Waste to Strength: Investigating Recycled Concrete Aggregates for Sustainable Construction

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Abstract:- The increasing generation of construction and demolition waste, combined with the rapid depletion of natural resources, has made it imperative to explore sustainable alternatives in the construction industry. One such alternative is the use of Recycled Concrete Aggregates (RCA) in the production of structural concrete. This research, titled "Waste to Strength: Investigating Recycled Concrete Aggregates for Sustainable Construction", aims to assess the viability of using recycled aggregates as a partial or full replacement for natural coarse aggregates in M30 grade concrete.

While recycled aggregate concrete (RAC) has been studied extensively for its compressive strength, limited attention has been given to its long-term durability, especially in reinforced concrete structures. This study focuses on both the mechanical and durability performance of RAC. The primary objectives include evaluating the compressive strength of M30 grade concrete made with recycled aggregates and assessing its resistance to chloride ion penetration through the Rapid Chloride Permeability Test (RCPT).

The study emphasizes the dual benefits of using RCA reducing environmental degradation caused by demolition waste and conserving natural aggregates while ensuring that the structural integrity of the concrete remains within acceptable limits. The findings contribute to the growing need for sustainable construction materials and promote the use of recycled waste in load-bearing applications.

Keywords: Recycled Concrete Aggregate (RCA), Recycled Aggregate Concrete (RAC), Demolition Waste, Sustainable Construction, Compressive Strength, Durability, Chloride Penetration, M30 Grade Concrete, Environmental Impact, Circular Economy in Construction.

1. Introduction

In today's world, a lot of waste from old buildings and structures is ending up in landfills. This has become a serious problem, and the main reason is the fast growth of the construction industry. To reduce this waste, it is important to reuse materials that come from demolished structures instead of just throwing them away. Concrete is the most widely used material in construction. It is made up mostly of aggregates like sand, gravel, or crushed stone, which make up about 80% of its volume. As cities grow, the demand for these natural aggregates is increasing. This leads to more mining, more transportation, and more damage to the environment. To solve this problem, the use of recycled materials, especially Recycled Concrete Aggregates (RCA), is becoming more important. This thesis, titled "Waste to Strength: Investigating Recycled Concrete Aggregates for Sustainable Construction," focuses on using recycled concrete materials to make new concrete. The main goal of the study is to check how strong and durable this recycled concrete is. For this, M30 grade concrete was prepared using Recycled Aggregates (RA), and two main tests were done:

- ❖ Compressive strength test to check how much load the concrete can handle.
- ❖ Chloride penetration test to check how durable the concrete is, especially against water and chemicals.

The study compares concrete made with recycled materials to regular concrete made with natural aggregates. It aims to find out if recycled aggregates can give similar or acceptable performance. In conclusion, this work highlights how using waste materials in concrete can help save natural resources, reduce environmental pollution, and support sustainable construction. Replacing natural aggregates with recycled ones is a smart and eco-friendly step for the future of the construction industry.

1.2 Scope of Study

The fast growth of the construction industry around the world has increased the use of natural resources especially natural aggregates like sand, gravel, and crushed stone. As a result, these resources are getting used up quickly, leading to serious environmental concerns**.** According to the Global Aggregates Information Network (GAIN) and other recent sources, the global demand for natural aggregates has crossed 55 billion metric tons per year by 2023, and is still rising. This increase is mostly due to rapid urbanization, infrastructure development, and large-scale construction projects.

As shown in Figure 1.1**,** the Asia-Pacific region still remains the largest consumer, using nearly 67% of the world's total aggregates. Other regions like North America (8%)**,** Western Europe (6%)**,** and others (19%) follow. This heavy consumption is also leading to massive construction and demolition (C&D) waste**.**

For example, the European Union reported that over 36% of total solid waste generated in 2022 was from construction activities. Similarly, Hong Kong continues to generate over 20 million tons of C&D waste annually, with nearly 50% coming from building demolitions. Unfortunately, most of this waste is still being dumped into landfills**,** harming the environment.

This study takes a step toward solving this issue by focusing on the recycling of concrete waste. The main objective is to test the strength and durability of concrete made using Recycled Concrete Aggregates (RCA)**.** By doing this, the research aims to promote the reuse of waste materials in construction and reduce the overuse of natural aggregates. This not only helps in saving resources but also supports sustainable and eco-friendly building practices**.**

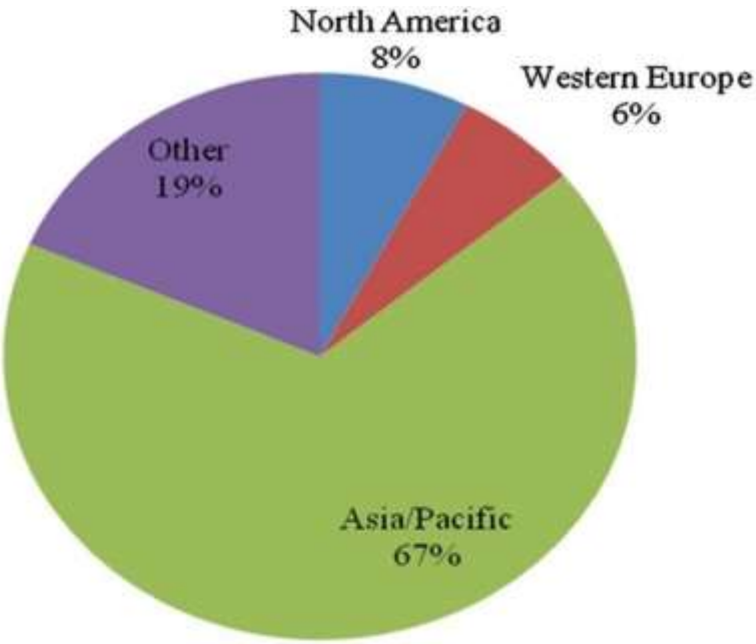

Figure 1.1 The Freedonia Group 2012

1.3 Goal of the Study

This project focuses on evaluating the strength and durability of Recycled Aggregate Concrete (RAC) made using M30 grade concrete. While most earlier studies have concentrated on using recycled aggregates in high-strength concrete, this research takes a different direction. The aim is to explore how recycled aggregates can be effectively used in medium- to low-grade concrete without causing large variations in performance. The key objective is to determine whether RAC can meet the required standards for strength and durability in regular construction, making it a practical and sustainable alternative to natural aggregates.

1.4 Objectives of the Study

The mechanical properties of concrete are distinctively affected by the presence of RAC present in it. The effort made by the research focuses on using RA. The use of recycled aggregates is a very important initiative that needs to be taken. The replacement of RA is also very useful in context of developing the sustenance and management in the modern construction industry. The preservation of the environment can be hugely impacted by replacing RA with natural coarse aggregates.

So the main objectives are following:

- To understand the importance of RAC in the construction industry.
- To determine the amount of recycled aggregates required to achieve suitable compressive strength for M 30 grade of concrete.
- To check the compressive strength gained by using RA.
- Determining the life of RAC by conducting durability test.
- Observing the affect of recycled aggregates on concrete.

1.5 Tests to be Conducted to Find out the Strength and Durability of RAC

- Compressive Strength Test
- RCPT(Rapid Chloride Permeability Test)
- The test which is done to check the load bearing capacity of concrete is undertaken by compressive strength test. To estimate different properties of concrete, the compression can be checked by casting cubes of concrete. This test alone can help us in verifying that is the concrete having enough strength to be used or not. The compressive strength for the structures usually fluctuates between 15 to 30Mpa for residential structures and the criteria for commercial is usually higher [12].

Apparatus

The testing can be conducted with the help of equipment which is called the chloride permeability test equipment; it consists of two types of holder. Out of these two holders one holds 3% Nacl and the other has 0.3M NaOH solution. The samples of concrete are usually having thickness of 50 mm and diameter of about 100mm.

Chloride Test Procedure

a) Samples having diameter of 90-100mm and thickness of 50 mm are casted.

b) The concrete specimen is located between the holders (known as a single cell) which hold both the solutions between them.

c) The holders are then attached to DC supply and concrete samples at both ends undergo a voltage of 60V.

d) The current passing’s through the samples are then noted according to the duration of time.

e) A device called LCD connected to the cell is then used to estimate the current passing through the sample [23].

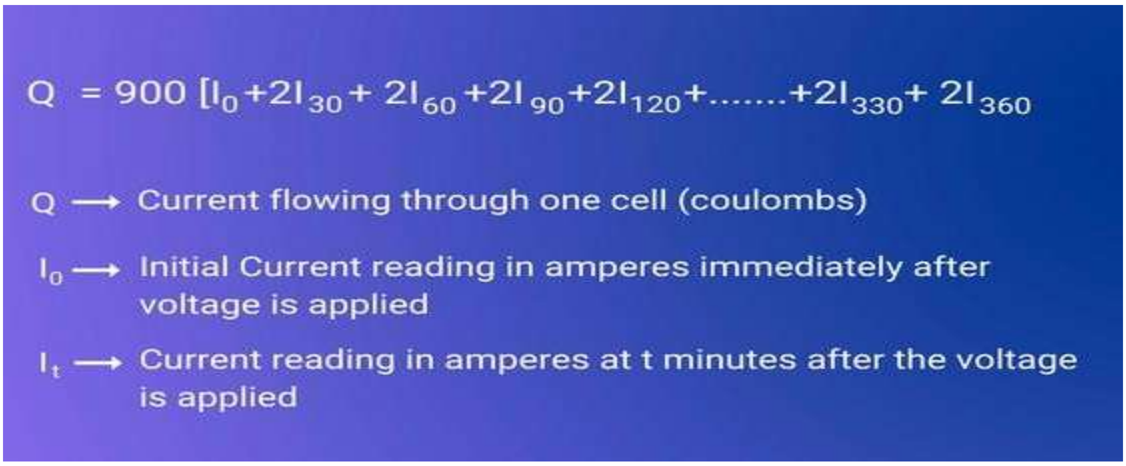

Figure 1.3 Formula for CPT Test

To estimate the amount of permeability in concrete 2-3 samples are tested from the same set of samples, the final result is the mean value of the above. LCD meter can have 2-3 cells connected to the permeability equipment to check those samples.

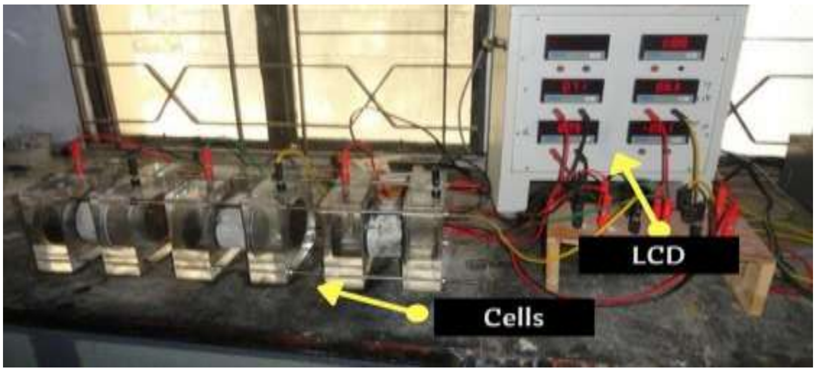

Figure 1.4 Permeameter [23]

Table to interpret CPT test Results:

The determination of the current can be done by the above given formula and can berated according to the table given below. [23]

Table 1.1 Table Used to Interpret CPT Results

Charge (Coulombs)	**Chloride Permeability**
>4000	High Permeable Concrete
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

2. Literature Review

2.3 Different Findings on RAC

Mortar and aggregates are the two main constituents of concrete. Slowly and gradually it's use is becoming common these days. The RA extracted from demolition is highly porous which makes its interfacial transition zone (ITZ) weak. The modulus of elasticity of RA is lower than natural aggregates and the reason for this is usually the porosity that the demolished aggregates are having. Uddin Ahmed [34] researched about the dividing strength which is possessed by concrete containing recycled aggregates. 192 concrete cylinders (100ϕ×200 mm) and 192 mortar cubes (50×50×50 mm) were studied by him and the values of NAC and RAC that were obtained after conducting the compressive strength test were compared. When NAC is used the linear relationship between mortar and concrete's strength is observed. Anyhow, when RAC is used, the relationship observed in mortar and concrete strength is a two stage relationship which proves the existence of dividing strength in the concrete that's tested. His research clearly shows how important is it to emphasize on researching more about the dividing strength of RAC as it varies according to the contents present in the material used.[34].

3. Methodology

3.1 General

The main aim of the experimentation is to study about the strength and durability of the RAC. Compressive strength test has been performed to check the strength of RAC at 7 and 28 days. A total of six samples of concrete were casted to check the compressive strength. The 15×15×15cm standard size moulds were used. Out of all these six samples, three were tested after 7 days of curing and the other three were tested after 28 days of curing. The RCPT (Rapid chloride permeability test) has not yet been performed.

3.2 Materials Used for the Study

The RCA used in the experiment was collected from the old samples which had already been tested in the university laboratory. The samples from which the RCA was collected were of the same grade as the one being used in this study i.e. M30 grade. The fine aggregates used in this study were not the recycled ones, perhaps the quality of the fine aggregates used was much more superior than the coarse aggregates and lastly the most extensively used cement i.e. Ordinary Portland cement was used to cast the samples in this study.

3.3 Methodology Followed

a) In this study, the recycled aggregate concrete were obtained from the concrete blocks which were previously tested in the university lab.

b) The blocks were crushed with use of hammer to a size of 40 mm or less.

c) To obtain the desirable size i.e.10mm-20mm, the aggregates were crushed further with the help of crusher.

d) The moisture content from the aggregates was removed by keeping the min oven for 24 hours.

e) Mix design of M30 grade of concrete was used with the help of IS10262-2009.

f) Compression test was then conducted to check the strength of RAC.

3.4 Procedure for Compression Test

Basically there are two types of samples that can be casted for cube and dimension for them are either 15×15×15cm or 10×10×10cm and it usually depends on the size of aggregates. The ones which are often used are 15×15×15cm molds. The pouring of concrete is done and to avoid the voids, it's made sure that tampering is done properly. The molds are deformed after 24 hours and water is used for curing. It is important for the top most surface of the sample to be smooth. To carry out this process the cement is very carefully used to make the layer smooth. The samples that are casted are checked with the help of compression machine. While applying the load we have to make sure it's gradual and should be applied at a rate of 140kg/cm^2.This procedure helps us in estimating the compressive strength.

Following are the steps for testing the Compressive strength of Concrete Cubes:

Apparatus for Concrete Cube Test:

Machine for testing compression

Preparation of Concrete Cube Specimen

The aggregates used in the test were obtained from previous lab tests.

Specimen

15cm cubes (6) Mix. M30 or above

Mixing of Concrete for Cube Test Concrete should be mixed thoroughly.

Hand Mixing

a) A water light clean setup should be used until and mixture should be created properly in order to gain efficiency.

b) The cement and fine aggregates have to be mixed with recycled aggregated and it should be done till a proper Mix is not achieved.

c) Then water has to be added to it and it has to be mixed thoroughly.

Sampling of Cubes for Test

a) Moulds have to be cleaned and the oil has to be applied.

b) The layers of filled concrete should at least behaving thickness of 5 cm.

c) Each layer has to be compacted with the help of tamping it 35 times (steel bar 16mm diameter and 60cm long, bullet-pointed at lower end).

d) Top surface has to be levelled and Smoothening of it should be done.

Curing of Cubes

Samples are kept in moist air for 24 hrs and when this time passes, the samples have to be separated from the molds and then these have to be kept in fresh water before conducting any kind of experiment on it.

Precautions for Tests

After every 7 days, the water should be tested and it should be having a temperature of about 27 -29 deg. Celsius.

Procedure for Concrete Cube Test

a) The excess water has to be wiped out after taking it out of the curing circumstances it was in.

b) Dimension of sample should not be 0.2 m

c) The bearing surface of the testing machine has to be cleaned.

d) The positioning of samples has to be done in a way that the load is applied from both sides of the cube.

e) The alignment should be proper and at the centre of the base plate.

f) The process has to be carried out gently in order to obtain the maximum output from the experiment.

g) The load at the rate of 140/kg/cm^2 has to apply very gradually to neatly carryout the experiment.

h) Unusual features should be noted and values have to be recorded.

4. Results and Discussion

The results of the study were not as expected. Experimentation on RAC is a very wide research topic with a number of outcomes. The use of RAC has become an urgent requirement in today's time, so continuous research needs to be done on this topic. Moreover, the effect of CDW on the environment is very adverse as we all know. There are many different factors that affect the mechanical properties of RAC, so in order to establish the proper amount of RA which can be used for the manufacturing of concrete, studies on mechanical properties of RAC too need to be done.

4.1 Compression Strength Test Results

Three samples were tested after 7 days of curing and three were tested after 28 days of curing so the results are as follows:

For seven days testing:

Table 4.1 Compressive Test Results after 7 Days

S. No.	Load (KN)	Compressive Strength (N/mm^2)
1	230	10.2
2	232	10.3
3	222	9.8

Therefore, average compressive strength after 7 days is equal to 10.1 N/mm^2

For 28 days testing:

Table 4.2 Compressive Test Results after 28 Days

S. No.	Load (KN)	Compressive Strength (N/mm^2)
1	456	20.3
2	462	20.5
3	452	20.2

So the average strength achieved after 28 days is equal to 20.3 N/mm^2

4.2 Observations Made from the Above Results

65% strength is achieved within 7 days but the strength achieved here is not desirable as M30 grade should be giving 20 N/mm^2 of strength after seven days and only 50% of it has been achieved. So, it is very clear that desirable strength cannot be achieved by using 100% RA for M30 grade therefore; experiments with different amount of quantities should be conducted in order to achieve the desirable strength. Experiments also show that the strength achieved after 28 days was doubled. Though it is a good amount of strength achieved by RAC but still it cannot be used in the industry. Hence experiments with different proportions need to be necessarily be done.

4.3 Chloride Penetration Test Results

In order to apply the solution indicator method of silver nitrate, R4 (from the NC- RCA) Concretes and C4 (from the OC-RCA concretes) we're exposed to saturated salt solution after it was broken after at an interval of 160 days. The 0.1 N silver nitrate solution which damaged the surface of broken blocks gave the results that indicated 30 and 20 mm Depth of chloride penetration in to NC-RCA and OC-RCA concrete, and this can be seen in Figures 4.1 and 4.2.

Figure 4.1:-Chloride Depth of Penetration in NC-RCA after 160 Days

Figure 4.2:-Chloride Depth of Penetration of OC-RCA after 160 Days

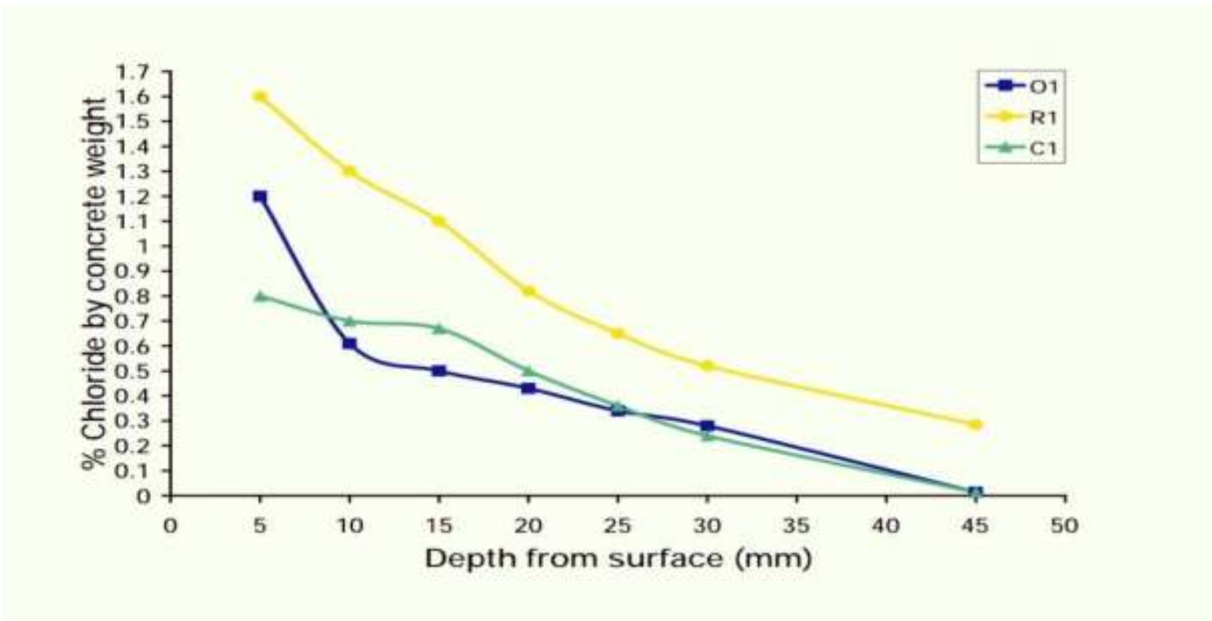

Figure 4.3:- Trend of Chloride Diffusion

Fick's 2nd law and linear curve fitting were used to calculate the chloride diffusion and the values were 15.3, 16.7 and 14.2×10-11m^2/s for O1, R1 and C1 concrete blocks respectively. Towards the concrete surface and the rebar, it was seen that there was decrement of values in these areas. Whereas, the content of chloride near the rebar's surface (40 mm from the surface of the concrete) was nearly the same for these two samples, 0.013% by concrete's weight, this result in the R1 concrete block was 0.275% concrete's weight. Rebar concrete interface had high value and the chloride diffusion curve showing downward slope in R1 sample block clearly show that OC-RCA and NA were not permeable as NC-RCA. The steel rebar were detached and the concrete blocks were sliced to check the chloride permeability. Though the downside part of the reinforced steel in the R1 Concrete block, just with the surface casted, was rusted (Figure 4.4), no signs of corrosion or rusting were found in the OC-RCA and NA samples that were tested.

5. Conclusion

65% strength is achieved within 7 days but the strength achieved here is not desirable as M30 grade should be giving 20 N/mm^2 of strength after seven days and only 50% of it has been achieved. So, it is very clear that desirable strength cannot be achieved by using 100% RA for M30 grade therefore; experiments with different amount of quantities should be conducted in order to achieve the desirable strength. Experiments also show that the strength achieved after 28 days was doubled. Though it is a good amount of strength achieved by RAC but still it cannot be used in the industry. Hence experiments with different proportions necessarily be done. The results which were seen by conducting these experiments done on different kind of characteristics which are permeability, strength in context of age and their impact on concrete durability, the conclusions and recommendations are given below: The age limit of RAC totally depends on the durability of these aggregates. The involvement of recycled concrete which is old and hard is used as coarse Aggregate with 16 mm nominal maximum size which is accompanied by sand that's natural. If we want the structural concrete to be more efficient the characteristics such as chloride penetration, reinforcing steel corrosion resistance and salt scaling of RCA concrete should be able to fulfill the requirements that are expected from natural aggregates. Comparatively the strength displayed by the OC-RCA was strong enough and very close to the natural materials.

5.2 Future Scope

➢ **Optimization of Recycled Aggregate Proportions**:-The study clearly indicates that using **100% recycled aggregates (RA)** in M30 concrete does not yield desirable strength for structural applications. Therefore, **future research can focus on experimenting with different replacement ratios** (e.g., 25%, 50%, and 75%) to identify the optimal percentage that balances **strength, durability, and sustainability.**

➢ **Enhancement with Admixtures and Supplementary Cementitious Materials**:-Investigations can be extended by incorporating **superplasticizers, fly ash, silica fume, or slag** to improve the **workability, compressive strength, and chloride resistance** of RAC. This can help overcome the common drawbacks such as high porosity and low durability of recycled aggregates.

➢ **Performance Under Different Environmental Conditions**:-Since environmental exposure plays a key role in concrete deterioration, further studies should be conducted on RAC under various conditions such as:

❖ **Freeze-thaw cycles**
❖ **Sulfate attack**
❖ **Marine environments**
❖ **High-temperature exposure**

➢ **Long-Term Durability Studies**:- While this thesis examined early-age (7-day, 28-day) compressive strength and chloride permeability, future studies should conduct **long-term performance evaluations** over 6 months, 1 year, or more to assess the **actual service life of RAC structures.**

➢ **Mechanical Characterization Beyond Compressive Strength**:- This research focused mainly on **compressive strength**. Future work should evaluate:

❖ **Tensile strength**
❖ **Flexural strength**
❖ **Modulus of elasticity**
❖ **Fracture toughness**

➢ **Microstructural Analysis**:-To gain deeper insights into the performance of RAC, **SEM (Scanning Electron Microscopy)** and **XRD (X-ray diffraction)** techniques can be employed to study the **Interfacial Transition Zone (ITZ),** bonding quality, and **pore structure** of recycled concrete.

➢ **Life Cycle Assessment (LCA) and Cost Analysis**:-**A comprehensive environmental and economic analysis** should be performed to evaluate the **carbon footprint, energy savings,** and **cost-benefit ratio** of RAC compared to conventional concrete.

➢ **Development of Mix Design Guidelines**:-Using the data collected from the above studies, **standardized guidelines or IS Code recommendations** can be proposed for the use of RCA in different grades of concrete, especially for low to medium strength applications.

➢ **Field Applications and Pilot Projects**:-Future work can extend to **pilot-scale field projects**, such as constructing pavements, footpaths, or low-load-bearing walls using RAC, to validate lab findings under real-world conditions.

➢ **Reinforcement Corrosion Study**:-Further testing is required to analyze the **bond behavior between RAC and steel reinforcement,** especially under chloride-laden environments, to ensure the long-term safety of reinforced concrete structures.

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