INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 09, September 2025, pp : 860-866
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

UTILIZATION OF RECYCLED COARSE AGGREGATE IN HIGH-GRADE CONCRETE (M60)

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ABSTRACT

Concrete is the most widely used construction material in the world, forming the backbone of modern infrastructure. Its primary ingredients—cement, water, fine and coarse aggregates—are consumed in enormous quantities, placing increasing pressure on natural resources. Among these, coarse aggregates make up a significant portion by volume, and their continuous extraction from natural sources such as riverbeds and quarries has raised serious environmental and ecological concerns, including resource depletion, landscape disruption, and increased carbon emissions. This study investigates the effects of recycled coarse aggregate (RCA) as a partial replacement for natural aggregates in M60 grade concrete. The research focuses on the workability, mechanical strength, and durability performance of concrete incorporating varying RCA percentages. It was observed that the slump value decreased with increasing RCA content due to the rougher texture and higher water absorption capacity of recycled aggregates. However, the use of superplasticizers effectively maintained workability even with up to 30% RCA replacement.

1. INTRODUCTION

1.1 General

Concrete is the most widely used construction material in the world, forming the backbone of modern infrastructure. Its primary ingredients—cement, water, fine and coarse aggregates—are consumed in enormous quantities, placing increasing pressure on natural resources. Among these, coarse aggregates make up a significant portion by volume, and their continuous extraction from natural sources such as riverbeds and quarries has raised serious environmental and ecological concerns, including resource depletion, landscape disruption, and increased carbon emissions.

1.2 At the same time, the construction industry is a major contributor to solid waste, especially in the form of construction and demolition (C&D) debris. This waste, if not properly managed, contributes to environmental pollution and occupies valuable landfill space. In response to these challenges, researchers and engineers have increasingly focused on sustainable alternatives, one of which is the use of recycled coarse aggregate (RCA) obtained from processed C&D waste. By replacing natural coarse aggregates with RCA, it is possible to address both material scarcity and waste management concerns, aligning with global goals for sustainable development and circular economy practices.

1.2Need for Study

With the rapid increase in demolition activities due to urbanization, infrastructure renewal, and population growth, the generation of construction and demolition (C&D) waste has become a major environmental concern. At the same time, 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.

1.3 Objectives

The main objectives of this study are as follows:

- To evaluate the mechanical properties of high-grade concrete with Recycled Coarse Aggregates (RCA), with a specific focus on assessing its compressive strength under varying replacement levels. The aim is to determine the feasibility of using RCA in producing M60 grade concrete without significantly compromising strength characteristics. This evaluation will provide insights into the structural performance, sustainability potential, and practical applications of RCA-based high-strength concrete in modern construction practices
- To evaluate the workability of concrete by conducting the slump test method, which provides a quantitative measure of the concrete's consistency and ease of placement. This objective aims to assess how factors such as water content, admixtures, and the use of alternative aggregates (like recycled coarse aggregates) affect the fresh properties of high-grade concrete.

1.4 Scope of the Study

The study has envisaged with the following scope of work.

- To determine the fundamental properties of the ingredients in concrete.
- To determine the fundamental properties of the recycled coarse aggregate.
- Casting of the samples with four different doses of recycled coarse aggregate RCA.
- Check the workability of the concrete using slum test method.

2. LITERATURE REVIEW

2.1 General

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

2.2 Use of RCA in Concrete

The intensified global focus on sustainable construction has accelerated research into replacing natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) sourced from construction and demolition waste. RCA typically exhibits higher water absorption, lower density, increased porosity, and residual adhered mortar—all factors known to detrimentally affect performance unless properly managed. Sasanipour and Aslani (2020) attributed these drawbacks to the porosity introduced by attached mortar, while Muduli and Mukharjee (2020) reported that RCA derived from high-strength parent concrete demonstrated improved interfacial transition zones and lower porosity.

Significant reductions in compressive strength (5–30%) and modulus of elasticity (typically larger than strength losses) have been documented, with effects intensifying at higher RCA replacement levels . For instance, Pacheco et al. (2019) noted that RCA's intrinsic porosity adversely affects stiffness and elastic modulus. Splitting tensile strength appears less sensitive to RCA incorporation, showing comparatively minor reductions. Moreover, shrinkage and permeability are generally elevated in RCA concrete, posing potential long-term durability concerns.

Despite these challenges, numerous studies illustrate that concrete with partial RCA replacement (20–50%) can deliver performance comparable to conventional mixes. This viability hinges on effective processing techniques—including cleaning, grading, and treatment—and tailored mix designs. Hansen (1992) and others suggest up to 30% RCA in structural applications is acceptable under proper control .

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.

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

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characteristics than conventional aggregates. They also came to the conclusion that 75% was the ideal dose for ferro chrome slag.

3. EXPERIMENTAL METHODOLOGY

3.1 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.

3.2 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. The first setting time of cement is calculated as the period between water inputs and time when the needle does not penetrated the block 50.5 mm from the bottommost side. To determine the F.S.T, exchange the rod bearing needle of the Vicat apparatus with a 50.05 mm annular ring diameter coupled to a 10-mm diameter collar. The ultimate set of cement paste is when the replacement annular ring with a collar makes a mark over the block top but not by the collar, and no further penetration occurs. FST is measured from the time amid water applications to the time when the needle leaves only an impression on the block surface. The setting time test is progress shown in the photo 2.

Photo 1 Setting time test in progress

Soundness

This test determines the ability of cement to retain its volume after hardening and to resist excessive expansion. The most common test method is the Le Chatelier test, where the length change of a cement specimen is measured after subjecting it to specific conditions of temperature and pressure.

Compressive Strength

Compressive strength is one of the most important properties of cement and concrete. It measures the ability of cement to withstand loads and is determined by objecting cement mortar cubes or cylinders to compressive forces until failure. The test results are used to assess the quality and performance of the cement.

In this study, cement will be used for the preparation of concrete mix of grade M-60. Cement will be responsible for the generation of the structural bond between aggregate in the concrete mix. For this purpose, the used cement properties that have been obtained from some perimetral work are shown in Table 3.1

Table 3.1: Cement test result

S.No	Physical Parameter	Test Method	Results	Requirement IS:269:2015 Grade 53
1	Fineness (m^2/kg)	IS 4031 (P-2)-1999	270	225 Min.
2	Soundness			
	a)By Le-chatelier (mm)	IS 4031 (P-3)-1988	2.5	10 Max.
	b)By Autoclave Expansion (%)	IS 4031 (P-3)-1988	0.06	0.8 Max.
3	Setting time (minutes)			
	a)Initial	IS 4031 (P-5)-1988	145	30 Min.
	b)Final	IS 4031 (P-5)-1988	250	600 Max.
4	Compressive Strength, Mpa			
	a) 72± 1 hours	IS 4031 (P-6)-1988	36.5	27 Min.
	b) 168± 2 hours	IS 4031 (P-6)-1988	45.0	37 Min.
	c) 672± 4 hours	IS 4031 (P-6)-1988	61.5	53 Min.
5	Consistency,%	IS 4031 (P-4)-1988	28.2	-
Looking over the obtained result, cement used in this study can be classified as OPC 53 grade.				

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

3.3 Mix Design

Mix design is a crucial process in the production of concrete, as it determines the proportions of various ingredients that will result in a concrete mix with desired properties. The mix design takes into account factors such as strength, durability, workability, and economy. By carefully selecting and proportioning the constituents of concrete, engineers and concrete producers can achieve optimal performance for specific applications. To design a concrete mix as per Indian Standard (IS) code, specifically IS 10262:2019.

In this Study, Mix design was done for M-60 grade of concrete with ordinary Portland cement OPC- 53. The four types of mixture of a grade M-60 were prepared according to IS: 10262. The water cementanious ration i.e. 0.28% and all the ingredient are same for all the four types of mixture but for the aching the workability the admixture content differ in four doses of RCA 0% (Control mix), 20%, 30% and 40% by weight of total coarse aggregate in the mix proportion.

The mix calculations steps for per unit volume of concrete shall be as follows:

a. Volume of concrete = 1 m^3

b. Volume of cement = $\frac{\text{mass of cement}}{\text{specific gravity of cement}} \times \frac{1}{1000}$

c. Volume of micro silica $= \frac{\text{mass of micro silica}}{\text{specific gravity of micro silica}} \times \frac{1}{1000}$

d. Volume of Admixture $= \frac{\text{mass of admixture}}{\text{specific gravity of admixture}} \times \frac{1}{1000}$

e. Volume of all in aggregate = [a - (b + c + d)]

f. Mass of coarse aggregate = f x volume of coarse aggregate x specific gravity of coarse aggregate x 1000

g. Mass of fine aggregate = f x volume of fine aggregate x specific gravity of coarse aggregate x 1000

h. Mass of recycled coarse aggregate RCA = f x volume of RCA aggregate x specific gravity of RCA aggregate x 1000

4. 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.

4.1 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 4.1.

Table 4.1: Slump 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.

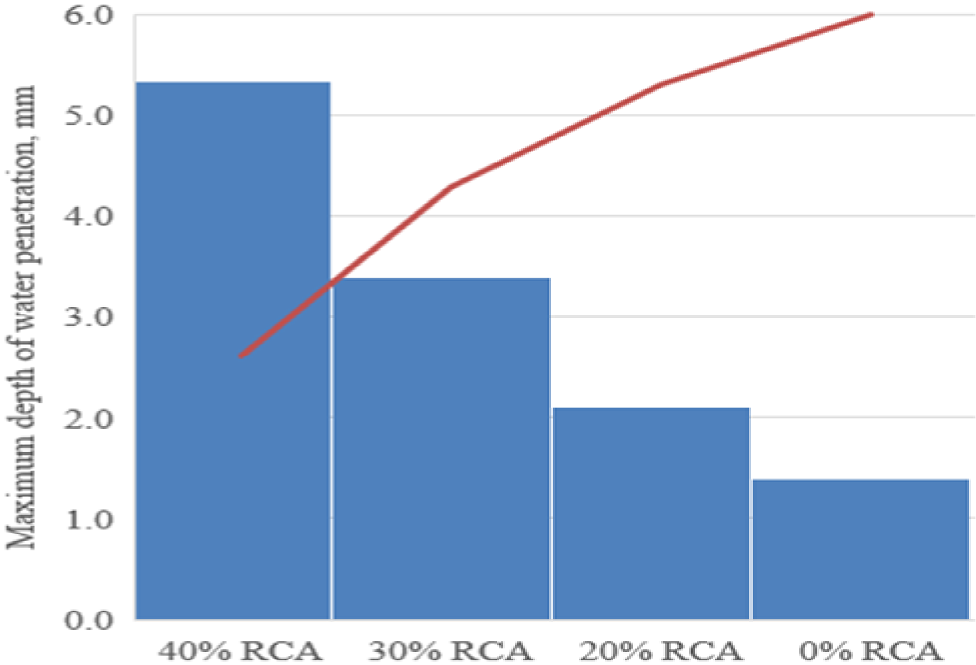
Water Permeability Test Result

Depth of water penetration was measured in mm after completed the four cycles. Depth of penetration depends upon the materials, method of cube casting, water cement ratio and grade of the concrete. The result is tabulated in the table 4.2 and increment of the water penetration shown in graph 3.

Table 4.2: Water permeability test result

	Average depth of penetration, mm			
Sample/Mix type	**0% RCA**	**20% RCA**	**30% RCA**	**40% RCA**
1	1.1	1.9	3.6	5.3
2	1.6	2.1	3.2	5.1
3	1.5	2.3	3.4	5.6
Average =	**1.4**	**2.1**	**3.4**	**5.3**

The water permeability test result shows, the average maximum depth of water penetration increase with increase the percentage of RCA in the concrete. The maximum water penetration in crease 1.4 mm to 5.3mm for the 0% RCA to 40% RCA in the concrete.



Graph 4.1: Maximum depth of water penetration vs. percentage of RCA

5. CONCLUSION

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. Based on the outcomes, practical recommendations are proposed for the effective utilization of RCA in structural and sustainable construction applications.

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

1. The slump value decreased with an increase in RCA content due to the rough texture and higher water absorption of recycled aggregates. The use of superplasticizers helped to maintain workable mixes even with up to 50% RCA.
2. Acceptable strength was maintained up to 35% RCA replacement M60 concrete grades. Beyond this, strength significantly declined.
3. In this study, the experimental results shows that the compressive strength after 7 days is decreased by an amount of 3.2%, 10.6% and 15.2 % vis-a-vis by adding the RCA of doses 20%, 30% and 40% of the coarse aggregate.
4. Based on the Experimental Results the compressive strength after 28 days is decreased by an amount of 1.3%, 3.7% and 15.3 % by adding the RCA of doses 20%, 30% and 40% of the coarse aggregate.

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