates from quarries and riverbeds leads to ecological imbalance, habitat destruction, soil erosion, and depletion of non-renewable resources. In this context, sustainable development principles demand alternative solutions that reduce dependence on virgin materials while minimizing environmental impact. Recycling and reuse of demolished concrete represent a promising and environmentally responsible approach. Recycled concrete aggregate (RCA) obtained from crushed demolition waste can potentially replace natural coarse aggregates in fresh concrete production. This approach supports circular economy concepts by converting waste material into a valuable construction resource, thereby reducing landfill burden and conserving natural aggregates. However, the use of RCA in structural-grade concrete remains a subject of ongoing research due to concerns regarding mechanical performance and durability. Unlike natural aggregates, recycled aggregates contain adhered mortar on their surface, which increases porosity, water absorption capacity, and variability in particle characteristics. These factors may influence workability, strength development, shrinkage, and long-term durability of concrete. Several studies have reported that partial replacement of natural aggregates with RCA can lead to a marginal reduction in compressive strength, especially at higher replacement levels. Nevertheless, controlled replacement percentages and proper mix design modifications can mitigate strength loss and produce structurally acceptable concrete. The performance of recycled aggregate concrete is strongly influenced by parameters such as replacement ratio, quality of source concrete, crushing process, water-cement ratio, and curing conditions. While lower replacement levels (20–30%) have generally shown minimal impact on compressive strength, higher replacement levels may require adjustments in mix design to maintain performance standards. Therefore, systematic evaluation of optimum replacement percentages for specific concrete grades is essential before large-scale implementation. M25 grade concrete is commonly used in structural elements such as beams, slabs, and columns in residential and commercial construction. Assessing the feasibility of incorporating demolished concrete aggregate in M25 grade concrete provides practical relevance for real-world applications. Evaluating compressive strength at different curing ages—7, 14, and 28 days—helps in understanding early-age strength development and long-term performance characteristics. The present study focuses on utilizing demolished concrete as partial replacement of natural coarse aggregate at 25%

and 50% levels in M25 grade concrete. The compressive strength of recycled aggregate concrete is experimentally evaluated and compared with conventional concrete to determine its structural suitability. The novelty of this research lies in its integrated approach toward optimizing replacement levels while addressing sustainability, resource conservation, and waste management challenges in developing countries. By quantifying strength performance at controlled replacement ratios, this study contributes to establishing practical guidelines for incorporating demolition waste into structural concrete. The findings aim to support environmentally conscious construction practices and promote large-scale adoption of recycled aggregates in infrastructure development, thereby advancing sustainable and circular construction methodologies.

II. LITERATURE REVIEW

Construction and demolition waste (CDW) management has become a major environmental concern due to rapid urbanization and infrastructure development. Demolished concrete constitutes a significant portion of CDW and poses disposal and environmental challenges. The reuse of demolished concrete as recycled concrete aggregate (RCA) has emerged as a sustainable alternative to natural aggregates in concrete production (Tam et al., 2005).

Kumar (2023) investigated recycled aggregates in Stone Matrix Asphalt, demonstrating cost reduction and satisfactory mechanical performance using rejuvenators and Marshall mix design. However, research gaps remain in long-term durability assessment, field performance evaluation, and comprehensive environmental impact analysis for large-scale application.

RCA contributes to resource conservation, reduction in landfill burden, and promotion of circular economy principles within the construction sector. Several researchers have investigated the mechanical performance of recycled aggregate concrete (RAC). Poon et al. (2004) reported that partial replacement of natural coarse aggregates with RCA resulted in a slight reduction in compressive strength due to higher porosity and water absorption of recycled aggregates.

Similarly, Xiao et al. (2012) observed that the adhered mortar present on RCA surfaces increases permeability and affects durability characteristics. However, at lower replacement levels (20–30%), the reduction in strength was found to be minimal and structurally acceptable. Workability and density characteristics of RAC have also been widely studied. Kou and Poon (2013) highlighted that RCA concrete typically requires higher water content or admixture adjustments to maintain workability due to increased absorption capacity. Nevertheless, optimized mix design and proper curing methods can significantly improve mechanical performance.

Furthermore, Limbachiya et al. (2000) demonstrated that recycled aggregate concrete could achieve comparable compressive strength to conventional concrete when replacement levels are controlled and aggregate quality is maintained. Recent investigations have focused on improving RCA quality through mechanical processing, thermal treatment, and chemical modification techniques. These approaches aim to reduce adhered mortar content and enhance interfacial transition zone (ITZ) properties (Kisku et al., 2017). While such treatments show promising results, their economic feasibility and large-scale implementation require further assessment.

Despite substantial progress in understanding RAC behavior, several research gaps remain. First, many studies focus primarily on 28-day compressive strength, with limited evaluation of intermediate curing periods such as 7 and 14 days, which are critical for construction scheduling decisions. Second, comparative studies analyzing moderate replacement levels (25% and 50%) in structural-grade concrete such as M25 under standardized conditions remain limited in developing country contexts. Third, there is a lack of integrated assessment linking mechanical performance with practical sustainability implementation at field scale. Therefore, the present study aims to evaluate the compressive strength performance of M25 grade concrete with 25% and 50% replacement of natural coarse aggregate using demolished concrete aggregate. The strength properties are assessed at 7, 14, and 28 days to provide a comprehensive understanding of performance development. This study contributes toward establishing practical guidelines for sustainable structural concrete applications using recycled materials.

III. OBJECTIVES

The objective of this study is to evaluate the feasibility of utilizing demolished concrete waste as a partial replacement for natural coarse aggregate in M25 grade concrete. The research aims to investigate the effect of 25% and 50% replacement levels on the compressive strength of concrete and to assess strength development at 7, 14, and 28 days. The performance of recycled aggregate concrete is compared with conventional concrete to determine its structural suitability. Additionally, the study seeks to promote sustainable construction practices by reducing dependence on natural aggregates and minimizing construction and demolition waste.

IV. MATERIALS AND METHODOLOGY

CEMENT

Portland Pozzolana Cement (PPC) conforming to Bureau of Indian Standards specifications (IS 1489 Part 1) was used in this study. PPC contains fly ash as a pozzolanic material, which enhances long-term strength and durability. The cement used had a specific gravity of 3.10 and standard consistency, initial setting time, and fineness within permissible limits as per relevant Indian Standards.

FINE AGGREGATE

Locally available river sand conforming to Zone II as per IS 383:2016 was used. The fine aggregate had a specific gravity of 2.65 and fineness modulus of 2.70.

COARSE AGGREGATE

Crushed granite aggregates of maximum size 20 mm conforming to IS 383:2016 were used. The specific gravity was 2.70 with water absorption within permissible limits. Recycled coarse aggregate (RCA) was obtained from demolished concrete structures. The collected waste concrete was crushed, screened, and cleaned to remove dust and unwanted materials. To improve the quality and interfacial bonding characteristics, the recycled aggregates were treated with hydrochloric acid (HCl) solution to remove adhered old mortar and reduce surface porosity shown in Table 4.1 and Fig. 4.1. After acid treatment, the aggregates were thoroughly washed with clean water and oven-dried before use in concrete preparation.

Table 4.1: Recycled Aggregate Treatment Details

Parameter	Description
Source	Demolished concrete waste
Processing	Crushing and sieving
Treatment	HCl acid treatment
Purpose	Removal of adhered mortar and reduction of porosity
Post-treatment	Washing and oven drying



Figure 4.1: Recycled Aggregate (Demolished Concrete) and treating with HCL solution

WATER

The dosage was adjusted (0.8–1.5% by weight of binder) to maintain the desired slump without altering the water-binder ratio. Potable water free from harmful impurities was used for mixing and curing as per IS 456:2000.

Concrete of M25 grade was designed as per IS mix design guidelines. Natural coarse aggregate was partially replaced with recycled aggregate at 25% and 50% by weight. A control mix with 0% replacement was also prepared for comparison shown in Table 4.2. The water-cement ratio was kept constant for all mixes to ensure uniform comparison of mechanical properties.

Table 4.2: Mix Proportions

Mix ID	% Replacement of Coarse Aggregate	Cement (kg/m ³)	Fine Aggregate (kg/m ³)	Natural Coarse Aggregate (kg/m ³)	Recycled Coarse Aggregate (kg/m ³)	Water (litres)
CM	0% (Control Mix)	400	650	1200	0	180
RCA-25	25%	400	650	900	300	180
RCA-50	50%	400	650	600	600	180

Concrete mixing was carried out using standard procedures to ensure uniform distribution of materials, shown in Table 4.3. The prepared concrete was cast into standard moulds for testing mechanical and durability properties. Specimens were compacted properly to eliminate air voids and were demoulded after 24 hours. All samples were cured in clean water at room temperature until the time of testing.

Table 4.3: Specimen Details and Testing Program

Test Type	Specimen Shape	Specimen Size	Number of Specimens per Mix	Testing Age (Days)
Compressive Strength	Cube	150 × 150 × 150 mm	3	7, 14, 28
Split Tensile Strength	Cylinder	150 mm × 300 mm	3	28
Flexural Strength	Beam	100 × 100 × 500 mm	3	28
Water Absorption	Cube	100 × 100 × 100 mm	3	28

V. EXPERIMENTAL INVESTIGATION

The experimental investigation was carried out to evaluate the performance of recycled aggregate concrete in comparison with conventional concrete. The study included assessment of both fresh, hardened and durability concrete properties.

FRESH CONCRETE PROPERTIES

The workability of concrete mixes was determined using the slump cone test in accordance with standard procedures shown in Fig5.1. The slump test was conducted for the control mix (0% recycled aggregate) and for mixes containing 25% and 50% recycled coarse aggregate. The slump values were recorded immediately after mixing. It was observed that the slump decreased with increasing recycled aggregate content due to higher water absorption and rough surface texture of recycled aggregates. However, all mixes maintained workable consistency within acceptable limits for structural concrete.



Figure 5.1: Slump test of Concrete

COMPRESSIVE STRENGTH

Compressive strength tests were conducted on 150 mm cube specimens at curing ages of 7, 14, and 28 days. The cubes were tested in a compression testing machine under uniform loading shown in Fig5.2. The results were compared to evaluate strength development. It was observed that partial replacement up to 25% showed marginal reduction in strength, while 50% replacement exhibited moderate strength reduction compared to conventional concrete.



Figure 5.2: Compressive strength test

SPLIT TENSILE STRENGTH

The tensile strength of concrete was determined using the split tensile strength test on cylindrical specimens (150 mm diameter × 300 mm height) shown in Fig5.3. The test was performed at 28 days of curing. The recycled aggregate concrete demonstrated slightly lower tensile strength due to weaker interfacial transition zones; however, the reduction remained within acceptable structural limits.



Figure 5.3: Tensile strength test

FLEXURAL STRENGTH

Flexural strength was evaluated using beam specimens subjected to two-point loading shown in Fig5.4. The test was conducted at 28 days to assess the bending performance of recycled aggregate concrete. The results indicated that flexural strength followed a similar trend to compressive strength, with moderate reduction at higher replacement levels.



Figure 5.4: Flexural strength test

WATER ABSORPTION

Water absorption tests were conducted on cured cube specimens to assess durability characteristics. Specimens were oven-dried and then immersed in water for 24 hours shown in Fig5.5. The percentage water absorption was calculated based on weight difference. Recycled aggregate concrete showed higher water absorption due to increased porosity and residual mortar attached to the aggregates.



Figure 5.5: Water absorption test

VI. RESULTS AND DISCUSSION

FRESH CONCRETE PROPERTIES

The slump values decreased from 80 mm for conventional concrete to 72 mm and 63 mm for 25% and 50% RCA replacement, respectively shown in Fig6.1. This reduction in workability can be attributed to the higher water absorption capacity and rough surface texture of recycled aggregates. The presence of adhered old mortar increases porosity, leading to greater water demand in the mix. Despite the reduction, all mixes maintained workable consistency suitable for structural applications without requiring additional admixtures.

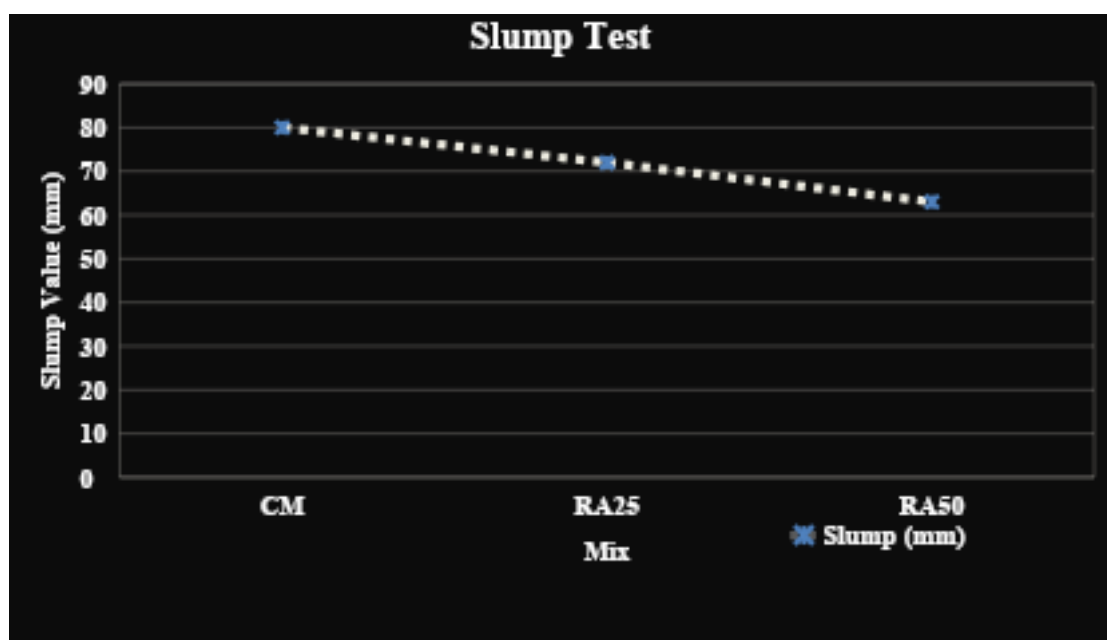


Figure 6.1: Graph of Slump Test on Concrete Mixes

COMPRESSIVE STRENGTH

Compressive strength results show a gradual reduction with increasing RCA content. At 28 days, RA25 exhibited only about 6% reduction compared to control concrete, while RA50 showed approximately 13% reduction. The reduction is primarily due to the weaker interfacial transition zone (ITZ) between recycled aggregates and fresh cement paste, as well as micro-cracks present in the adhered mortar. However, even at 50% replacement, the strength achieved (27.4 MPa) exceeded the characteristic strength requirement of M25 concrete (25 MPa) shown in Fig6.2. indicating structural feasibility.

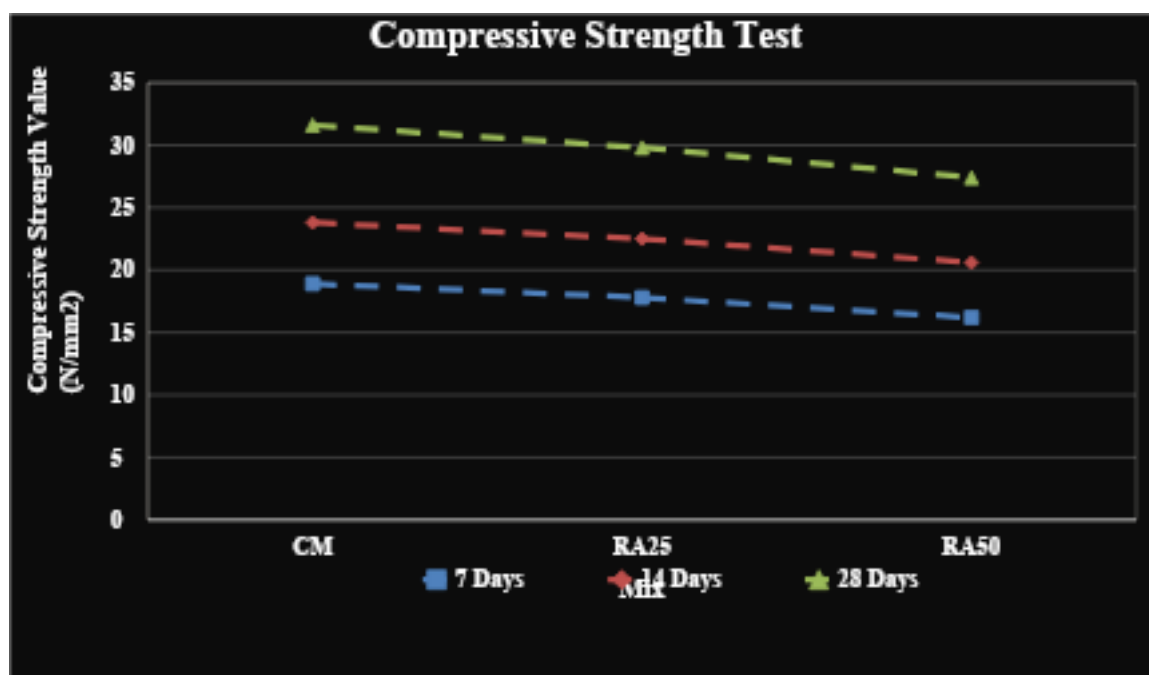


Figure 6.2: Graph of Compressive strength on Concrete Mixes

SPLIT TENSILE AND FLEXURAL STRENGTH

Both tensile and flexural strengths followed trends similar to compressive strength. The reduction in tensile strength is slightly more pronounced due to the sensitivity of tensile behavior to bond quality and internal micro-cracks. The flexural strength reduction remained moderate, confirming that partial replacement up to 25% does not significantly compromise structural performance shown in Fig6.3.

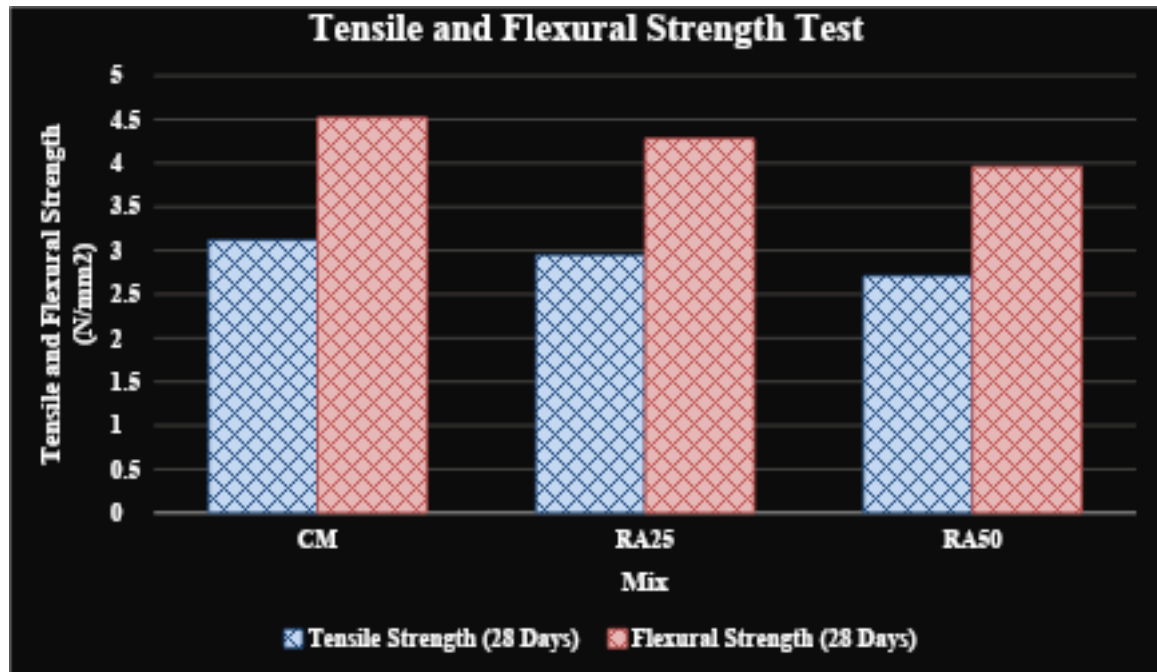


Figure 6.3: Graph of Tensile and Flexural strength on Concrete Mixes

WATER ABSORPTION

Water absorption increased with RCA content, rising from 1.85% for conventional concrete to 2.92% for 50% replacement shown in Fig6.4. This is expected due to the porous nature of recycled aggregates and residual mortar. However, the increase remained within acceptable durability limits. The HCl acid treatment contributed to partial removal of adhered mortar, thereby limiting excessive water absorption and strength loss.

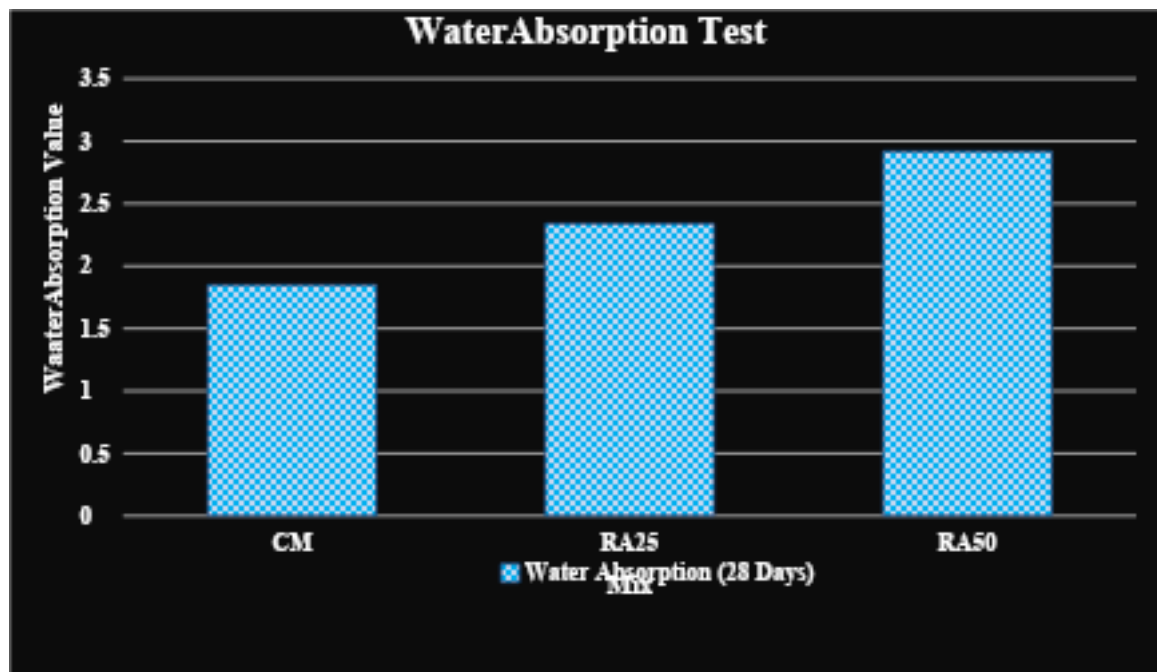


Figure 6.4: Graph of Water absorption Test on Concrete Mixes

VII. CONCLUSIONS

The present study investigated the feasibility of utilizing hydrochloric acid (HCl) treated recycled coarse aggregate (RCA) as partial replacement of natural coarse aggregate in M25 grade concrete at 25% and 50% replacement levels. Based on the experimental investigation of fresh and hardened concrete properties, the following conclusions are drawn:

- The slump value decreased with increasing RCA content due to higher water absorption and rough surface characteristics of recycled aggregates; however, all mixes exhibited workable consistency suitable for structural applications.
- Compressive strength showed a gradual reduction with increasing RCA replacement. At 28 days, RA25 exhibited approximately 6% reduction, while RA50 showed about 13% reduction compared to conventional concrete. Nevertheless, both mixes achieved strength values above the characteristic strength requirement of M25 grade concrete.
- Split tensile and flexural strengths followed a similar decreasing trend; however, the reductions remained within acceptable structural limits, indicating adequate bonding performance of HCl-treated aggregates.
- Water absorption increased with higher RCA content due to increased porosity, but the values remained within permissible durability limits.

Overall, the results demonstrate that 25% replacement of natural coarse aggregate with treated recycled aggregate can be effectively used in structural concrete without significant compromise in mechanical performance. The study confirms that treated recycled aggregate concrete is a sustainable and technically viable alternative for reducing construction and demolition waste while conserving natural resources.

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