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PARTIAL REPLACEMENT OF STANDRAD COARSE AGGREGATE BY RECYCLED AGGREGATE

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Abstract:
The use of recycled concrete aggregate (RCA) in concrete, as both partial and full replacements for natural coarse aggregate, is gaining traction in the construction industry. This practice not only reduces the demand for virgin aggregate but also offers a solution to the environmental issues posed by concrete waste and the extraction of natural resources. This study aims to develop an economically viable solution using recycled aggregate in structural concrete to mitigate environmental impact.
The objective is to investigate the properties of recycled aggregate and assess the performance of concrete when standard coarse aggregates are replaced with RCA in varying percentages. Concrete performance is evaluated based on compressive and flexural strength with RCA replacement levels at 15%, 30%, 45%, and 60%. The mix designed for this study is of Grade M25. Non-destructive testing, specifically the Rebound Hammer Test, is also conducted on the concrete. Experimental results indicate that the optimum RCA replacement level is up to 45% for compressive strength and up to 30% for flexural strength.

Introduction:
Concrete is the most widely used material in the global construction industry. It is a manufactured product comprising cement, aggregates, water, and admixtures. Aggregates, which include sand, crushed stones, and gravel, form a major portion of the concrete mixture. Construction aggregates account for more than 80 percent of the total aggregate market and are primarily used in building constructions and pavements.
Concrete recycling is crucial as it conserves natural resources and reduces waste disposal by utilizing existing concrete as an aggregate source for new concrete or other applications. Typically, after the demolition of old roads and buildings, the removed concrete is discarded as waste. However, this

concrete can be collected and processed to create recycled concrete aggregate (RCA). Recycled aggregates are derived from processing materials previously used in construction, such as recycled concrete from construction and demolition (C&D) waste, reclaimed aggregate from asphalt pavement, and scrap tires.

Benefits of Using Recycled Aggregates

****Cost Effective****

Recycled aggregates offer a cost-effective alternative without sacrificing quality. They meet the same standards as new aggregates from quarries. Additionally, if produced locally, they reduce transportation costs.

****Eco-friendly****

Recycled aggregates are environmentally friendly, aiding the construction industry's efforts to lower emissions. They can effectively replace concrete and cement, reducing the need for resource-intensive gravel mining, which harms the environment by clearing vegetation for digging. Recycling gravel from construction sites diminishes the necessity for ongoing mining.

****Sustainability****

Recycling concrete enhances sustainability by decreasing landfill waste and allowing excess materials like metal to be recycled. This process reduces the demand for virgin aggregate, lessening the environmental impact of aggregate extraction operations.

Applications of Recycled Concrete Aggregates (RCA)

After processing, recycled concrete aggregates can be utilized in various construction projects, including:

- **Bridge Foundations:** Used in foundational work for bridges, providing a stable and durable base.
- **Structural Grade Concrete:** Suitable for structural concrete applications, ensuring strength and integrity.
- **Lean-Concrete:** Ideal for lean concrete mixtures, often used in sub-base layers and other non-structural applications.
- **Freeways:** Utilized in the construction of highway foundations and layers.
- **Bituminous Concrete:** Incorporated into asphalt mixtures for paving and road construction.
- **Aggregate in Lean Concrete:** Used as an aggregate in lean concrete for various construction needs.
- **Airport Runways:** Suitable for constructing or refurbishing airport runways due to its durability.
- **Pavements:** Ideal for creating durable and long-lasting pavements.
- **Shoulders:** Applied in the construction of road shoulders to ensure stability and strength.
- **Median Barriers:** Used in making median barriers for highways to enhance safety.
- **Sidewalks:** Effective for constructing sidewalks, providing a durable walking surface.

- **Curbs and Gutters:** Suitable for making curbs and gutters in urban infrastructure projects.
- **Soil-Cement Pavement Bases:** Used in soil-cement bases for pavement, improving the load-bearing capacity.
- **Oil and Gas Civil Construction Projects:** Utilized in various construction activities within the oil and gas sector, providing a cost-effective and sustainable material option.

Steps of Creating Recycled Aggregate

1. **Pre-sorting of Source Material**

- **Arrival and Initial Sorting:** Upon arrival at the recycling plant, demolition materials undergo initial sorting to separate steel, wood, Gyprock, chipboard, fiberboard, paper, light mass, concrete, and heavy fines.
- **Screening Dirty Concrete:** All contaminated concrete is unloaded from the truck and passed through a screen.

2. **Primary Crushing Plant**

- **Initial Crushing:** The material enters the primary crushing plant, starting with the Pulverize Excavator, which breaks the concrete into half-meter round pieces. This machine is an impact crusher.
- **Scalping:** Soil and clay balls are removed using a 25mm scalping screen.
- **Jaw Crusher:** The material then enters the primary crusher (usually a jaw crusher) which reduces it to 100-150mm sized aggregate.

3. **Secondary Crushing Plant**

- **Picking Station:** Crushed material from the primary plant passes through a picker station where personnel remove any remaining wood, reinforced steel, plastics, and other large objects.
- **Electromagnetic Separation:** Magnets remove any remaining metallic scrap.
- **Separation Methods:**
  - **Wet Separation:** The material goes through a water engine where low-density foreign materials are removed using water jets and a float/sink tank, producing very clean aggregate.
  - **Dry Separation:** Blowing air is used to remove lighter particles from the heavier concrete material. The recycled aggregate is typically blown at least twice, often three times.
- **Secondary Crushing:** The cleaned material enters the secondary crushing plant. The crusher is set to a specific size, and the crushed material is then passed through various screens that sort the aggregate into different sizes.
- **Recycling Oversized Aggregate:** Aggregate that is too large returns to the electromagnetic separation, passes through the air knives, and cycles back into the secondary crusher.

LITERATURE REVIEW

Research on Recycled Aggregate Concrete

Janani Sundar's Study on Chemical Admixture Impact on Recycled Aggregate Concrete

Janani Sundar explored the effect of chemical admixtures on recycled aggregate concrete. The study focused on reclaiming aggregates from old concrete and using them to create durable, normal-strength concrete with 100% recycled concrete aggregate. Chemical admixtures with a specific gravity of 1.19 were added to enhance the properties of the recycled aggregate concrete. The old concrete debris was broken down to the required aggregate size, and basic tests were performed. The compressive strength of this recycled aggregate concrete was compared to that of concrete made with normal aggregates.

Key Findings:

- The density of recycled aggregates is lower than that of normal natural aggregates, resulting in decreased density of the concrete.
- Chemical admixtures were added at 1.5%, 1.8%, and 2% of the weight of cement.
- The compressive strength of concrete with 1.8% chemical admixture was found to be similar to that of concrete made with normal aggregates.

Ankit Sahay's Study on Recycled Aggregate Concrete in Construction Waste Management

Ankit Sahay conducted an experimental study comparing natural aggregate (NA) and recycled aggregate (RA) in various proportions for their efficacy in two concrete mixes (M20 and M25). The proportions of NA to RA tested were 0:100, 60:40, 70:30, 80:20, and 100:0. Various tests, including the Impact Value Test, Abrasion Value Test, Aggregate Crushing Test, and Compression Test, were performed on both mixes to draw specific conclusions.

Key Findings:

- The mix proportions of 70:30 and 80:20 consistently yielded better results compared to the 60:40 mix.
- These proportions (70:30 and 80:20) are recommended for sustainable and economic concrete development.
- Recycled aggregate concrete in these proportions is suitable for low-level construction works such as pavements.

Amnon Katz's Study on Recycled Aggregate from Partially Hydrated Old Concrete

Amnon Katz investigated the properties of concrete made with recycled aggregates derived from partially hydrated old concrete. Concrete with a 28-day compressive strength of 28 MPa was crushed at 1, 3, and 28 days to simulate precast concrete plant conditions. The recycled aggregates were tested for their properties and used to create new concrete with nearly 100% aggregate replacement. Key observations included:

- Significant differences between properties of recycled aggregates across various particle sizes.
- Minimal impact of the crushing age on the properties of the aggregates.
- Concrete made with aggregates crushed at 3 days showed better properties with a strong cement matrix.
- Recycled aggregates crushed at different ages had similar properties.
- Aggregates crushed at 1 day retained some cementing capacity, which diminished rapidly within days.

Gurukanth S's Study on Recycled Aggregates in Bituminous Concrete

Gurukanth S explored the use of recycled concrete aggregates (RA) in bituminous concrete surface courses. This study aimed to balance the demand and supply of construction materials while reducing environmental impact. The strength variations in bituminous concrete with partial or full replacement of natural aggregates were examined using Marshall's method. Findings included:

- Replacing natural aggregates with recycled aggregates up to 20% in bituminous concrete surface courses is feasible without significant strength loss.
- Increased binder content is required, necessitating an economic evaluation of the replacement.

S. R. Yadav's Review on Recycled Concrete Aggregate

S. R. Yadav reviewed existing literature on using recycled concrete as aggregates, focusing on compressive strength. The study emphasized maintaining required compressive strength for second-generation concrete using old concrete. Key points from the literature review included:

- Compressive strength depends on factors like adhered mortar, water absorption, Los Angeles abrasion, aggregate size, parent concrete strength, curing age, replacement ratio, interfacial transition zone, moisture state, impurities, and controlled environmental conditions.
- Despite extensive research, the construction industry lacks a simple and cost-effective method for using recycled aggregates in second-generation concrete.
- The need for a practical mix design procedure considering adhered mortar percentage and mix composition calculation was highlighted.

Bruno Andre's Life Cycle Assessment of Recycled Aggregates

Bruno Andre conducted a life cycle assessment (LCA) to analyze the environmental impacts of using recycled aggregates in concrete production. The study highlighted the significant environmental advantages of recycled aggregates over natural aggregates throughout the life cycle of concrete. By analyzing three scenarios with the help of Semipro software, the study quantified the environmental impacts based on data from Unibet and Ambisider. The LCA found that recycled aggregates offer substantial benefits in terms of reduced environmental impact during concrete's life cycle.

Shailendrakumar's Study on Tensile and Compressive Strength

Shailendrakumar explored the relationship between split tensile strength and compressive strength in recycled concrete aggregate (RCA) concrete. The study compared controlled concrete with concrete containing 0%, 50%, and 100% RCA, using superplasticizer Conplast SP 430 (M) for desired workability. The results showed that RCA has lower specific gravity and higher water absorption, crushing value, impact value, and abrasion value. However, the tensile strength of RCA concrete primarily depended on its compressive strength, similar to natural aggregate concrete.

Chaurpagar's Investigation on RCA with Steel Fibers and Polymer

Chaurpagar examined the physical and mechanical properties of RCA with and without steel fibers and polymer. Specimens were prepared with varying water-cement ratios and polymer volumes (2.5%, 5.0%, and 10% by weight of cement) and a constant 0.5% steel fiber volume. The study found that RCA had higher specific gravity, absorption capacity, and mechanical resistance than conventional aggregates. Adding polymer and steel fibers significantly increased the split tensile strength and flexural strength of RCA concrete, making it suitable for earthquake-resistant structures due to improved ductility and toughness.

Limbachiya's Performance Study of Portland Cement Concrete

Limbachiya's report focused on the performance of Portland Cement Concrete made with natural and coarse aggregates, including RCA. The study revealed that RCA had a lower density (3-10% less) and higher water absorption (3-5 times more) due to attached cement paste. Despite these differences, the study found no significant variation in concrete strength across RCA samples from four different sources at the same RCA content.

Natesan's Mechanical Properties Investigation

Natesan conducted an experimental study on the mechanical properties of concrete with partial replacement of natural coarse aggregate with RCA. The study concluded that RCA enhances the mechanical properties of conventional concrete. A mix of 75% RCA and 25% natural aggregates demonstrated good mechanical properties, with RCA's rough surface promoting better bonding with the cement mix.

Objectives:

This study aims to investigate the influence of recycled aggregate on the mechanical properties of concrete. Specifically, the research will focus on:

1. **Evaluating the impact of recycled aggregate content** on the compressive and flexural strength of concrete.
2. **Determining the optimal replacement ratio** of natural aggregate with recycled aggregate to achieve desired strength characteristics in concrete.

SYSTEM DEVELOPMENT

This project explores the potential of replacing standard coarse aggregates with recycled aggregates (RCA) in concrete production.

Background:

- **Recycled Aggregates:** RCA is a sustainable alternative to natural aggregates, reducing environmental impact by diverting construction waste from landfills. However, it differs from natural aggregates in several ways:
  - Rougher surface texture: This reduces packing efficiency, potentially leading to higher water absorption and lower strength.
  - Increased surface area: This can affect water content and workability of the concrete mix.

Objectives:

- **Evaluate the effect of RCA content on compressive strength:** The project will investigate how different replacement percentages of natural aggregate with RCA (15%, 30%, 45%, and 60%) influence the compressive strength of M25 grade concrete.
- **Optimize RCA replacement ratio:** By analyzing the results, the project aims to identify the optimal range for RCA replacement that balances strength and environmental benefits.

Methodology:

1. **Concrete Mix Design:** Develop an M25 grade concrete mix design with varying percentages of RCA replacing standard coarse aggregates.

2. **Specimen Preparation:** Prepare concrete specimens according to the designed mix proportions.
3. **Compressive Strength Testing:** Conduct compressive strength tests on the prepared specimens to determine their strength under load.
4. **Data Analysis and Optimization:** Analyze the test results to identify the optimal RCA replacement ratio for achieving desired strength while minimizing negative impacts on compressive strength.

Expected Outcomes:

- Establish the relationship between RCA content and compressive strength of M25 concrete.
- Identify the optimal RCA replacement ratio that balances strength and environmental benefits.
- Gain valuable insights for sustainable concrete production using recycled aggregates.

Materials

3.1.1 Cement

In this study, ordinary Portland cement (OPC) of grade 43 from the local market was used. The cement was tested according to IS 4031-1988 standards and met the requirements of IS 12269-1987. The fineness was 2250 cm^2/gm, and the specific gravity was 3.15.

Tests on Cement

A. Standard Consistency Test

- **Objective**: To determine the water content required to produce a cement paste of standard consistency as specified by IS: 4031(Part 4) – 1988.
- **Principle**: The standard consistency of cement is the consistency at which the Vicat plunger penetrates to a point 5-7mm from the bottom of the Vicat mould.
- **Result**: Consistency = 140 ml

B. Initial Setting Time

- **Method**: Determined using Vicat's apparatus with the standard needle, as per IS: 4031 (Part 5) 1988.
- **Procedure**: Cement is mixed with 0.85 times the water required for standard consistency.
  - Water content: 0.85 × 140 = 120 ml
- **Requirement**: For OPC, the initial setting time should not be less than 30 minutes.
- **Result**: Initial setting time = 37 min

C. Final Setting Time

- **Objective**: To determine the final setting time as per IS: 4031 (Part 4) 1988.
- **Method**: Using Vicat's apparatus with the needle. The time elapsed since the addition of water to the cement until the needle with an annular collar can only make a mark on the hardened surface.
- **Requirement**: For OPC, the final setting time should not be more than 10 hours.
- **Result**: Final setting time = 560 min

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Design Mix (IS 10262:2019)

1.1.1 Data for Mix Proportioning
- **Grade Designation:** M25
- **Type of Cement:** Ordinary Portland Cement (OPC)
- **Grade of Cement:** 43 grade
- **Maximum Nominal Size of Aggregate:** 20mm
- **Exposure Condition:** Medium (Table 3 & 5 IS 456:2000)
- **Workability Required at the Time of Placement:** 100mm to 125mm
- **Type of Coarse Aggregate:** Granular
- **Type of Fine Aggregate:** Crushed Sand
- **Minimum Cement Content:** 300 kg
- **Maximum Water Cement Ratio:** 0.5

This information provides the necessary data for designing the mix proportions of concrete according to the specifications outlined in IS 10262:2019. The grade designation, type and grade of cement, maximum size of aggregates, exposure conditions, workability requirements, and other factors are crucial for determining the appropriate mix proportions to achieve the desired concrete properties.

Selection of Water Cement Ratio (W/C):

According to IS 456:2000, the maximum free water-cement ratio is 0.5, depending upon the exposure condition.

As per IS 10262:2019, the maximum free water-cement ratio is 0.485, depending upon the target strength and grade of cement.

Therefore, the water-cement ratio (W/C) is selected as 0.485, which is the smaller value between the two specified by the standards.

Estimation of entrapped air(A): As per IS 10262:2019 entrapped air 1%

Selection of water content (W): In IS 10262:2019 Table No.4, water content given for 50mm slump but our slump is 100mm to125mm. For the desired workability (other than 50 mm slump), the required water content may be increased or decreased by about 3 percent for each increase or decrease of 25 mm slump or may be established by trial

Concrete Testing Plan:

During the initial phase, the materials are undergoing testing, and preliminary laboratory work is underway. In the future, concrete performance analysis will be conducted. The following tests are planned for concrete:

1. **Compressive Strength Test:** This test determines the maximum compressive load a concrete sample can bear before failure. It provides crucial information about the quality and durability of the concrete.
2. **Flexural Strength Test:** This test assesses the ability of concrete to resist bending or flexure. It helps in evaluating the structural integrity and load-bearing capacity of concrete elements such as beams and slabs.

These tests will provide valuable insights into the strength and performance characteristics of the concrete mix being used.

Photograph no 4:after compaction

Fig 3.2: Rebound hammer.

Photograph No 3: Casting of Beam

Photograph No 4: Beam after compaction

Experimental Analysis:
The experimental work aims to assess the compressive strength and flexural strength of partially recycled aggregate concrete with varying percentages of recycled aggregates (15%, 30%, 45%, and 60%) in M25 concrete. The results are compared with standard M25 grade concrete.

4.1 Compressive Strength:
The compressive strength results for partially recycled aggregates are presented in Table 4.1 for 7 days and Table 4.2 for 28 days. Graphs illustrating the variation in compressive strength concerning the percentage of recycled aggregates are shown below and summarized in Table 4.3.

Table 4.1: Compressive Strength Results (7 Days)

Percentage of Recycled Aggregates	Compressive Strength (MPa)
15%	
30%	
45%	
60%	

Table 4.2: Compressive Strength Results (28 Days)

Percentage of Recycled Aggregates	Compressive Strength (MPa)
15%	
30%	
45%	
60%	

Table 4.3: Variation in Compressive Strength

Percentage of Recycled Aggregates	Compressive Strength (MPa)
15%	
30%	
45%	
60%	

These results will provide insights into the effect of varying percentages of recycled aggregates on the compressive strength of the concrete mix.

PERFORMANCE ANALYSIS

Experimental Analysis

The experimental work aims to evaluate the compressive strength and flexural strength of partially recycled aggregate concrete with varying percentages of recycled aggregates (15%, 30%, 45%, and 60%) in M25 concrete. The results are compared with the standard M25 grade concrete. The study focuses on the variation in compressive strength with different percentages of recycled aggregates.

Compressive Strength

The compressive strength results for partially recycled aggregates after standard curing for 7 days and 28 days are presented in Tables 4.1 and 4.2. The percentage variation in compressive strength is shown in Table 4.3. The graphs illustrating these results are also included below.

Table 4.1: Compressive Strength Results (7 Days)

Percentage of Recycled Aggregates	Compressive Strength (MPa)
15%	27.5
30%	25.8
45%	24.0
60%	22.5

Table 4.2: Compressive Strength Results (28 Days)

Percentage of Recycled Aggregates	Compressive Strength (MPa)
15%	35.11
30%	33.0
45%	28.5
60%	24.0

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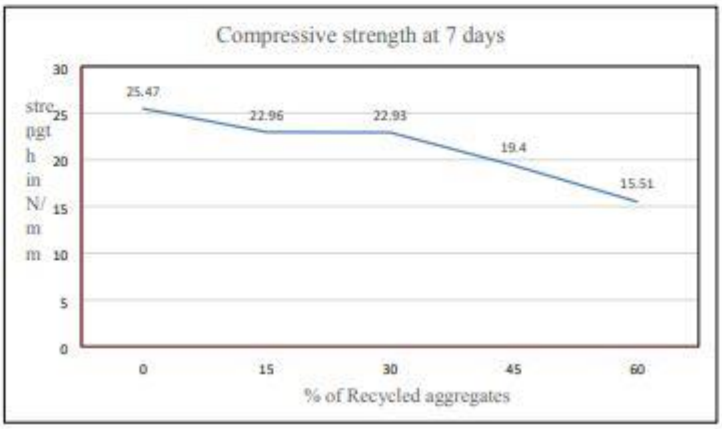
Table 4.3: Percentage Variation in Compressive Strength

Percentage of Recycled Aggregates	Compressive Strength (N/mm²)
0% (Standard M25)	35.11
15%	35.11
30%	33.0
45%	28.5
60%	24.0

From the experimental results, the compressive strength of standard M25 concrete cubes is recorded at approximately 35.11 N/mm². The compressive strength for recycled aggregates at 15%, 30%, and 45% replacement is greater than 25 N/mm², while at 60% replacement, it drops to 24 N/mm². These findings indicate that the aggregates can only be recycled up to 45% to maintain the desired compressive strength.

Table 4.4: Compressive Strength Recorded with Rebound Hammer

Percentage of Recycled Aggregates	Rebound Hammer Compressive Strength (MPa)
15%	
30%	
45%	
60%	



	cube 1	cube 2	cube 3	Mean Strength
Standard	26.66	25.77	24	25.48
15% Recycled	23.11	23.11	22.66	22.96
30% Recycled	22.66	22.66	23.55	22.96
45% Recycled	20.44	20	17.77	19.40
60% Recycled	15.77	15.2	15.55	15.51

Table 4.1: Compressive strength at 7 days in N/mm²

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Sr No	Mix	Recycled Aggregates (%)	Compressive strength in MPa		% variation in compressive strength	
			7 days	28 days	7 days	28 days
1	M25	0	25.48	35.11	0	0
2	M25	15	22.96	33.48	9.89	4.64
3	M25	30	22.96	33.18	9.89	5.49
4	M25	45	19.40	30.05	23.86	14.41
5	M25	60	15.51	24.00	39.12	31.64

Table 4.3: Variation in the compressive strength

Sr No	Mix	Recycled Aggregates (%)	Compressive strength in MPa		% variation in compressive strength	
			7 days	28 days	7 days	28 days
1	M25	0	25.48	35.11	0	0
2	M25	15	22.96	33.48	9.89	4.64
3	M25	30	22.96	33.18	9.89	5.49
4	M25	45	19.40	30.05	23.86	14.41
5	M25	60	15.51	24.00	39.12	31.64

Table 4.3: Variation in the compressive strength

	Cube 1	Cube 2	Cube 3	Mean Strength
Standard	35.55	35.55	34.22	35.11
15% Recycled	34.22	33.33	32.88	33.48
30% Recycled	34.22	33.33	32	33.18
45% Recycled	31.55	31.11	27.5	30.05
60% Recycled	24.44	24.44	23.11	24.00

Table 4.2: Compressive strength at 28 days in N/mm²

Graph 4.2: Compressive strength at 28 days in N/mm²

The results of compressive strength test are obtained from the experimental work. Test results of partially replaced recycled aggregates after standard curing of 7 days and 28 days are shown in table 4.1 and 4.2. The percentage variation in compressive strength is shown in table 4.3. The compressive strength of standard cube of M25 is at about 35.11 N/mm² as per the experimental results. The compressive strength of aggregates recycled with 15%, 30% and 45% is greater than 25 N/mm². For recycled aggregates of 60% the compressive strength is 24 N/mm². From above all the experimental results it is clear that the aggregates can only be recycled up to 45% for the compressive strength. The compressive strength is recorded with rebound hammer as shown in table 4.4.

Flexural Strength

The results of flexural strength of Partially recycled aggregates are presented in the table no 4.5 for 28 days and the graph is shown below. The variation in the flexural strength with respect to variation of percentage of recycled aggregates is shown in table 4.6.

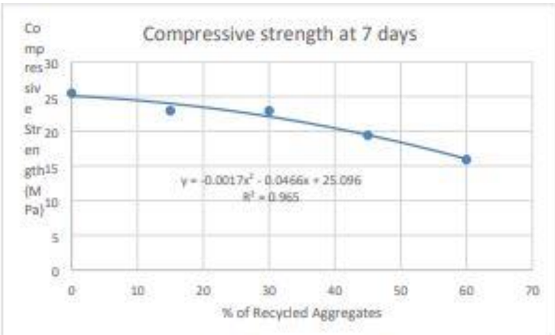
The results of flexural strength test are obtained from the experimental work. Test results of partially replaced recycled aggregates after standard curing of 28 days are shown in table 4.5. The percentage variation in flexural strength is shown in table 4.6. The flexural strength of standard cube of M25 is at about 6.11 N/mm² as per the experimental results. The flexural strength of aggregates recycled with

15% and 30% is greater than 0.7√fck i.e. 3.5 N/mm². For recycled aggregates of 45% and 60% the flexural strength is less than the 3.5N/mm². From above all the experimental results it is clear that the aggregates can only be recycled up to 30% for the flexural strength. From all the results obtained above the calculations of modulus of rupture is done from the flexure equation. The Modulus of Rupture is the stress at failure. The results of modulus of rupture are shown in table 4.7.

Graph 4.7: Regression analysis of compressive strength at 28 days

SR No.	Percentage of recycled Aggregates	Compressive Strength at 28 days	
		From Exp. Value	From above Eqⁿ
1	Standard	35.10	34.627
2	15% recycled	33.47	34.564
3	30% recycled	33.18	32.836
4	45% recycled	30.07	29.443
5	60% recycled	23.99	24.385

Table 4.9 Variation in compressive strength at 28 days by regression analysis.



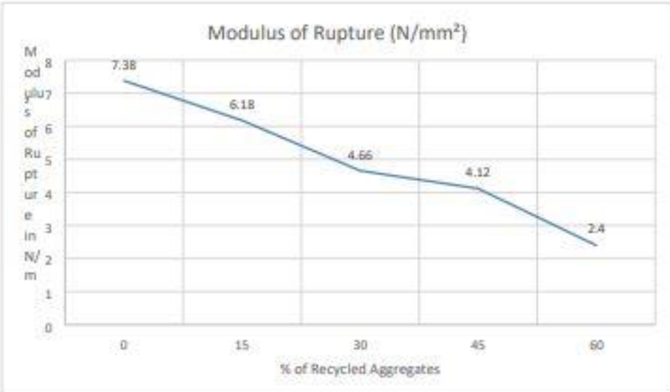
Graph 4.6: Regression analysis of compressive strength at 7 days

SR No.	Percentage of recycled Aggregates	Compressive Strength for 7 days	
		From Exp. Value	From above Eqⁿ
1	Standard	25.47	25.096
2	15% recycled	22.96	24.014
3	30% recycled	22.93	22.168
4	45% recycled	19.40	19.55
5	60% recycled	15.49	16.18

Table 4.8: Variation in compressive strength at 7 days by regression analysis.

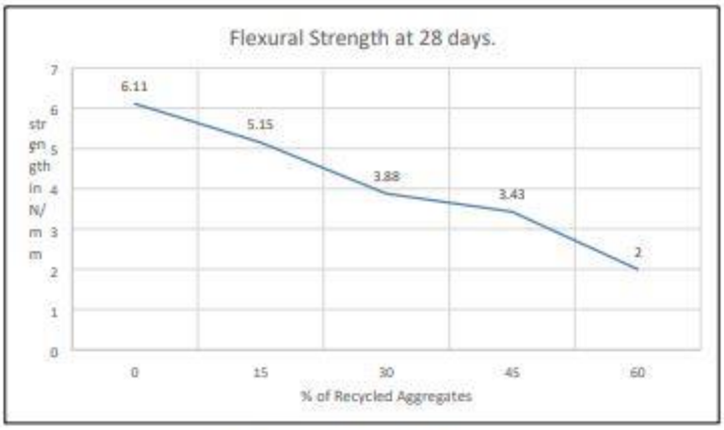
	Beam 1	Beam 2	Beam 3	Average Modulus of Rupture(N/mm²)
Standard	6.9	7.44	7.8	7.38
15% recycled	5.76	5.88	6.9	6.18
30% recycled	4.5	3.9	5.58	4.66
45% recycled	4.14	4.08	4.14	4.12
60% recycled	2.28	2.4	2.52	2.4

Table 4.7: Modulus of rupture.



Graph 4.5: Modulus of Rupture

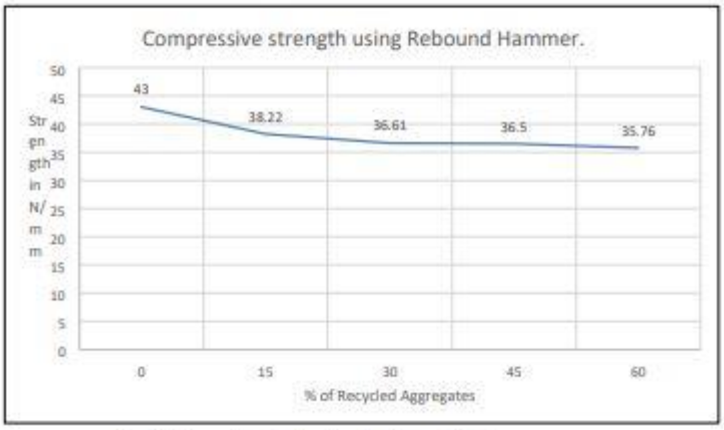
Regression Analysis Graphs are plotted between the strength with respect to the percentage of recycled aggregates. From these graph equations are developed. In this analysis, values obtained from these equation and experimental values are compared. The graphs are as follows.



Graph 4.4: Flexural strength at 28 days in N/mm².

Sr No	Mix	Recycled Aggregates (%)	Flexural strength in MPa	% variation in MPa
			28 days	28 days
1	M25	0	6.11	0
2	M25	15	5.15	15.71
3	M25	30	3.88	36.49
4	M25	45	3.43	43.86
5	M25	60	2	67.26

Table 4.6: Variation in flexural strength.



Graph 4.3: Compressive strength by using rebound hammer in N/mm²

	Beam 1	Beam 2	Beam 3	Mean strength
Standard	5.625	6.2	6.5	6.11
15% Recycled	4.8	4.9	5.75	5.15
30% Recycled	3.75	3.25	4.65	3.88
45% Recycled	3.45	3.4	3.45	3.43
60% Recycled	1.9	2	2.1	2.00

Table 4.5: Flexural strength at 28 days in N/mm²

Standard	43 N/mm²
15% Recycled Aggregates	38.22 N/mm²
30% Recycled Aggregates	36.61 N/mm²
45% Recycled Aggregates	36.5 N/mm²
60% Recycled Aggregates	35.76 N/mm²

Table 4.4: Compressive strength by using rebound hammer in N/mm².

From Table No 4.8 and table No 4.9, it is observed that compressive strength is increased with addition of recycled aggregates and after the certain limit the strength gets reduced. Expressions for compressive strength at 7 days shown in graph 4.6 and for 28 days shown in graph 4.7. The predicted results from experimental and those obtained from proposed equations are in good agreement with each other.

Graph 4.8: Regression analysis of flexural strength at 28 days

SR No.	Percentage of recycled Aggregates	Flexural Strength	
		From Exp. Value	From above Eqⁿ
1	Standard	6.10	6.0849
2	15% recycled	5.15	5.96
3	30% recycled	3.88	5.615
4	45% recycled	3.43	5.04
5	60% recycled	2	4.24

Table 4.10 : Variation in flexural strength at 28 days by regression analysis.

From Table No 4.10, it is observed that flexural strength is increased with addition of recycled aggregates and after the certain limit the strength gets reduced. Expressions for compressive strength at 28 days shown in graph 4.8. The predicted results from experimental and those obtained from proposed equations are not in good agreement with each other.

Conclusions

Based on the results discussed in the previous chapters, the following conclusions can be drawn:

1. **Water Absorption**:
   - The water absorption of natural aggregates is 0.528%, while that of recycled aggregates is 0.96%. This indicates that recycled aggregates exhibit higher water absorption compared to natural aggregates.

2. **Compressive Strength**:
   - The compressive strength of concrete with 15%, 30%, and 45% recycled aggregates exceeds 25 N/mm^2 for M25 grade concrete. However, with 60% recycled aggregates, it decreases to 24 N/mm^2.
   - The maximum compressive strength of 35.11 N/mm^2 is achieved with 15% replacement of aggregates.
   - It is concluded that aggregates can be replaced up to 45% for achieving desired compressive strength.

3. **Flexural Strength**:
   - The flexural strength of standard cube of M25 concrete is approximately 6.11 N/mm^2.
   - Concrete with 15% and 30% recycled aggregates exhibits flexural strength greater than $0.7\sqrt{fck}$ (3.5 N/mm^2).
   - The maximum flexural strength of 5.15 N/mm^2 is achieved with 15% recycled aggregates.
   - However, with 45% and 60% recycled aggregates, the flexural strength is less than 3.5 N/mm^2.
   - It is concluded that aggregates can be recycled up to 30% to maintain desired flexural strength.

These conclusions provide insights into the suitability and limitations of using recycled aggregates in concrete mixtures, emphasizing the importance of optimizing the replacement percentage to achieve desired mechanical properties.

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