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Experimental Investigation on the Use of Recycled Aggregate in Concrete

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Abstract- In recent years, rapid urbanization and infrastructure development have resulted in a significant increase in construction and demolition (C&D) waste, creating serious environmental concerns. At the same time, the excessive use of natural aggregates has led to depletion of natural resources. To address these issues, the use of recycled aggregates obtained from demolished concrete has emerged as a sustainable alternative in the construction industry. The present study focuses on the experimental investigation of recycled aggregate concrete (RAC) using M30 grade concrete. Recycled coarse aggregates were prepared from previously tested concrete specimens and used as a replacement for natural coarse aggregates. The main objective of this research is to evaluate the compressive strength and durability performance of RAC. Concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast and tested after 7 days and 28 days of curing. The results indicate that the compressive strength of RAC is lower compared to conventional concrete, especially at early ages. The average compressive strength achieved at 7 days is 10.1 N/mm², while at 28 days it increases to 20.3 N/mm². Although there is significant strength gain over time, the target strength of M30 grade concrete is not fully achieved when 100% recycled aggregates are used. The durability of concrete was evaluated using the chloride penetration test, which showed higher permeability in RAC due to the porous nature and presence of adhered mortar on recycled aggregates. The study concludes that recycled aggregate concrete can be effectively used for non-structural and low-strength applications. However, for structural use, partial replacement of recycled aggregates along with proper mix design and use of admixtures is recommended to improve strength and durability. The use of recycled aggregates contributes to sustainable construction by reducing waste and conserving natural resources.

Keywords: Recycled Aggregate, Recycled Aggregate Concrete (RAC), Compressive Strength, Durability, Chloride Penetration, Sustainable Construction, M30 Concrete, Construction and Demolition Waste (C&D Waste).

I. INTRODUCTION

Concrete is the backbone of the modern construction industry and is one of the most widely used construction materials across the world. It is extensively used in buildings, bridges, roads, dams, pavements, and other infrastructure projects due to its high compressive strength, durability, workability, and cost-effectiveness. The basic ingredients of concrete include cement, fine aggregate, coarse aggregate, and water. Among these, aggregates occupy nearly 70–80% of the total volume of concrete, making them a very important component in determining the overall properties of concrete. In addition to strength and durability, concrete also offers advantages such as ease of moulding into different shapes, fire resistance, and long service life, which makes it the most preferred construction material. With the advancement in technology, different types of concrete such as high-performance concrete, self-compacting concrete, and geopolymer concrete have been developed to meet modern engineering requirements. However, the dependency on natural aggregates still remains very high in all these types.

However, due to rapid urbanization, industrialization, and population growth, the demand for construction activities has increased significantly. This has resulted in excessive consumption of natural resources, especially natural aggregates obtained from rivers, quarries, and mines. Continuous extraction of these materials is causing serious environmental issues such as:

1. Depletion of natural resources
2. Loss of biodiversity
3. Soil erosion and land degradation
4. Increase in carbon footprint

Apart from environmental issues, excessive mining of aggregates also leads to disturbance of ecological balance, lowering of groundwater levels, and damage to natural landscapes.
Many regions are already facing scarcity of good quality aggregates, which has increased the cost of construction materials and affected project economics. At the same time, demolition of old buildings and structures is generating a large quantity of waste known as Construction and Demolition (C&D) waste. This waste mainly consists of concrete, bricks, tiles, steel, wood, and other materials. In developing countries like India, proper management of this waste is still a major challenge due to lack of recycling facilities and awareness.

Improper disposal of this waste leads to several problems such as:

1. Environmental pollution
2. Landfill problems
3. Health hazards
4. Visual pollution

In addition to these issues, dumping of C&D waste in open areas or water bodies can lead to blockage of drainage systems, flooding during rainy seasons, and contamination of soil and groundwater. Therefore, effective utilization of this waste has become an urgent need. To overcome these issues, it is necessary to adopt sustainable construction practices. One of the most effective solutions is the use of recycled aggregates (RA) obtained from demolished concrete. These aggregates can be processed by crushing and grading, and then reused in new concrete production. The use of recycled aggregates helps in:

1. Reducing demand for natural aggregates
2. Minimizing environmental pollution
3. Reducing landfill usage
4. Promoting sustainable development

Furthermore, the use of recycled aggregate concrete (RAC) supports the concept of circular economy, where waste materials are reused and recycled instead of being discarded. This approach not only conserves natural resources but also reduces energy consumption and greenhouse gas emissions associated with extraction and transportation of natural aggregates. However, the properties of recycled aggregates are different from natural aggregates due to the presence of old mortar attached to their surface. This affects properties such as water absorption, density, strength, and durability of concrete. Therefore, it becomes necessary to experimentally investigate the performance of recycled aggregate concrete before using it in structural applications.

II. METHODOLOGY

Materials Used:
The selection of materials is a very important step in concrete production, as the properties of concrete largely depend on the quality and characteristics of its constituent materials. In this experimental study on recycled aggregate concrete (RAC), all materials were carefully selected and tested to ensure consistency and reliability of results. The main materials used in this study include cement, fine aggregate, natural coarse aggregate, recycled coarse aggregate, and water.
Each material plays a specific role in the concrete mix, and their proper proportioning is essential to achieve the desired strength and durability.

The materials used in this study are listed below:

1. Cement

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2. Fine Aggregate (Sand)
3. Natural Coarse Aggregate
4. Recycled Coarse Aggregate (RCA)
5. Water

Mix Design:
The mix design for concrete is a systematic process of selecting suitable ingredients and determining their relative proportions to produce concrete of the required strength, durability, and workability. In this study, the mix design was carried out for M30 grade concrete as per the guidelines of IS 10262:2009. The aim of mix design is to achieve the target mean strength while maintaining proper workability and durability. For M30 grade concrete, the characteristic compressive strength required at 28 days is 30 N/mm². However, during mix design, a higher target mean strength is considered to account for variations in materials and workmanship. The mix proportions are selected based on factors such as type of cement, maximum size of aggregate, water-cement ratio, and exposure conditions.
In the present study, special consideration was given to the use of recycled coarse aggregates (RCA), as they have different properties compared to natural aggregates. Recycled aggregates generally have higher water absorption and lower density, which affects the water requirement and workability of concrete. Therefore, necessary adjustments were made during the mix design process to maintain the desired consistency and strength.
The mix design was carried out for M30 grade concrete as per IS 10262:2009 guidelines.

Table 2.1: Mix Proportion

Material	Quantity
Cement	1
Fine Aggregate	1.5
Coarse Aggregate	3

Casting of Specimens:
Casting of specimens is an important stage in the experimental investigation, as it directly affects the quality and accuracy of test results. In this study, concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast for the determination of compressive strength. Proper casting ensures uniformity, good compaction, and minimum defects in the specimens.
Before casting, all materials such as cement, fine aggregate, coarse aggregate (including recycled aggregate), and water were measured accurately as per the mix design. The moulds used for casting were cleaned properly and oiled to prevent the concrete from sticking to the sides. This also helps in easy removal of specimens after setting.

1. **Casting Procedure**

The following steps were followed during the casting of concrete specimens:

2. **Batching of Materials**: All materials were weighed according to the required mix proportion. Proper batching ensures uniformity in concrete mix.

3. **Mixing of Concrete**: The materials were first mixed in dry condition to achieve uniform distribution of cement, sand, and aggregates. After that, water was added gradually and mixing was continued until a homogeneous and workable mix was obtained. Special care was taken to account for the water absorption of recycled aggregates.

4. **Filling of Moulds**: The fresh concrete was placed into the cube moulds in three equal layers. Each layer was compacted properly to remove entrapped air.

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5. **Compaction**: Compaction was done using a tamping rod by giving approximately 25 strokes per layer. Proper compaction ensures maximum density and strength of concrete.

6. **Surface Finishing**: After filling the moulds, the top surface was leveled and finished smoothly using a trowel to ensure uniform surface.

7. **Initial Setting and Storage**: The moulds were kept undisturbed at room temperature for **24 hours** to allow initial setting of concrete.

8. **Demoulding**: After 24 hours, the specimens were carefully removed from the moulds without causing any damage.

Fig 2.1: Casting of Concrete Cubes

Curing of Specimens:
After casting, specimens were cured in water for:
1. 7 days
2. 28 days

Fig 2.2: Curing Tank

Compressive Strength Test:

The compressive strength test was conducted using a Compression Testing Machine (CTM).

The compressive strength test is one of the most important tests conducted on concrete to determine its load carrying capacity. It gives a direct indication of the quality, strength, and performance of concrete. In this study, the compressive strength test was carried out on recycled aggregate concrete (RAC) specimens using a Compression Testing Machine (CTM). The test was performed on cube specimens of size 150 mm × 150 mm × 150 mm, as per the guidelines of IS 516:1959. The compressive strength values obtained from this test are used to evaluate whether the concrete meets the required design strength, especially for M30 grade concrete.

1. **Test Procedure**

The procedure followed for the compressive strength test is given below:

2. **Preparation of Specimens** Concrete cubes of standard size (150 mm × 150 mm × 150 mm) were cast using the prepared mix. Proper compaction was ensured using a tamping rod to remove air voids.

3. **Curing of Specimens** After casting, the specimens were kept in moulds for 24 hours and then demoulded. The cubes were cured in clean water for 7 days and 28 days to study strength development at different ages.

4. **Surface Preparation** Before testing, the surface of the cube was cleaned and checked to ensure it was free from loose particles and unevenness.

5. **Placement in CTM** The specimen was placed in the Compression Testing Machine in such a way that the load was applied uniformly on opposite faces of the cube.

6. **Application of Load** Load was applied gradually and continuously at a constant rate until the specimen failed. Care was taken to avoid shock loading.

7. **Recording of Load** The maximum load at which the specimen failed was recorded in kilonewtons (kN).

8. **Calculation of Compressive Strength**

The compressive strength of concrete is calculated using the formula:

$$\text{Compressive Strength} = \frac{\text{Maximum Load}}{\text{Cross-sectional Area}}$$

Where:

- Maximum Load = Load at failure (in Newtons)
- Area = 150 mm × 150 mm = 22500 mm²

Fig 2.3: Compression Testing Machine

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III. RESULTS AND DISCUSSION

Compressive Strength Results:

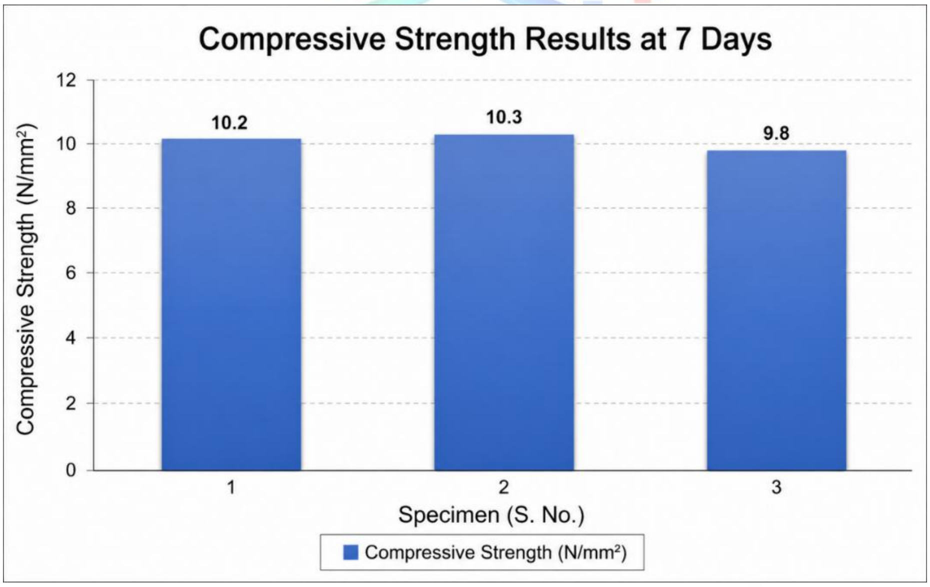
Compressive strength is the most important property of concrete, which indicates its load carrying capacity. In this study, cube specimens of size 150 mm × 150 mm × 150 mm were tested at 7 days and 28 days curing periods.

Compressive Strength at 7 Days:

Table 4.1: Compressive Strength Results at 7 Days

S. No.	Load (kN)	Compressive Strength (N/mm²)
1	230	10.2
2	232	10.3
3	222	9.8

Average Compressive Strength (7 Days) = 10.1 N/mm²



Graph 4.1: Compressive Strength Results at 7 Days

Discussion:

1. The strength achieved at 7 days is relatively low.
2. For M30 grade concrete, expected strength at 7 days is approximately 18–20 MPa, but the obtained strength is only about 10.1 MPa.
3. This indicates that recycled aggregate concrete shows slow early strength development.
4. The reduction in strength is mainly due to:
   - Higher water absorption of recycled aggregates
   - Presence of old mortar
   - Weak interfacial transition zone (ITZ)

Compressive Strength at 28 Days:

Table 4.2: Compressive Strength Results at 28 Days

S. No.	Load (kN)	Compressive Strength (N/mm²)
1	456	20.3
2	462	20.5
3	452	20.2

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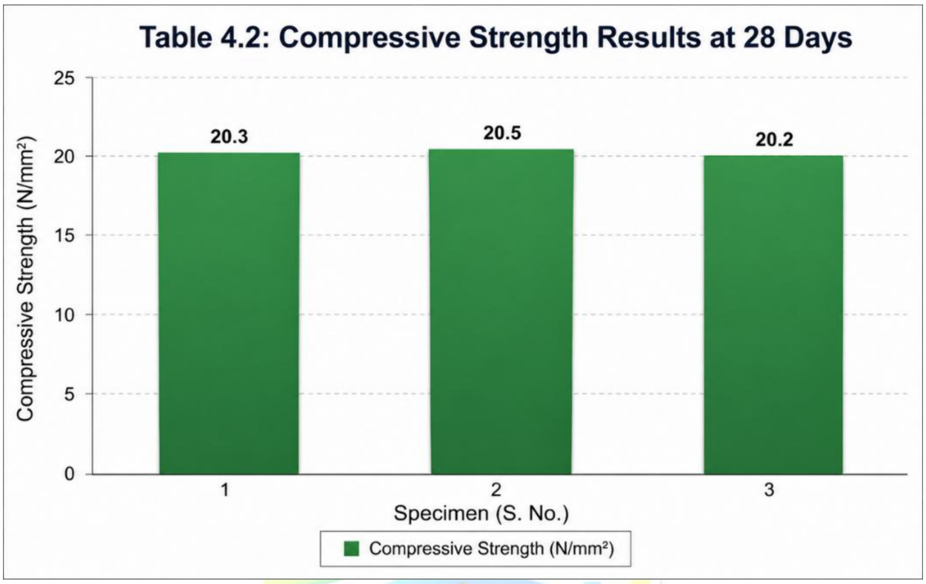
Average Compressive Strength (28 Days) = 20.3 N/mm^2



Graph 4.2: Compressive Strength Results at 28 Days

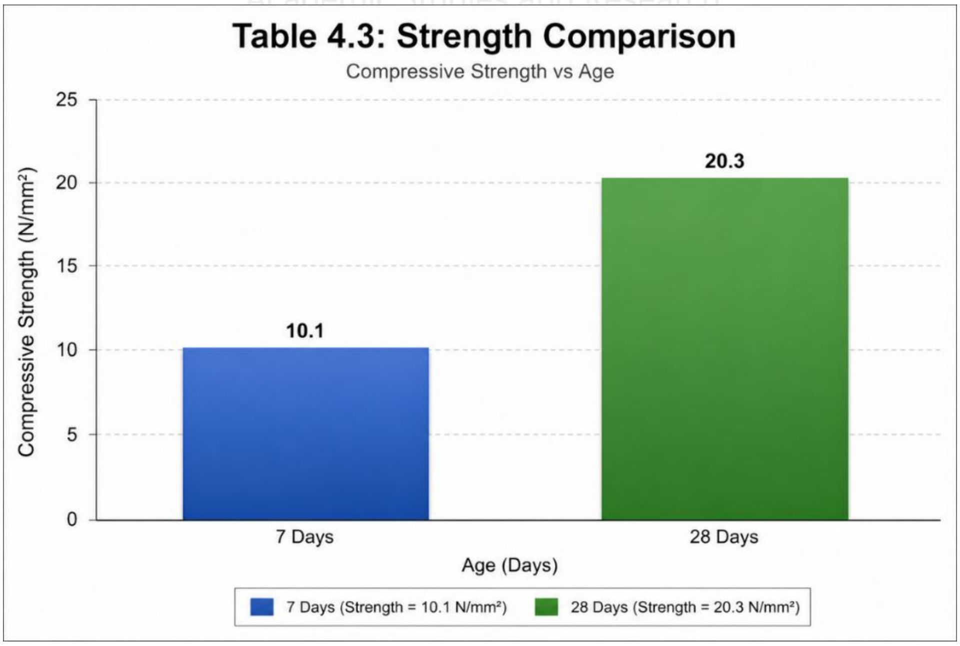
Discussion:

1. The 28-day strength is significantly higher than 7-day strength.
2. Strength nearly doubles from 7 days to 28 days, indicating continued hydration.
3. However, the obtained strength (20.3 MPa) is still lower than required M30 grade strength (30 MPa).
4. This shows that 100% recycled aggregate replacement is not suitable for structural M30 concrete.

Comparison of Strength Development:

Table 4.3: Strength Comparison

Age (Days)	Strength (N/mm^2)
7 Days	10.1
28 Days	20.3



Graph 4.3: Strength Comparison

Discussion:

1. Strength increases with curing period
2. Rate of strength gain is slower compared to conventional concrete
3. Long-term strength development is significant

Failure Pattern of Concrete Cubes:

The failure pattern of concrete cubes under compressive load provides important information about the internal structure, bonding characteristics, and overall quality of concrete. In this study, the behavior of recycled aggregate concrete (RAC) cubes during compression testing was carefully observed to understand the mode of failure and compare it with conventional concrete. During the compressive strength test, the concrete cubes were placed in the Compression Testing Machine (CTM) and load was applied gradually until failure occurred. It was observed that the failure of RAC cubes was not sudden but rather gradual, indicating a relatively lower stiffness and strength compared to conventional concrete. The cracks started developing at lower loads and propagated slowly with increasing load. The typical failure pattern observed in the RAC cubes was characterized by the formation of vertical and inclined cracks along the surface of the cube. These cracks generally originated from the edges and corners of the specimen and extended towards the center. In many cases, the failure occurred along weak zones, particularly at the interfacial transition zone (ITZ) between the recycled aggregates and the new cement paste. The presence of old adhered mortar on recycled aggregates plays a significant role in influencing the failure pattern. This adhered mortar is generally weaker and more porous than natural aggregates, which leads to the formation of weak bonding zones within the concrete matrix. As a result, cracks tend to initiate and propagate more easily through these कमजोर regions, leading to early failure.

Compared to conventional concrete, RAC cubes exhibited:

1. More visible and wider cracks
2. Lower resistance to crack propagation
3. Slightly irregular and non-uniform failure surfaces

In some specimens, partial crushing and spalling of edges were also observed, which indicates non-uniform stress distribution within the cube. This behavior can be attributed to the heterogeneous nature of recycled aggregates and the variation in their quality. Despite these limitations, the failure pattern still followed the general behavior of concrete under compression, which confirms that recycled aggregate concrete can carry load, although with reduced efficiency. The gradual nature of failure may also be considered beneficial in some cases, as it provides warning before complete collapse.

a) Early cracks b) Following cracks c) Final pattern

Fig 4.1: Failure Pattern of Concrete Cube

Observation:

1. Cracks developed along vertical planes
2. Failure is gradual due to weaker aggregate bond
3. More cracks observed compared to normal concrete

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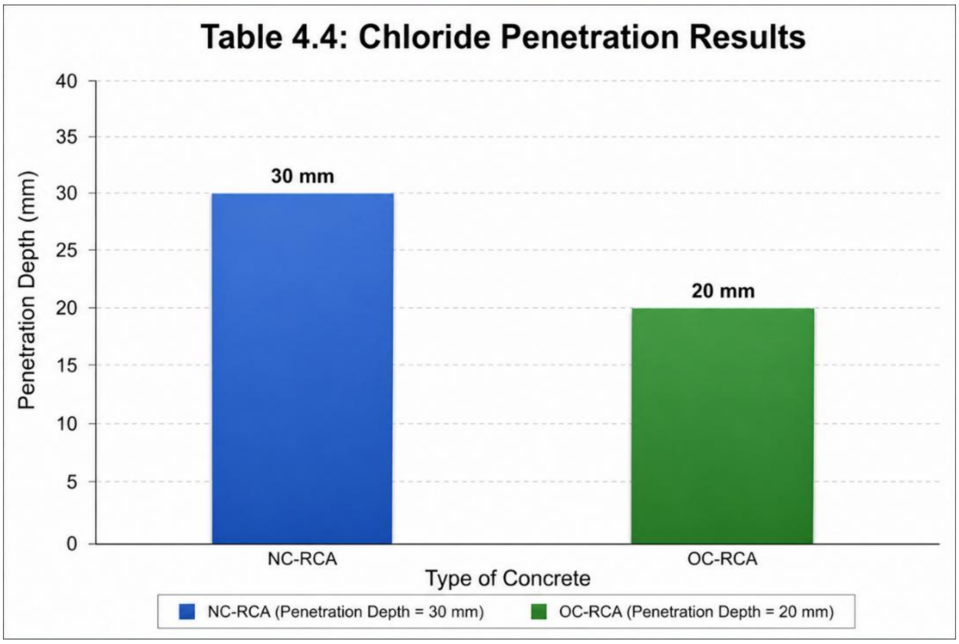
Durability Results (Chloride Penetration Test):

Durability of concrete was evaluated using the chloride penetration test, which is an important method to assess the resistance of concrete against the ingress of chloride ions. Chloride penetration is one of the major causes of deterioration in reinforced concrete structures, as it leads to corrosion of steel reinforcement and reduces the overall service life of the structure. In this study, the durability performance of recycled aggregate concrete (RAC) was analyzed by measuring the depth of chloride penetration into the concrete specimens. The test results indicate that the depth of chloride penetration varies depending on the type and quality of recycled aggregates used. The concrete prepared with NC-RCA (Natural Coarse Recycled Aggregate) shows a penetration depth of 30 mm, whereas the concrete prepared with OC-RCA (Old Concrete Recycled Aggregate) shows a comparatively lower penetration depth of 20 mm. This clearly indicates that NC-RCA concrete is more permeable and allows more chloride ions to pass through its structure, while OC-RCA concrete performs better in terms of resistance to chloride penetration.

Table 4.4: Chloride Penetration Results

Type of Concrete	Penetration Depth
NC-RCA	30 mm
OC-RCA	20 mm

The higher penetration in recycled aggregate concrete is mainly due to the porous nature of recycled aggregates, which contain old adhered mortar. This adhered mortar increases the overall porosity and water absorption capacity of concrete, resulting in the formation of more interconnected voids. These voids act as pathways for chloride ions, allowing them to penetrate deeper into the concrete matrix. As a result, RAC generally shows lower durability compared to conventional concrete made with natural aggregates. However, the comparatively better performance of OC-RCA concrete suggests that the quality and source of recycled aggregates play a significant role in determining durability. Aggregates obtained from stronger and denser parent concrete tend to have lower porosity and better bonding characteristics, which improves the resistance to chloride penetration. From the results, it can be concluded that although recycled aggregate concrete exhibits higher permeability, its durability can be improved by adopting proper measures such as using mineral admixtures (fly ash, silica fume), improving mix design, reducing water-cement ratio, and proper curing practices. Therefore, while RAC may not perform as well as conventional concrete in aggressive environments, it can still be used effectively in moderate exposure conditions with proper design considerations.



Graph 4.4: Chloride Penetration Results

Discussion:

1. Higher penetration indicates lower durability
2. NC-RCA shows higher penetration (30 mm)
3. OC-RCA performs better (20 mm)
4. Recycled aggregate concrete is more permeable due to porous structure

CONCLUSION

Based on the experimental investigation on recycled aggregate concrete (RAC) of M30 grade, it is concluded that the use of recycled aggregates is an eco-friendly and sustainable approach that helps in reducing construction and demolition waste while conserving natural resources. The study observed that recycled aggregates have higher water absorption, lower density, and adhered old mortar, which affect the overall performance of concrete. The compressive strength results showed lower strength development compared to conventional concrete, with 7-day strength reaching only 10.1 N/mm² and 28-day strength reaching 20.3 N/mm², which is below the target strength of M30 grade concrete. This indicates that 100% replacement of natural aggregates is not suitable for high-strength structural applications without modifications. The reduced strength is mainly due to higher porosity, weak interfacial transition zone, and old mortar attached to recycled aggregates. Durability tests also revealed higher chloride penetration and permeability in RAC, indicating comparatively lower durability. The study further showed that the quality and source of recycled aggregates significantly influence concrete performance. Overall, recycled aggregate concrete can be effectively utilized for non-structural and low-strength applications, contributing towards sustainable construction practices.

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