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Recycled Coarse Aggregate Evlauation of its Strength and Durability

[1]Sahil, [2]Ujjwal Boora,
[1]M.Tech Scholar, Dept. of Civil. Engineering, PKGCET PANIPAT, Haryana, India.
[2]Assistant Prof., Dept. of Civil. Engineering, PKGCET Panipat, Haryana, India
pkgi.civil@gmail.com

Abstract:
Compressive strength tests, a significant decline in strength was recorded. Specifically, 7-day compressive strength decreased by 3.2%, 10.6%, and 15.2% for 20%, 30%, and 40% RCA, respectively. Similarly, 28-day compressive strength decreased by 1.3%, 3.7%, and 15.3% for the same RCA levels. Durability assessments indicated a rise in water permeability, with penetration depth increasing by 0.7 mm, 2.0 mm, and 3.9 mm at 20%, 30%, and 40% RCA replacement, respectively. This suggests a direct correlation between RCA content and concrete porosity.
Resistance to acidic and sulfate environments declined with higher RCA content, though moderate durability was observed up to 40% RCA. Moreover, chloride ion permeability increased substantially, with a 271.9% rise at 40% RCA, highlighting potential long-term durability concerns. Overall, the study concludes that RCA replacement up to 30% is optimal for M60 grade concrete, balancing sustainability with acceptable mechanical and durability properties.

Keyword: Use of recycled coarse aggregate, RCA, water permeability of concrete, Durability of the concrete.

Introduction

1.1 General

While the use of RCA in low to medium-strength concrete has shown promising results, its application in high-grade concrete (typically M40 and above) is still under critical evaluation. High-grade concrete demands superior mechanical strength, durability, and long-term performance, which can be significantly influenced by the physical and chemical properties of the aggregate. RCA, due to the presence of adhered mortar and inherent porosity, often shows higher water absorption, lower density, and reduced strength compared to natural aggregates. These characteristics raise questions about its suitability in high-strength and structural-grade concrete applications, where durability under aggressive environmental conditions is crucial.
Recent advancements in concrete technology—such as the use of supplementary cementitious materials, chemical admixtures, and improved pre-treatment methods for RCA—have opened new possibilities for enhancing the performance of recycled aggregates. However, comprehensive studies focusing on the durability aspects of high-grade concrete incorporating RCA are limited, and there remains a need for experimental validation under various exposure conditions.
This thesis aims to fill this research gap by evaluating the mechanical and durability performance of high-grade concrete containing recycled coarse aggregate. The study involves a systematic analysis of strength development, water absorption, chloride penetration resistance, and other key durability parameters to determine the viability of RCA for use in high-performance structural applications. The findings are expected to contribute to the development of sustainable concrete mix designs that reduce environmental impact without compromising quality or performance.
Advancements in materials science and concrete technology, including the use of supplementary cementitious materials (SCMs), chemical admixtures, and pre-treatment techniques for RCA, have shown potential to mitigate these drawbacks. However, empirical data and standardized guidelines for their effective application in high-performance concrete are still evolving.
This thesis aims to evaluate the feasibility of using RCA in high-grade concrete by examining

its mechanical properties and durability performance. The study focuses on key durability indicators such as compressive strength retention, permeability, carbonation depth, and resistance to aggressive environmental conditions. The findings are expected to provide a scientific basis for the broader adoption of RCA in structural applications, aligning with sustainable construction practices and reducing the environmental impact of concrete production.

1.3 Need for Study

Natural aggregate resources are depleting rapidly, leading to ecological damage and rising material costs. In this scenario, the use of recycled coarse aggregate (RCA) in high-grade concrete (M60) emerges as a sustainable solution. It not only reduces the environmental burden by minimizing landfill waste and conserving natural resources but also supports the development of eco-friendly, cost-effective construction practices without compromising structural performance.

Objectives

The main objectives of this study are as follows:

- To determine the optimum percentage replacement of Recycled Coarse Aggregates (RCA) in high-grade concrete, where the goal is to identify the maximum proportion of RCA that can be used without significantly compromising the concrete's mechanical properties, durability, and workability.
- To assess the durability of concrete incorporating Recycled Coarse Aggregates (RCA) by performing the Rapid Chloride Penetration Test (RCPT), which evaluates the concrete's resistance to chloride ion ingress. This objective aims to determine the permeability and long-term durability of RCA-based concrete, especially in aggressive environments where chloride-induced corrosion of reinforcement is a major concern.
- To assess the durability of concrete by conducting the four-cycle water permeability test method, which measures the concrete's resistance to water penetration under repeated wetting and drying conditions. This objective aims to evaluate the influence of different replacement levels of Recycled Coarse Aggregates (RCA) on the concrete's pore structure and its ability to prevent water ingress.

Scope of the Study

The study has envisaged with the following scope of work.

- ❖ Check the workability of the concrete using slum test method.
- ❖ Conducting the compressive strength test.
- ❖ Conducting the durability test by RCPT (Rapid Chloride penetration Test) method-ASTM-C-1202
- ❖ Conduction the four-cycle water permeability test as per DIN 1048-05.

Overview of Chapters

- ❖ The work presented in the thesis has been divided into five chapters followed with references.

Literature Review

General

This chapter presents a review of the utilization of recycled coarse aggregate RCA in concrete, and durability of the concrete.

K. Sreenivasa Sudheer et al. worked by substituting some of the cement with bentonite, concrete durability was improved. When bentonite mixtures were 28 days old, he discovered that the compressive strength had decreased. Alkali solution caused just a minor amount of weight loss, but acid attack caused a significant amount of weight loss for all combinations. He came to the conclusion that the sulphate and alkali assaults were not to blame for the rise in compressive strength of concrete mixed with bentonite, but rather, it was related to an increase in age.

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Chetna M. Vyas et al. examined the durability characteristics of concrete using recycled coarse particles to replace some of the native aggregates. They found that 40% was the ideal amount of recycled coarse aggregate.They also came to the conclusion that recycled coarse aggregate may be utilised as construction material, but engineers must make wise choices.

T.Karun Kumar and N.Priyanka carried out an experimental investigation on the strength and durability of concrete by partially substituting the fine aggregate with copper slag and the cement with eggshell powder for concrete of classes M-30 and M-40. They came to the conclusion that 20% to 40% of copper slag was the ideal range.

A.H.L.Swaroop et al. worked on concrete durability experiments using fly ash and ggbs. By submerging the cubes for 7 days, 28 days, and 60 days in the aforementioned solutions, they were able to study the effects of sea water and 1% H2SO4 on the concrete mixes and note the corresponding changes in compressive strength and weight loss. When compared to concrete built with regular conventional aggregate in harsh environmental circumstances, it was found that concrete made with GGBS and fly ash had good strength and durability attributes.

Darshan S. Shah and Jayeshkumar Pitroda worked on an experimental investigation of the resilience and water-absorbing capabilities of pervious concrete. According to their findings, pervious concrete with a concrete mix ratio of 1:6 had less water absorption and better durability, whereas pervious concrete with a concrete mix ratio of 1:10 had less durability and more water absorption. They came to the additional conclusion that the relationship between durability and water absorption is inverse.

Sanjith J et al. Studied on High Strength Ferrochrome Slag Aggregate Concrete in the Chloride and Sulphate Regimes: Durability Characteristics. They came to the conclusion that ferro chrome slag aggregate has better physical characteristics than conventional aggregates. They also came to the conclusion that 75% was the ideal dose for ferro chrome slag.

P Daisy Angelin and P Ravi Kishore worked on studies of the durability of concrete that replaced some of the fine aggregate in an HCl solution with manufacturing sand. They came to the conclusion that 60% was the ideal dose for replacing some of the fine aggregate with industrial sand.

Kosmas K. Sideris et. al. studied how crystalline admixtures affected the durability of concrete. Two reference concretes and two substitute concretes total four different concrete combinations. On concrete slab specimens, the effect of curing on crystal activation was studied. Measured characteristics included compressive strength and several indices of durability. The outcomes showed that adding crystals to the alternative combinations improved their durability and strength.

Experimental Methodology

General

This chosen technique for the use of RCA materials in the concrete is briefly described in this section of the research. The following tests were conducted for this dissertation study: testing of ingredient of design mix and their details, aggregate impact value, aggregate gradation, aggregate specific gravity, water absorption testing, cement testing, water testing, design mix preparation and then tests on design mix, and so on. The primary goal of this research is to make the design mix for the M-60 grade of concrete with four different percentages i.e. 0% (Control Sample), 20%, 30% and 40% of Recycled Coarse Aggregate. The goals of this research are to use of maximum percentage of the recycled coarse aggregate RCA in the design mix. For achieving these goals, the slump test, compressive strength test, durability tests by Rapid Chloride Penetration Test (RCPT) and by four cycle water permeability tests were performed of these four types of concrete.

This chapter will look at a variety at materials and their characteristics, make the design mix with four doses of the Recycled Coarse Aggregate RCA according to the IS: 10262 and

IS:456 after that conduct the compressive strength test and rapid chloride penetration test (RCPT). Several literature reviews were conducted by various component of the mix and testing of the mix's characteristics.

Materials Used

This chapter outlines the materials used and the detailed methodology adopted for experimental investigation. It includes the selection of concrete mix grades, properties of raw materials, mix proportioning, specimen preparation, and the testing procedures conducted to evaluate the behavior of high-grade concrete incorporating recycled concrete aggregate (RCA). The materials used for making the concrete mix design for M-60 grade cube are coarse aggregate, fine aggregate, cement, water, micro silica, recycled coarse aggregate and admixture.

Cement

For this research, OPC-53 grade cement was utilized. The cement is an essential ingredient of the concrete mix and it's providing the strength to the mix. The cement used to prepare the M-60 grade concrete mix will have a major influence on the final characteristics. Because of the significance of cement for mix purpose, various cement tests were conducted to provide us with the necessary knowledge on cement characteristics. The photo 1 shows the OPC cement.

Photo 1Cment OPC-53

In this research, 470 kg /m^3 cement is utilized as a binding material.

Fineness

The particle size distribution of cement is measured to assess its fineness. This is usually done with the use of a special tool, such a sieve or an air permeability device. The outcomes are presented as either a specified surface area or a percentage of cement particles that pass through particular sieves.

Initial setting time and final setting time of the cement

The selected cement kind will be completely mixed and delivered to the melding chamber at a constant temperature of 272 degrees Celsius and a humidity of 65 percent. a Vicat equipment will be utilized to conduct this test. IS 4031(Part 5)-1988 specifies the maximum allowable variation in cement weight. Cement paste with a standard consistency of 0.85 w/c ratio will be produced in the future. The paste shall be gauged with a gauging trowel in accordance with IS: 10086-1992, and the technique will follow IS: 4031(Part 5)-1988. After preparing the paste, quickly fill the Vicat mold by resting it on a nonporous plate. After filling, place it under the rod bearing needle with a diameter of 1.130.05 mm; gently lower the needle until it contacts the top surface of the prepared test block, then release the rod bearing needle and allow the needle to penetrate the block; the needle will initially fully penetrate the block, but we will repeat this process on the text block so that the needle does not penetrate the text block.

3.2.2 Aggregates and Recycled Coarse Aggregate (RCA)

Fresh aggregate is through to be most significant part of the compressive strength and durability of the concrete. Broken stone, or other good quality material should be used as the aggregate. The main aggregate will be bigger than the biggest stone in the grading to be used to ensure that the material is completely crushed. The aggregate must be gray and devoid of organic waste, other harmful materials, and clay balls. The project will be halted if there is excessive rough material or the existence of clay balls, and it must satisfy the following criteria. IS 383:2016, titled "Coarse and fine aggregates for Concrete - Specification," provides guidelines for the quality requirements of aggregates used in concrete. The fresh aggregate shown in the photo 3.

Photo 2Fresh Aggregate

The use of recycled coarse aggregate (RCA) in concrete mix design has gained significant attention as a sustainable solution to address the growing concerns of environmental degradation and the depletion of natural aggregate resources. RCA is primarily sourced from construction and demolition waste, particularly old concrete structures, which are processed through crushing, screening, and cleaning to produce aggregate suitable for reuse in new concrete. Integrating RCA into concrete mix design not only reduces the demand for virgin materials but also minimizes landfill waste, making it an environmentally responsible alternative. The RCA was sieved, washed, and dried before use. Properties such as specific gravity, water absorption, and impact value were determined**.**
It specifies various tests that need to be conducted to assess the suitability of aggregates and recycled coarse aggregate RCA for construction purposes. Some of the important tests are conducted for this study. The Recycled coarse aggregate shown in the photo 4.

Photo 3Recycled coarse aggregate

Gradation test

This test determines the particle size distribution of aggregates and RCA materials. It involves passing the aggregate through a series of sieves and measuring the percentage of material retained on each sieve.

Specific gravity and water absorption

The apparent SG and water-absorbing capacity of aggregate and recycled coarse aggregate RCA are all determined using this test technique as shown in photo 5. We used around 2 kg of aggregate for this, which was then cleaned to eliminate any dirt or fines at the surface of the chosen aggregate. The aggregate was then put into a wire bucket with a mesh size of less than 6 millimeters. It will also be submerged in a water tank at room temperature, with the water level in the tank being 5-mm just above top of the aggregate surface. After then, 25 drips will be supplied by raising the wire buckets at least 25 mm from the water tank's bottom to release trapped air. Then it will stay underwater for another 240.5 hours. The aggregate's weight plus the weight of the wire bucket will then be measured under submerged circumstances without disturbing it. Spread the submerged aggregate over a dry towel to dry its surface, then let it out in the sun for 10 minutes to dry. Subtract the mass of the wired bucket in submerged state from the weight of aggregates and wire bucket in submerged condition to get A. The mass of the dry surface aggregate is then be taken as B, and the dry surface aggregate will be oven-dried for 240.5 hours at 110°C. The specific gravity of the dry aggregate will be determined using the formula provided in IS: 2386(Part 3)-1963 after it has been oven dried.

Flakiness index and elongation index

The flakiness index and elongation index test determine the shape characteristics of coarse aggregates and RAC. Flakiness index measures the percentage of flat and elongated particles, while elongation index measures the percentage of elongated particles. The presence of such particles affects the workability and strength of concrete. The flakiness and elongated testing gauge as specified in IS: 2386 (Part-4)-1963, was utilized for this test.

The physical characteristics of fresh coarse aggregate and recycled coarse aggregate have a significant role in the development of strength, and durability. In this study 20mm, 10 mm coarse fresh aggregate, 20mm and 10 mm of RCA and fine aggregate are used. Physical properties of aggregate are shown in table 2

Table 1Fresh Aggregate and RCA tests result

	Test results of fresh coarse aggregate, RCA					
S. No .	**Test**	**Test Method**	**Fresh Aggerate Result 10mm**	**Fresh Aggerate Result 20mm**	**RCA Result 10mm**	**RCA Result 20mm**
1	Sieve Analysis, % of Passing	IS 2386(Pt-I):1963 Reaff-2011				
	40mm			100		100
	20mm			91.3		93.2
	12.5mm		100		100	
	10mm		86.4	5.4	85.2	6.1
	4.75mm		12.7	1.1	10.5	2.1
	2.36 mm		2.8		3.1	
2	Elongation Index, %	IS 2386(Pt-I):1963 Reaff-2011	17.6	14.20	16.8	15.6
3	Flakiness Index, %	IS 2386(Pt-I):1963 Reaff-2011	15.1	18.6	16.1	15.2
4	Combined Flakiness & Elongation Index, %	IS 2386(Pt-I):1963 Reaff-2011	32.7	32.8	32.9	30.8
6	Specific Gravity	IS 2386(P-III):1963 Reaff-2011	2.65	2.71	2.64	2.69
7	Water Absorption, %	IS 2386(P-III):1963 Reaff-2011	0.65	0.42	0.70	0.45

8	Bulk Density, kg/litre	IS 2386(P-III):1963 Reaff-2011	1.55	1.51	1.52	1.50
9	Aggregate Crushing Value, %	IS2386(P-IV):1963 Reaff-2011	22.0	20.0	23.5	21.6
10	Los angles Abrasion Value,%	IS2386(P-IV):1963 Reaff-2011	25	23.0	26.8	25.1
11	Aggregate Impact Value, %	IS2386(P-IV):1963 Reaff-2011	19	17	20.2	18.5

Table 2 Fine aggregate tests result

Test results of fine aggregate			
S. No.	**Test**	**Test Method**	**Fine Aggregate**
1	Sieve Analysis, % of Passing	IS 2386(Pt-I):1963 Reaff-2011	
	10mm		100
	4.75mm		93.4
	2.36 mm		77.2
	1.18mm		60.5
	600 micron		53.1
	300 micron		26.2
	150 micron		7.5
2	Specific Gravity	IS 2386(P-III):1963 Reaff-2011	2.62
3	Water Absorption, %	IS 2386(P-III):1963 Reaff-2011	1.14
4	Bulk Density, kg/litre	IS 2386(P-III):1963 Reaff-2011	1.72

Rapid Chloride Penetration Test

The Rapid Chloride Penetration Test (RCPT) is a widely used method to assess the durability of concrete and evaluate its resistance to chloride ion penetration. It provides an indication of the concrete's ability to withstand chloride attack, which is one of the main causes of concrete deterioration, especially in marine and coastal environments or where deicing salts are used.

In this study, a cubical concrete specimen is subjected to an electrical potential gradient, simulating the movement of chloride ions through the concrete shown in the photo 13. The test measures the quantity of electrical charge passed through the specimen over a specific duration of time. This charge, known as coulombs, correlates with the amount of chloride ions that have penetrated the concrete.

: Results and Discussion

This chapter presents the results obtained from the experimental investigation of high-grade concrete mixes incorporating recycled coarse aggregate (RCA). The outcomes of tests on workability, compressive strength, rapid chloride penetration test and 4 cycle water permeability test parameters are analyzed and discussed. The behavior of concrete mixes with different RCA replacement levels (0%, 20%, 30%, and 40%) is compared for concrete grades M60.

Workability test result

The workability of the concrete was measured using the slump cone test method and the slump was measured in the millimeter after the one hours. The results of the slump test for all four types of concrete mixture i.e. 0%, 20%, 30% and 40% recycled coarse aggregate in the concrete are tabulated in the table 6.

Table 3Slump test result

Mix type	Slump, mm
0% RCA	90
20% RCA	85
30% RCA	75
40% RCA	70

After the slump test of all four mixes of concrete it was observed that the slump decreased with higher RCA content due to rough surface texture and higher water absorption. The slump was reduced from 90 mm to 70 mm at 0% to 40 % of the RCA. The workability was manageable using superplasticizers.

Compressive strength test result

To know the compressive strength of the concrete with different percentage of the recycled coarse aggregate RCA 150 mm concrete cube are tested. The compressive strength test results at 7 days and 28 days are shown in table 7 and 28 respectively and the graph 1 shows the compression of the compressive strength vs. percentage of RCA used in concrete.

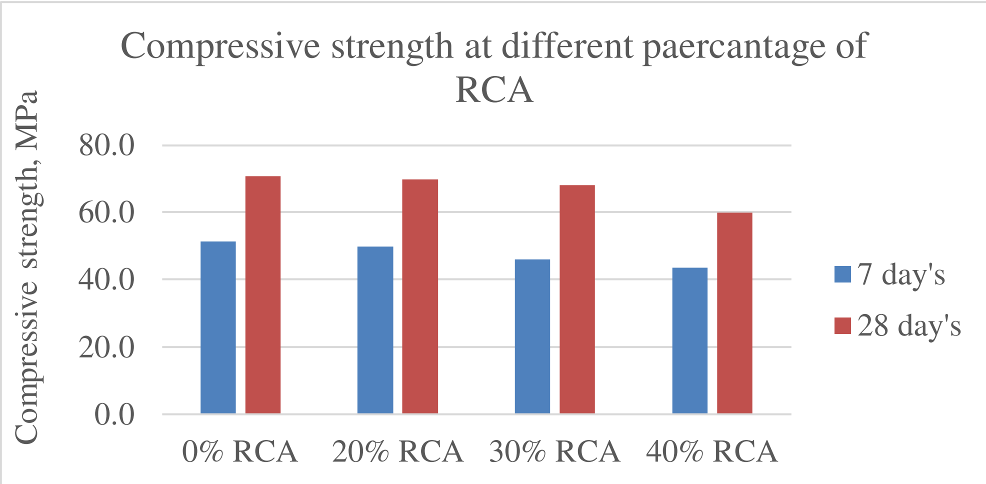
Table 4, 7 days compressive strength

	7 day's Compressive strength, N/mm^2			
Sample/Mix type	**0% RCA**	**20% RCA**	**30% RCA**	**40% RCA**
1	51.5	50.2	48.6	44.3
2	50.9	50.6	49.2	43.6
3	51.8	48.5	40.1	42.9
Average =	**51.4**	**49.8**	**46.0**	**43.6**

Table 5 28 days compressive strength

	28 day's Compressive strength, N/mm^2			
Sample/Mix type	**0% RCA**	**20% RCA**	**30% RCA**	**40% RCA**
1	70.6	69.5	67.9	60.2

2	70.1	70	68.4	59.2
3	71.3	69.8	67.9	60.1
Average =	**70.7**	**69.8**	**68.1**	**59.8**



Graph 1Compressive strength at 7 & 28 days vs. percentage of RCA

After the obtained compressive strength test results at 7 days and 28 days it was noted that the strength decreased with increasing the RCA percentage. It is also noted that the up to 30%RCA, strength remained nearby target strength of the concrete but above the 30%RCA, a significant drop in compressive strength was observed.

Rapid Chloride Penetration Test Result

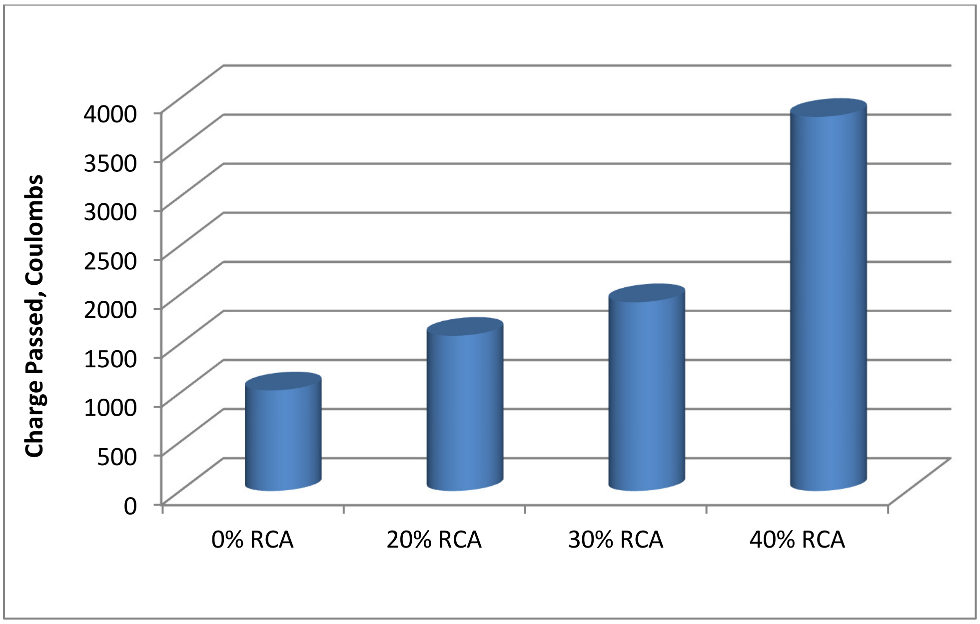
The Rapid chloride penetration test measures the quantity of electrical charge passed through the specimen over a specific duration of time. This charge, known as coulombs, correlates with the amount of chloride ions that have penetrated the concrete. The test result of the different four percentage of RCA in the concrete mix are tabulated in the table 9 and the graph 2 shows the RCPT test results. The table 10 shows the Chloride Ion penetrability based on charged passed (As Per ASTM C 1202-22)

Table 6 Rapid chloride penetration test result

	After 28 day's Charge Passed, Coulombs			
Sample/Mix type	**0% RCA**	**20% RCA**	**30% RCA**	**40% RCA**
1	1018	1536	1958	3862
2	1023	1584	1950	3732
3	1034	1624	1862	3841
Average =	**1025**	**1581**	**1923**	**3812**

Table 7Chloride Ion penetrability based on charged passed (As Per ASTM C 1202-22)

S.No.	Charge Passed, Coulombs	Chlorine Ion Penetrability
1	>4000	High
2	2000-4000	Moderate
3	1000-2000	Low
4	100-1000	Very Low
5	<100	Negligible



Graph 2Charge passed vs. percentage of RCA

After analyzing the RCPT test results it was observed the RCA concrete was more vulnerable to acid attack due to micro-cracks and residual mortar. The 0% RCA concrete has low chlorine ion penetrability while 40% of RCA concrete has the moderate chlorine ion penetrability.

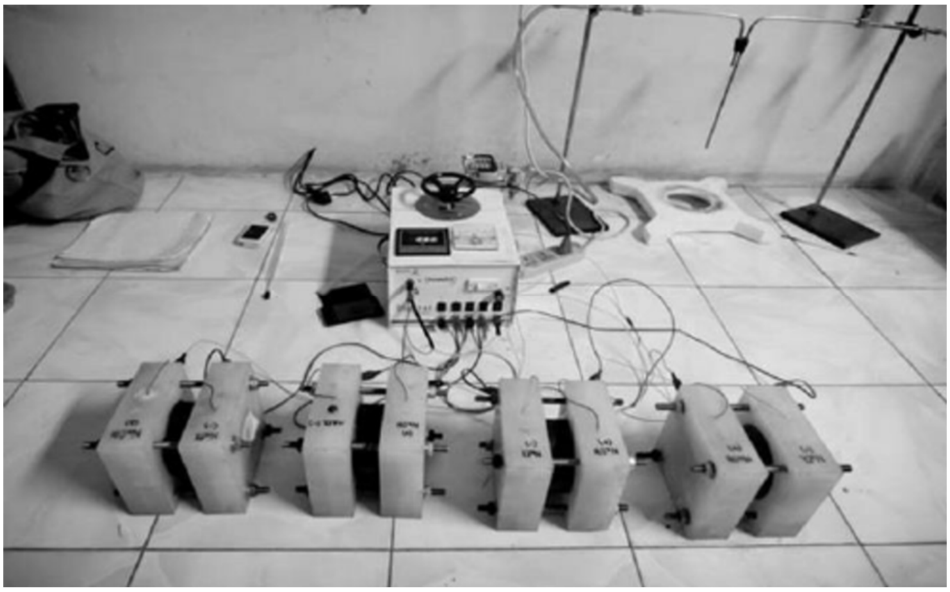


Photo 4RCPT test setup

CONCLUSIONS

This chapter illustrates the fructuous conclusion that can be drawn from the investigation of utilization of recycled coarse aggregate (RCA) in high-grade concrete (M60) and evaluation of its strength and durability. Several experiments with different percentage of RCA have been performed in the lab and several conclusions have been made. The main aim of this experiment is to evaluate the mechanical properties of high-grade concrete with RCA, to determine the optimum percentage replacement of RCA and to assess the durability of concrete using RCA through the rapid chloride penetration test (RCPT) and Water permeability test.

These are some conclusions that have been derived in this study.

1. Water penetration increased with RCA percentage, indicating higher porosity.
2. The water permeability in term of depth of water penetration are increase an amount 0.7 mm, 2.0 mm and 3.9 mm by adding the RCA of percentage 20%, 30% and 40% of the coarse aggregate.
3. Acid and sulfate resistance reduced with higher RCA levels, but concrete remained moderately resistant up to 40% replacement.
4. The chlorine ion permeability test shows that the ion permeability inside the concrete confinement is hugely increased by up to 271.9% by adding the RCA of doses 40% of the coarse aggregate.
5. RCA replacement up to 30% is recommended for M60 concrete grades.

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