

PARTIAL REPLACEMENT OF COARSE AGGREGATE BY PLASTIC WASTE IN CONCRETE

Gaurav R. Choukhunde¹, Dhanesh Pushpatode², Krunal Chaudhari³, Kunal Awathare⁴, Vaishnavi Satewar⁵.

Department of Civil Engineering

G H Raisoni College of Engineering and Management, Nagpur – 440016, India

Abstract

The rapid growth of industrialization and urbanization has led to a significant increase in plastic waste generation across the world. Plastic materials are non-biodegradable in nature and create serious environmental problems due to their accumulation in landfills and natural surroundings. At the same time, the construction industry is facing a shortage of natural resources such as coarse aggregates due to excessive consumption.

This study focuses on the utilization of plastic waste as a partial replacement for coarse aggregate in concrete. The main objective is to investigate the effect of replacing coarse aggregate with plastic waste on the properties of concrete. Different percentages of plastic waste such as 0%, 10%, 20%, and 30% were used in concrete mixes, and their compressive strength was evaluated after standard curing periods.

The experimental results indicate that the compressive strength of concrete decreases with an increase in the percentage of plastic waste. However, up to a certain limit, the strength remains within acceptable ranges for specific applications. The use of plastic waste reduces the overall weight of concrete and contributes to sustainable waste management. This study concludes that plastic waste can be effectively used in concrete for non- structural applications.

Keywords

Plastic Waste, Coarse Aggregate, Compressive Strength, Sustainable Construction, Lightweight Concrete, Waste Utilization

I. Introduction

Concrete is one of the most widely used construction materials due to its high compressive strength, durability,

and versatility. It is composed of cement, fine aggregate, coarse aggregate, and water. Among these components, coarse aggregate occupies a major portion of the total volume and significantly influences the strength and performance of concrete.

In recent years, the demand for construction materials has increased rapidly, leading to excessive extraction of natural aggregates. This has resulted in environmental degradation and depletion of natural resources. Simultaneously, plastic waste generation has increased at an alarming rate due to the widespread use of plastic products in daily life.

Plastic waste is non-biodegradable and poses a serious threat to the environment. Improper disposal of plastic waste leads to land pollution, water contamination, and harm to living organisms. Therefore, there is an urgent need to find effective methods for recycling and reusing plastic waste.

One of the promising solutions is the use of plastic waste in concrete as a replacement for natural aggregates. This approach not only helps in reducing environmental pollution but also conserves natural resources. The present study aims to evaluate the feasibility of using plastic waste as a partial replacement for coarse aggregate in concrete.

II. Problem Statement

The rapid growth of urbanization and industrialization has led to a significant increase in plastic waste generation worldwide. Materials such as polyethylene, polypropylene, and other non-biodegradable plastics are extensively used in packaging, construction, and daily life applications. However, due to their non-degradable nature, plastic wastes accumulate in landfills and natural environments, causing severe environmental pollution and ecological imbalance.

At the same time, the construction industry, particularly concrete production, consumes a vast quantity of natural resources such as coarse aggregates. Continuous extraction of these aggregates from quarries and riverbeds has resulted in depletion of natural resources, environmental degradation, and increased material costs. This creates a dual challenge: effective disposal of plastic waste and sustainable sourcing of construction materials.

Conventional waste management techniques such as landfilling and incineration are not sufficient or environmentally friendly solutions for plastic waste disposal. Therefore, there is an urgent need to explore alternative methods that can simultaneously address environmental concerns and resource scarcity.

One promising approach is the utilization of plastic waste as a partial replacement for coarse aggregates in concrete. This method not only helps in reducing plastic waste accumulation but also minimizes the demand for natural aggregates. However, incorporating plastic waste into concrete may affect its mechanical properties, durability, workability, and long-term performance. The behaviour of such modified concrete under different loading and environmental conditions is not yet fully understood and requires detailed investigation.

Therefore, this study focuses on evaluating the feasibility of partial replacement of coarse aggregate with plastic waste in concrete. The research aims to analyse the impact of plastic waste on compressive strength, tensile strength, durability, and overall structural performance of concrete. It also seeks to determine the optimum replacement percentage that ensures both environmental sustainability and acceptable engineering performance.

This problem is critical in the context of sustainable construction practices, as it addresses both waste management issues and the conservation of natural resources while promoting eco-friendly alternatives in civil engineering.

III. Methodology

A. Research Design and Experimental Framework

This study adopts a comprehensive experimental methodology to evaluate the feasibility of partially replacing conventional coarse aggregates with plastic waste in concrete. The research is structured to systematically analyse the influence of plastic aggregate incorporation on both fresh and hardened properties of concrete.

A controlled experimental approach is used, wherein a reference mix (control specimen) is compared with multiple modified mixes containing varying proportions of plastic waste. The methodology ensures consistency in all parameters except the replacement variable, allowing for accurate assessment of the impact of plastic waste on concrete behaviour.

The experimental program is divided into the following major phases: material selection and characterization, processing of plastic waste, mix proportioning, specimen preparation, curing, testing, and analytical evaluation.

B. Material Characterization

1) Cement

Ordinary Portland Cement (OPC) conforming to relevant IS standards is used. The cement is tested prior to use to ensure compliance with quality requirements. The following properties are determined:

- Fineness (to assess particle size distribution and its effect on hydration rate)
- Standard consistency (to determine water requirement for hydration)
- Initial and final setting times (to understand workability duration)
- Compressive strength (to ensure adequate binding capability)

These parameters are critical in maintaining uniformity and reliability in the concrete mix.

2) Fine Aggregate

Locally available natural river sand is used as fine aggregate. It is tested to evaluate its suitability for concrete production. The following tests are conducted:

- Sieve analysis to determine grading and zone classification
- Specific gravity to assess density characteristics
- Water absorption to estimate moisture content adjustments

Proper grading ensures improved workability, reduced voids, and enhanced bonding between particles.

3) Coarse Aggregate

Crushed angular aggregates of nominal size 20 mm are used as the conventional coarse aggregate. The following tests are performed:

- Aggregate crushing value (to determine resistance to crushing under load)
- Aggregate impact value (to assess toughness)
- Specific gravity (to evaluate density)
- Water absorption (to understand porosity characteristics)

These properties influence the strength and durability of concrete significantly.

4) Plastic Waste (Replacement Material)

Plastic waste is utilized as a partial substitute for coarse aggregate. The selection and preparation process is carried out with careful attention to uniformity and cleanliness.

Collection and Processing:

- Plastic waste is collected from municipal and local sources, including discarded plastic bags, bottles, and packaging materials.
- The collected plastic is segregated based on type and cleaned thoroughly to remove impurities such as dust, organic matter, and oils.
- The plastic is then mechanically shredded into aggregate-sized particles (approximately 10–20 mm).

Properties Considered:

- Low density compared to natural aggregates
- Hydrophobic nature (non-absorbent)
- Irregular shape affecting bonding characteristics

The processed plastic waste is stored in dry conditions to maintain consistency in mixing.

5) Water

Potable water free from harmful substances is used for both mixing and curing. The quality of water is essential to ensure proper hydration and to avoid adverse chemical reactions.

C. Concrete Mix Design

The mix design is carried out as per IS guidelines to achieve the desired strength and workability.

1) Control Mix

A conventional concrete mix (without plastic waste) is designed to serve as the reference for comparison. This mix provides baseline values for strength, workability, and durability.

2) Replacement Strategy

Coarse aggregate is partially replaced with plastic waste at different percentages by volume. The selected replacement levels are:

- 0% (Control Mix)

- 5% Replacement
- 10% Replacement
- 15% Replacement
- 20% Replacement

This range allows for detailed analysis of performance trends and identification of optimum replacement levels.

3) Batching and Mixing

All materials are batched by weight to ensure accuracy. The mixing process is carried out as follows:

- Dry mixing of cement, fine aggregate, and coarse aggregate is performed to achieve uniform distribution.
- Plastic waste is then added according to the replacement percentage and mixed thoroughly.
- Water is added gradually while mixing continues to ensure proper hydration and homogeneity.

Special care is taken to prevent segregation, particularly due to the lightweight nature of plastic particles.

D. Specimen Preparation

1) Types of Specimens

Different types of specimens are prepared to evaluate various mechanical properties:

- Cube specimens (150 mm × 150 mm × 150 mm) for compressive strength
- Cylindrical specimens for split tensile strength
- Beam specimens (if required) for flexural strength

2) Casting Procedure

- Moulds are cleaned, assembled, and lubricated with oil to prevent adhesion.
- Concrete is placed in moulds in multiple layers (typically three layers).
- Each layer is compacted using a tamping rod or mechanical vibrator to remove entrapped air.
- The top surface is finished smoothly using a trowel.

E. Curing Process

After casting, specimens are covered to prevent moisture loss and kept undisturbed for 24 hours. Subsequently:

- Specimens are demoulded carefully.
- They are submerged in a curing tank filled with clean water.
- Curing durations include 7 days, 14 days, and 28 days.

Proper curing ensures adequate hydration, leading to improved strength and durability.

F. Testing Procedures

1) Workability Test

The slump test is conducted to evaluate the workability of fresh concrete. This test helps in understanding the influence of plastic waste on flow characteristics and ease of placement.

2) Compressive Strength Test

Cube specimens are tested using a compression testing machine at different curing ages (7, 14, and 28 days). The compressive strength is calculated as:

$$\text{Compressive Strength} = \frac{\text{Load at Failure}}{\text{Cross-sectional Area}}$$

This test is the primary indicator of concrete performance.

3) Split Tensile Strength Test

Cylindrical specimens are subjected to diametrical loading to determine tensile strength. This test evaluates the cracking resistance of concrete.

4) Flexural Strength Test

Beam specimens are tested under two-point loading to determine flexural strength. This provides insight into the bending behaviour of concrete.

5) Density and Durability Assessment

- Density of hardened concrete is measured to observe the effect of lightweight plastic.
- Visual inspection is conducted to identify cracks, surface defects, and water absorption characteristics.

G. Data Analysis and Interpretation

All experimental data are recorded systematically and analysed using graphical and comparative methods.

- Strength values are plotted against percentage replacement
- Workability trends are analysed

- Performance is compared with control mix

The optimum percentage of plastic replacement is identified based on a balance between strength and sustainability.

IV. Results and Analysis

The experimental investigation on concrete with partial replacement of coarse aggregate by plastic waste revealed clear and consistent trends in both fresh and hardened properties. The results obtained from the control mix and the modified mixes were carefully analyzed to understand the influence of plastic content on workability, strength characteristics, density, and overall performance of concrete.

The workability of concrete showed a noticeable variation with the inclusion of plastic waste. As the percentage of plastic replacement increased, the slump value exhibited a gradual reduction. This behaviour can be attributed to the irregular shape and rough surface texture of shredded plastic particles, which hinder the flow of concrete. Additionally, the hydrophobic nature of plastic reduces the lubrication effect that is normally provided by water in conventional mixes. As a result, the mixes with higher plastic content appeared slightly harsher and less cohesive. However, at lower replacement levels, particularly up to about 10%, the reduction in workability was not severe and remained within acceptable limits for practical construction.

The compressive strength results demonstrated a significant relationship between plastic content and load-bearing capacity of concrete. The control mix exhibited the highest compressive strength, serving as a benchmark for comparison. With the introduction of plastic waste as a partial replacement, a gradual decrease in compressive strength was observed as the replacement percentage increased. At lower replacement levels, such as 5% and 10%, the reduction in strength was relatively small and did not drastically affect the structural performance. This indicates that a limited amount of plastic waste can be incorporated without severely compromising the strength of concrete. However, beyond this range, particularly at 15% and 20% replacement, the reduction became more pronounced. This reduction is primarily due to the lower stiffness and strength of plastic compared to natural aggregates, as well as weaker bonding between plastic particles and cement paste.

A similar trend was observed in the split tensile strength of concrete. The tensile strength decreased with increasing plastic content, which can be explained by the reduced interfacial bond between the plastic surface and the cement matrix. Since plastic does not chemically interact with cement paste and has a smooth surface, it leads to weaker adhesion, resulting in reduced resistance to tensile stresses. Despite this reduction, the mixes with lower replacement percentages still maintained reasonable tensile strength, indicating their potential suitability for non-critical structural applications.

The density of concrete showed a decreasing trend with an increase in plastic content. This is due to the significantly lower specific gravity of plastic compared to natural aggregates. As a result, the concrete became lighter in weight with higher plastic replacement. This reduction in density can be considered advantageous in applications where lightweight concrete is desirable, such as in non-load-bearing elements or structures requiring reduced dead load. However, this benefit must be balanced against the reduction in strength observed at higher replacement levels.

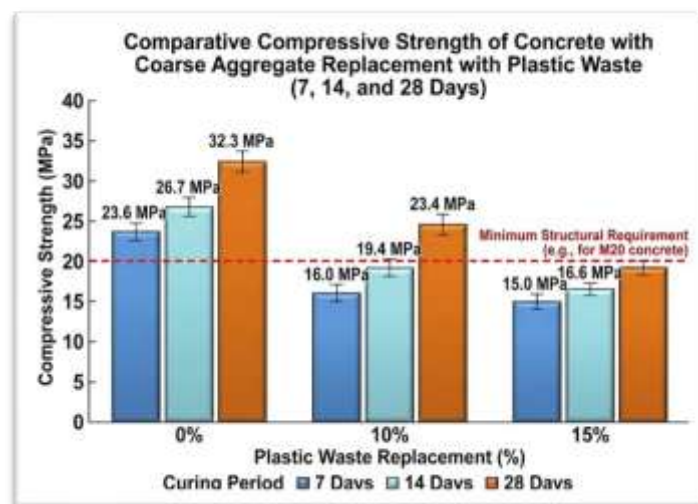
Durability-related observations indicated that concrete containing plastic waste exhibited lower water absorption compared to conventional concrete. This is mainly because plastic is non-porous and does not absorb water. Consequently, the presence of plastic particles reduces the overall permeability of the concrete to some extent. However, it was also observed that improper bonding between plastic and cement paste could create micro-voids, which may affect long-term durability if not properly controlled.

Visual inspection of the specimens after testing showed that cracks in plastic-modified concrete tended to propagate more easily through the interfacial zones between plastic particles and cement paste. This confirms that the interfacial transition zone is a critical factor influencing the mechanical performance of such concrete. The failure patterns indicated that while conventional concrete exhibited more uniform crack distribution, plastic-containing concrete showed localized failure around plastic inclusions.

Overall analysis of the results suggests that partial replacement of coarse aggregate with plastic waste is feasible up to a certain limit. The optimum replacement

level is generally found to be around 5% to 10%, where the reduction in strength is minimal and the benefits of waste utilization and reduced density are achieved. Beyond this range, the adverse effects on strength and bonding become significant, limiting its application in structural components.

The study clearly demonstrates that the use of plastic waste in concrete can contribute to sustainable construction practices by reducing environmental pollution and conserving natural resources. However, careful consideration must be given to the percentage of replacement and the intended application of the concrete to ensure that performance requirements are not compromised.



V. Future Scope

The present study on partial replacement of coarse aggregate with plastic waste in concrete establishes a strong foundation for sustainable construction practices. However, the scope of research in this area is vast and offers multiple opportunities for further investigation and improvement. Future research can focus on enhancing the mechanical properties of plastic-modified concrete by optimizing the size, shape, and type of plastic aggregates. Since plastic materials have lower bonding characteristics with cement paste, advanced surface treatment techniques such as chemical coating or roughening of plastic particles can be explored to improve interfacial bonding and overall strength performance.

Further studies can also investigate the behaviour of plastic aggregate concrete under different environmental conditions, including exposure to high temperatures, freeze-thaw cycles, and aggressive chemical

environments such as sulphates and chlorides. This will help in understanding its suitability for use in extreme climatic conditions and specialized infrastructure projects. Long-term durability studies, including creep, shrinkage, and fatigue behaviour, can provide deeper insights into the structural reliability of such concrete over extended service life.

Another important direction for future work involves the use of hybrid replacement techniques, where plastic waste is combined with other industrial by-products such as fly ash, silica fume, or slag. This approach can potentially compensate for the reduction in strength caused by plastic inclusion and improve overall performance. Additionally, the development of lightweight concrete using higher percentages of plastic aggregates can be explored for non- structural applications such as partition walls, pavement blocks, and precast elements.

The application of advanced technologies such as machine learning and optimization algorithms can further enhance mix design processes by predicting the behaviour of plastic-modified concrete under varying conditions. Field implementation studies on real construction projects can also be conducted to evaluate practical challenges, cost implications, and large-scale performance. Moreover, environmental impact assessments and life cycle analysis should be carried out to quantify the sustainability benefits in terms of waste reduction, carbon footprint, and conservation of natural resources.

Future research can also focus on developing standardized guidelines and codes for the use of plastic waste in concrete, as the lack of uniform standards currently limits its widespread adoption. By addressing these aspects, plastic waste concrete can evolve into a reliable, eco-friendly, and economically viable material for modern construction.

VI. Conclusion

The present study investigates the feasibility and performance of concrete produced by partially replacing conventional coarse aggregates with plastic waste. Based on the experimental analysis and observations, it can be concluded that the incorporation of plastic waste in concrete offers a promising solution for addressing both environmental and resource-related challenges in the construction industry. The utilization of plastic waste helps in reducing the dependency on natural aggregates

while simultaneously contributing to effective waste management and pollution control.

The results of the study indicate that the inclusion of plastic aggregates significantly influences the mechanical and physical properties of concrete. It is observed that as the percentage of plastic replacement increases, there is a gradual reduction in compressive strength, split tensile strength, and overall density of concrete. This reduction can be attributed to the lower stiffness, smooth surface texture, and poor bonding characteristics of plastic materials when compared to natural aggregates. However, at lower replacement levels, particularly in the range of 5% to 10%, the reduction in strength is not substantial and remains within acceptable limits for certain structural and non- structural applications.

The workability of concrete is found to be slightly improved with the addition of plastic waste due to its non-absorbent and smooth surface properties. This enhances the ease of mixing and placement, although excessive plastic content may lead to segregation and reduced cohesiveness. The density of concrete decreases with increasing plastic content, indicating the potential for producing lightweight concrete, which can be advantageous in reducing dead loads in structures.

From a durability perspective, plastic-modified concrete shows resistance to water absorption due to the hydrophobic nature of plastic particles. However, long- term durability aspects such as resistance to chemical attack, thermal effects, and fatigue behavior require further detailed investigation. The study highlights that proper mix design, controlled replacement levels, and adequate curing are essential to achieving satisfactory performance.

Overall, the research confirms that plastic waste can be effectively utilized as a partial replacement for coarse aggregate up to an optimum level, generally around 5% to 10%, without significantly compromising the strength and performance of concrete. This approach not only promotes sustainable construction practices but also provides an innovative solution to the growing problem of plastic waste disposal. With further research, technological advancements, and the development of standardized guidelines, plastic aggregate concrete has the potential to become a viable and eco-friendly alternative in the field of civil engineering.

References

- [1] M. Batayneh, I. Marie, and I. Asi, "Use of selected waste materials in concrete mixes," *Waste Management*, vol. 27, no. 12, pp. 1870–1876, 2007.
- [2] S. Choi, Y. Yuan, and J. W. Lee, "Characteristics of waste plastic fiber-reinforced concrete," *Cement and Concrete Research*, vol. 35, no. 4, pp. 776–781, 2005.
- [3] IS 456:2000, *Plain and Reinforced Concrete – Code of Practice*, Bureau of Indian Standards.
- [4] IS 10262:2019, *Concrete Mix Proportioning – Guidelines*, Bureau of Indian Standards.
- [5] R. Siddique, J. Khatib, and I. Kaur, "Use of recycled plastic in concrete: A review," *Waste Management*, vol. 28, no. 10, pp. 1835–1852, 2008.
- [6] A. Al-Manaseer and T. Dalal, "Concrete containing plastic aggregates," *Concrete International*, vol. 19, no. 8, pp. 47–52, 1997.
- [7] K. R. Lakshmi and S. Nagan, "Utilization of waste plastic in concrete," *International Journal of Engineering Research*, vol. 3, no. 5, pp. 201–205, 2014.
- [8] G. Singh and A. Gupta, "Strength characteristics of concrete using plastic waste," *International Journal of Civil Engineering*, vol. 5, no. 3, pp. 45–50, 2016.