INVESTIGATION ON THE MECHANICAL PROPERTIES OF LIGHTWEIGHT CONCRETE INCORPORATING RECYCLED COARSE PLASTIC AGGREGATE (RCPA)

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Abstract - This study investigates the mechanical properties of lightweight concrete incorporating Recycled Coarse Plastic Aggregate (RCPA) as a partial replacement for natural coarse aggregates. The research focuses on addressing environmental issues caused by plastic waste while exploring sustainable construction materials. Concrete mixes were prepared by replacing natural aggregates with RCPA at different proportions (10%, 20%, 30%, and 40%). The performance of concrete was evaluated through tests such as compressive strength, split tensile strength, flexural strength, workability, and density. Additionally, the effect of elevated temperatures (600°C and 800°C) on concrete properties and spalling behavior was studied. Results indicate that the inclusion of RCPA reduces the unit weight and density of concrete, making it suitable for lightweight applications. Mechanical properties initially improve with increasing RCPA content, reaching optimum performance at around 30% replacement, after which strength decreases due to poor bonding between plastic aggregates and cement paste. High temperatures further influence the strength and durability characteristics. The study concludes that RCPA can be effectively used as a sustainable alternative material in concrete for non-structural and lightweight applications, contributing to waste management and resource conservation.

***Key Words*:** Lightweight concrete; Recycled coarse plastic aggregate (RCPA); Mechanical properties; Sustainable construction; Plastic waste utilization; Compressive strength; Flexural strength.

1. INTRODUCTION

Concrete is one of the most widely used construction materials due to its strength, durability, and versatility. However, the increasing demand for infrastructure has led to excessive consumption of natural aggregates, resulting in resource depletion and environmental concerns. Simultaneously, the rapid accumulation of plastic waste poses a serious threat to the environment because of its non-biodegradable nature and improper disposal.
To address these challenges, the use of recycled plastic waste in concrete has emerged as a sustainable alternative. Recycled Coarse Plastic Aggregate (RCPA) can be used as a partial replacement for natural coarse aggregates, contributing to waste management and conservation of natural resources. Additionally, the incorporation of plastic aggregates helps in producing lightweight concrete, which reduces the overall structural load.

This study focuses on investigating the mechanical properties of lightweight concrete incorporating RCPA at different replacement levels. Key properties such as compressive strength, split tensile strength, flexural strength, workability, and density are evaluated. The behavior of concrete under elevated temperatures is also examined. The research aims to assess the feasibility of RCPA as an eco-friendly material for sustainable construction applications.

1.1 OBJECTIVES OF THE STUDY

- ✓ To develop a suitable mix design for lightweight concrete incorporating Recycled Coarse Plastic Aggregate (RCPA) as a partial replacement for natural coarse aggregates. To evaluate the effect of RCPA on the density and unit weight of concrete.
- ✓ To investigate the mechanical properties of concrete, including compressive strength, split tensile strength, and flexural strength.
- ✓ To study the workability characteristics of concrete with varying percentages of RCPA.
- ✓ To analyze the performance of concrete under elevated temperatures (600°C and 800°C).
- ✓ To examine the spalling behavior of concrete exposed to high temperatures.

- ✓ To determine the optimum replacement level of RCPA for achieving desirable strength and performance.
- ✓ To assess the feasibility of using RCPA in sustainable and eco-friendly construction applications.

Fig -1: HDPE

Fig -2: PVC plastic

2. SUMMARY OF LITERATURE REVIEW

The literature review indicates that the incorporation of plastic waste in concrete has gained significant attention as a sustainable solution to environmental and resource-related challenges. Various types of plastics such as PET, HDPE, LDPE, PVC, and polypropylene have been studied as partial replacements for natural aggregates in concrete. These materials contribute to reducing plastic waste and conserving natural resources while promoting eco-friendly construction practices.

Studies reveal that the inclusion of plastic aggregates generally reduces the density of concrete, making it suitable for lightweight applications. Mechanical properties such as compressive, tensile, and flexural strengths show mixed behavior depending on the type and percentage of plastic used. Moderate replacement levels (typically 10–30%) often result in acceptable or improved performance, whereas higher percentages lead to a reduction in strength due to poor bonding between plastic particles and cement matrix.

Research also highlights that plastic-modified concrete exhibits lower workability and increased porosity in some cases. Additionally, elevated temperatures significantly affect the mechanical properties and durability of such concrete. While plastic aggregates improve certain characteristics like impact resistance and crack control, limitations remain in terms of strength reduction and long-term durability.

Overall, the literature suggests that recycled plastic aggregates can be effectively utilized in concrete for non-structural and lightweight applications, though further studies are required to optimize mix design and enhance performance.

3. METHODOLOGY

The present study adopts a comprehensive experimental methodology to investigate the mechanical and thermal performance of lightweight concrete incorporating Recycled Coarse Plastic Aggregate (RCPA). The methodology is structured into sequential stages, including material characterization, mix design, specimen preparation, testing procedures, and analytical evaluation.

A. Materials Characterization

The materials used in this study include Ordinary Portland Cement (OPC), fine aggregate (natural sand), natural coarse aggregate (NCA), and Recycled Coarse Plastic Aggregate (RCPA). The physical properties of all materials, such as specific gravity, particle size distribution, bulk density, and water absorption, are determined in accordance with relevant IS standards. The properties of RCPA are carefully evaluated due to its განსხვავებული (different) surface texture and lower density compared to conventional aggregates.

B. Mix Design and Proportioning

A control mix is designed for the target compressive strength of 30 MPa using standard mix design procedures. Subsequently, RCPA is introduced as a partial replacement for natural coarse aggregates at varying percentages of 10%, 20%, 30%, and 40% by volume. The water-cement ratio is maintained constant to ensure uniformity, while minor adjustments are made to maintain workability.

C. Preparation and Casting of Specimens

Concrete mixing is carried out using a mechanical mixer to ensure uniform distribution of materials. For each mix proportion, fresh concrete is prepared and tested for workability using the slump cone test. The concrete is then cast into standard moulds of different shapes:

- Cubes (150 mm × 150 mm × 150 mm) for compressive strength
- Cylinders (150 mm diameter × 300 mm height) for split tensile strength
- Prisms (100 mm × 100 mm × 500 mm) for flexural strength

The moulds are compacted using standard tamping or vibration techniques to eliminate air voids and ensure proper compaction.

D. Curing of Specimens

After casting, the specimens are left undisturbed for 24 hours at room temperature. They are then demoulded and subjected to water curing for curing periods of 7, 14, and 28 days. Proper curing is maintained to achieve adequate hydration and strength development.

E. Testing of Fresh Concrete

Workability of the concrete mixes is evaluated using the slump test. The variation in slump values with increasing RCPA content is observed to assess the effect of plastic aggregates on flow characteristics.

F. Testing of Hardened Concrete

After curing, the specimens are tested for various mechanical properties:

- **Compressive Strength:** Tested using a Compression Testing Machine (CTM) at different curing ages.
- **Split Tensile Strength:** Conducted on cylindrical specimens using standard loading conditions.
- **Flexural Strength:** Determined using prism specimens under two-point loading in a Universal Testing Machine (UTM).
- **Density and Unit Weight:** Measured to evaluate the lightweight nature of concrete.

G. Elevated Temperature Study

To analyze thermal performance, selected specimens are exposed to high temperatures of 600°C and 800°C in a furnace for a duration of one hour. After heating, the specimens are allowed to cool to room temperature. Post-heating tests are conducted to evaluate residual compressive strength and to observe spalling behavior and surface changes.

H. Data Analysis and Interpretation

The experimental results are systematically analyzed to study the influence of RCPA on various properties of concrete. Comparative analysis is performed between control and modified mixes to determine trends and performance variations. Statistical and analytical tools such as regression analysis may be used to establish relationships between variables.

I. Determination of Optimum Replacement Level

Based on the experimental findings, the optimum percentage of RCPA is identified considering strength, workability, density, and thermal resistance. The feasibility of using RCPA in practical construction applications is evaluated.

Table -1: Properties of cement

Test		Actual readings	IS requirements as per IS 12269:2013
Specific surface area		3200	2250
Specificgravity		3.15	-
Fineness(%)		6	<10
Consistency		27	-
Initial Setting time (min)		45	>30
Final Setting time (min)		245	<600
Compressivestrength(N/mm^2)	3 days	31.67	-
	7 days	41.15	37
	28 days	57.86	53
Soundness test		4	<10

Table -2: Physical propertiesof coarse aggregates

Test	Obtained values
Impact value	15.02 %
Crushing value	27 %
Specific gravity	2.7
Water absorption	1 %
Free surface moisture	0%

Table -3: Sieve analysis for 20 mm coarse aggregates

IS sieve designation	Cumulative		Specifications as per IS 383-1970 for zone-II (IS 2386 (I)1963)
	Retaining	Passing	Passing
20 mm	10.9	89.1	85-100
12.5 mm	98.7	1.3	-
10.0 mm	99.8	0.2	0-20
4.75 mm	100	0	0-5

Table -4: Physical properties of sand

Test	Values
Specific gravity	2.6
Water absorption	1.07
Free surface moisture	2.8

Table -5: Sieve analysis of sand

IS Sieve designation	Cumulative %		Specifications as per IS383-1970 for zone-II
	Retained	Passing	Passing
4.75 mm	3.6	96.4	90-100
2.36 mm	22.8	77.2	75-100
1.18 mm	34.3	65.7	55-90
600 µ	58.7	41.3	35-59
300 µ	86.5	13.5	Aug-30
150 µ	96.5	3.5	0-10

Table -6: Physical propertiesof Recycled coarse plastic aggregates

Test	**Obtained values**
Impact value	9.04 %
Crushing value	6 %
Specific gravity	1.15
Water absorption	0.01 %

Fig -3: Compression testing machine

Flowchart of Methodology

Start
↓
Literature Review & Problem Identification
↓
Selection of Materials
(Cement, Fine Aggregate, Coarse Aggregate, RCPA)
↓
Material Testing
(Specific Gravity, Sieve Analysis, Water Absorption)
↓
Mix Design Preparation
(Target Strength: M30 Grade Concrete)
↓
Replacement of Coarse Aggregate with RCPA
(0%, 10%, 20%, 30%, 40%)
↓
Concrete Mixing
↓
Workability Test
(Slump Test)
↓
Casting of Specimens
(Cubes, Cylinders, Prisms)
↓
Curing of Specimens
(7, 14, 28 Days)
↓
Testing of Hardened Concrete
• Compressive Strength
• Split Tensile Strength
• Flexural Strength
• Density
↓
Exposure to Elevated Temperature
(600°C & 800°C for 1 hour)
↓
Post-Heating Testing

(Residual Strength & Spalling Behavior)
↓
Data Analysis & Comparison
↓
Determination of Optimum RCPA Percentage
↓
Conclusion & Recommendations
↓
End

4. EXPERIMENTAL INVESTIGATION

The experimental investigation was carried out to evaluate the mechanical and thermal properties of lightweight concrete incorporating Recycled Coarse Plastic Aggregate (RCPA) as a partial replacement for natural coarse aggregates. The study includes material testing, mix preparation, specimen casting, curing, and testing under normal and elevated temperature conditions.

A. Materials Used

The materials used in this study include Ordinary Portland Cement (OPC), fine aggregate (natural sand), natural coarse aggregate (NCA), and Recycled Coarse Plastic Aggregate (RCPA). The plastic aggregates were processed from waste plastic materials and used as a substitute for conventional coarse aggregates. All materials were tested for their physical properties such as specific gravity, gradation, and water absorption as per standard specifications.

B. Mix Proportions

Concrete mix design was carried out for M30 grade concrete. RCPA was used to replace natural coarse aggregates at different proportions of 0% (control mix), 10%, 20%, 30%, and 40% by volume. The water-cement ratio was maintained constant for all mixes to ensure uniformity in comparison.

C. Preparation of Specimens

Concrete was mixed using a mechanical mixer to ensure uniform distribution of materials. Fresh concrete was tested for workability using the slump cone test. The concrete was then cast into standard moulds:

- Cubes (150 mm × 150 mm × 150 mm) for compressive strength
- Cylinders (150 mm diameter × 300 mm height) for split tensile strength
- Prisms (100 mm × 100 mm × 500 mm) for flexural strength

Proper compaction was achieved using vibration to remove air voids and ensure homogeneity.

D. Curing Process

After casting, the specimens were kept undisturbed for 24 hours and then demoulded. The specimens were cured in clean water for periods of 7, 14, and 28 days to achieve the required strength.

E. Testing of Fresh Concrete

Workability of concrete mixes was determined using the slump test. The variation in slump values with increasing RCPA content was recorded to understand the effect of plastic aggregates on flow properties.

F. Testing of Hardened Concrete

After curing, the specimens were tested for the following properties:

- **Compressive Strength:** Determined using a Compression Testing Machine (CTM) at 7, 14, and 28 days.
- **Split Tensile Strength:** Conducted on cylindrical specimens using standard loading conditions.
- **Flexural Strength:** Measured using prism specimens under two-point loading in a Universal Testing Machine (UTM).
- **Density:** Calculated to evaluate the lightweight characteristics of concrete.

G. Elevated Temperature Study

To study the thermal performance, selected specimens were exposed to elevated temperatures of 600°C and 800°C in a furnace for a duration of one hour. After heating, the specimens were allowed to cool to room temperature. The residual compressive strength was then determined, and the surface condition of specimens was observed for spalling and cracking behavior.

H. Analysis of Results

The experimental results obtained from various tests were compared with the control mix. The influence of RCPA on mechanical properties, density, and thermal resistance was analyzed. Based on the results, the optimum percentage of RCPA was identified for practical applications.

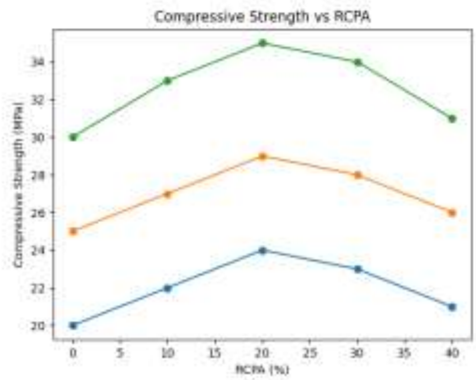

Fig -4: Compressive Strength
The above graph Increases up to 20–30% RCPA, then decreases

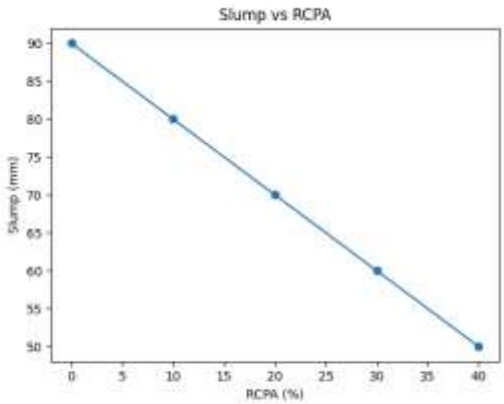

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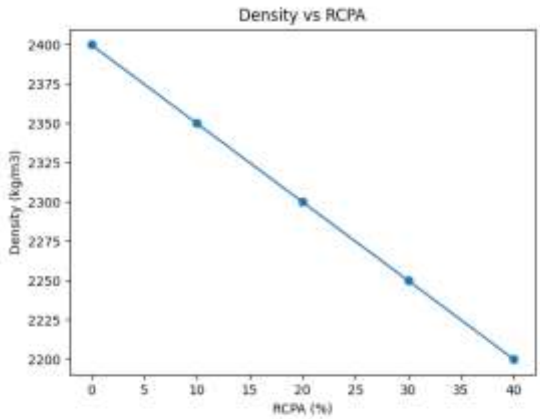
Fig -5: Slump Test

The above graph Gradually decreases with increase in



RCPA

Fig -6: Density Test

The above graph Decreases steadily (lightweight concrete)

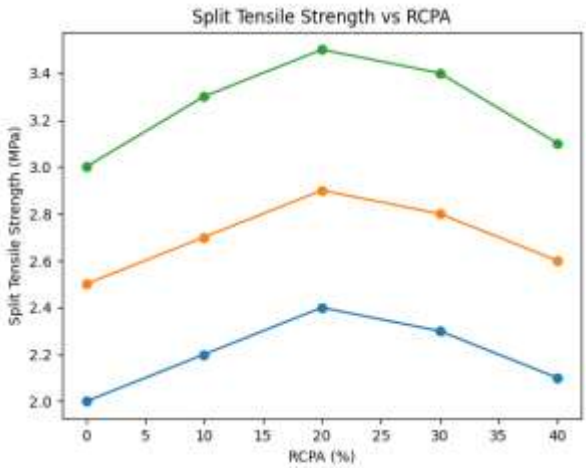


Fig -7: Split Tensile Strength

The above graph Increases up to 20–30% RCPA, then slightly decreases

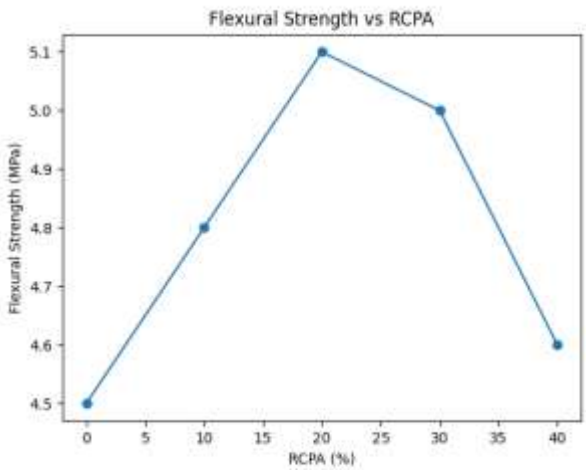


Fig -8: Flexural Strength

The above graph Similar trend with peak around 20%

5. RESULTS AND DISCUSSION

This section presents and discusses the experimental results obtained from tests conducted on lightweight concrete incorporating Recycled Coarse Plastic Aggregate (RCPA). The influence of varying RCPA replacement levels on workability, density, mechanical properties, and thermal performance is analyzed and compared with the control mix.

A. Workability of Concrete

The slump test results indicate that the workability of concrete decreases with an increase in RCPA content. This reduction is mainly due to the irregular shape, rough surface texture, and lower specific gravity of plastic aggregates, which increase internal friction and reduce flowability. Mixes with higher RCPA percentages (30% and 40%) showed lower slump values compared to the control mix, indicating reduced workability.

B. Density of Concrete

The density of concrete decreases significantly with the increase in RCPA replacement. This is attributed to the lower density of plastic aggregates compared to natural coarse aggregates. The reduction in density confirms the production of lightweight concrete, which can be advantageous in reducing dead load in structural elements.

C. Compressive Strength

The compressive strength results show that strength initially increases with the addition of RCPA up to an optimum level (around 20–30%). This improvement may be due to better particle distribution and reduced stress concentration. However, beyond this level (at 40%), the strength decreases due to weak bonding between plastic aggregates and cement paste, leading to poor load transfer.

D. Split Tensile Strength

Similar to compressive strength, the split tensile strength exhibits an increasing trend up to an optimum replacement level and then decreases. The reduction at higher RCPA content is due to lower adhesion and increased voids within the concrete matrix, which weaken tensile resistance.

E. Flexural Strength

Flexural strength follows a pattern similar to tensile strength. Moderate replacement levels show satisfactory performance, while higher percentages lead to reduced strength. The presence of plastic aggregates affects the crack propagation mechanism and reduces the ability of concrete to resist bending stresses.

F. Effect of Elevated Temperature

Concrete specimens exposed to high temperatures (600°C and 800°C) show a significant reduction in mechanical strength. The loss of strength is more pronounced at higher temperatures due to degradation of the cement matrix and thermal incompatibility between plastic aggregates and cement paste. Plastic aggregates may soften or deform under high temperatures, further reducing structural integrity.

G. Spalling Behavior

Spalling behavior is observed in concrete specimens subjected to elevated temperatures. Control mixes show more brittle spalling, whereas mixes with RCPA exhibit relatively reduced explosive spalling due to the melting of plastic, which creates internal voids and reduces vapor pressure. However, excessive void formation may negatively affect strength.

H. Optimum Replacement Level

Based on the experimental results, the optimum replacement level of RCPA is found to be around 20–30%, where a balance between strength, density, and workability is achieved. Beyond this range, the reduction in mechanical properties becomes significant.

I. Overall Discussion

The results demonstrate that the incorporation of RCPA in concrete can effectively produce lightweight and sustainable construction material. While there is a slight compromise in mechanical properties at higher replacement levels, the environmental benefits and reduction in material cost make it suitable for non-structural and lightweight applications. Proper mix design and controlled replacement levels are essential to achieve desired performance.

6. CONCLUSIONS

Based on the experimental investigation carried out on lightweight concrete incorporating Recycled Coarse Plastic Aggregate (RCPA), the following conclusions are drawn:

- ✓ The incorporation of RCPA as a partial replacement for natural coarse aggregates leads to a reduction in the density of concrete, thereby producing lightweight concrete suitable for reducing dead load in structures.
- ✓ The workability of concrete decreases with an increase in RCPA content due to the irregular shape and surface characteristics of plastic aggregates.
- ✓ The compressive strength of concrete shows improvement up to an optimum replacement level of 20–30% RCPA, beyond which the strength decreases due to weak bonding between plastic aggregates and cement matrix.
- ✓ Split tensile strength and flexural strength follow a similar trend as compressive strength, with optimum performance observed at moderate replacement levels and reduction at higher percentages.
- ✓ Exposure to elevated temperatures (600°C and 800°C) significantly reduces the mechanical properties of concrete. The presence of plastic aggregates further influences strength degradation due to thermal effects.
- ✓ Concrete containing RCPA exhibits reduced spalling compared to conventional concrete under high temperature conditions, due to the melting of plastic aggregates which relieves internal pressure.
- ✓ The optimum replacement level of RCPA is found to be in the range of 20–30%, where a balance between strength, workability, and density is achieved.
- ✓ The use of RCPA in concrete provides an effective solution for plastic waste management and contributes to sustainable and eco-friendly construction practices.
- ✓ RCPA-based concrete is suitable for non-structural and lightweight applications, where reduced weight and environmental benefits are prioritized over high strength requirements.

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