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USING PLASTIC WASTE AS PARTIAL REPLACEMENT FOR AGGREGATE IN STRUCTURAL CONCRETE

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Abstract: This study investigates the use of plastic waste as a partial replacement for coarse aggregate in M-25 grade structural concrete. Experiments were conducted with varying replacement levels of 0%, 10%, 15%, and 20%. The results indicate that plastic aggregates can replace up to 15% of natural aggregates without significantly compromising compressive strength, making the concrete suitable for structural applications. Beyond 15% replacement, the strength decreases notably. Additionally, the use of plastic waste reduces the weight of concrete, offering potential benefits for lightweight construction. While the cost is currently higher than conventional concrete, in-house processing of plastic waste could enhance economic feasibility.

I. INTRODUCTION

The growing accumulation of plastic waste has become a significant environmental concern worldwide. Plastic waste is non-biodegradable and often ends up in landfills, oceans, and other natural habitats, leading to severe ecological issues. In the response of this challenge, the construction industry has been exploring innovative ways to incorporate plastic waste into building materials. This research aims to investigate the feasibility of using plastic waste as a partial replacement for coarse aggregates in structural concrete.

The most popular building material in the world is concrete because of its strength, durability, and adaptability.. However, the production of concrete requires substantial amounts of natural aggregates, which depletes natural resources and has a considerable environmental impact. Incorporating plastic waste into concrete mixes presents a dual benefit: it reduces the demand for natural aggregates and provides a practical use for plastic waste, thus mitigating environmental pollution.

Previous studies have shown that plastic waste can be effectively utilized in concrete mixes, either as a partial replacement for fine or coarse aggregates. These studies have reported mixed results regarding the mechanical properties of plastic-modified concrete. While some research indicates a reduction in compressive strength, others highlight improvements in specific characteristics such as durability and thermal insulation. This project focuses on the specific use of polypropylene (PP) plastic waste as a replacement for coarse aggregates in M-25 grade concrete.

The primary objective of this study is to evaluate the impact of varying percentages of plastic aggregate replacement on the compressive strength, density, and cost-efficiency of concrete. The study aims to determine the optimal percentage of plastic waste that can be used without significantly compromising the structural integrity of the concrete. Additionally, the study assesses the economic feasibility of this innovative approach by comparing the costs of plastic-modified concrete with conventional concrete.

As part of the study technique, concrete mixes containing varying amounts of plastic trash (10%, 15%, 20%, and 0%) are prepared in place of coarse particles. The workability, density, and strength of the concrete mixes are assessed using standardized procedures such the slump test, density test, and compressive strength test. The feasibility of using plastic waste in structural concrete applications is then assessed by analyzing the data.

In conclusion, this study aims to contribute to sustainable construction practices by providing an alternative solution to the disposal of plastic waste. By integrating plastic waste into concrete, the construction industry can reduce its environmental footprint and promote the development of eco-friendly building materials. This research not only addresses environmental concerns but also explores the potential for cost savings and improved material properties in the construction sector.

II. LITERATURE REVIEW

The use of waste materials in concrete has been extensively researched over the past few decades, driven by the need for sustainable construction practices and the mitigation of environmental issues associated with waste disposal. This section provides an overview of previous studies and findings related to the incorporation of plastic waste in concrete, focusing on its effects on the mechanical and physical properties of concrete.

A. Utilization of Plastic Waste in Concrete

Several studies have explored the feasibility of using plastic waste as a replacement for natural aggregates in concrete. Patil et al. (2014) investigated the use of various types of plastic waste in concrete mixes and reported that the inclusion of plastic waste can improve certain properties of concrete, such as its durability and resistance to chemical attacks. Similarly, Khajuria and Sharma (2019) examined the effects of plastic aggregates on the workability and strength of concrete, finding that plastic waste could be a viable alternative to traditional aggregates if used in appropriate proportions.

B. Mechanical Properties of Plastic-Modified Concrete

Concrete's mechanical qualities, such as its tensile and compressive strengths, are essential for its structural uses. Kamal et al. (2021) studied the compressive strength of concrete containing recycled plastic aggregates and observed a decrease in strength with increasing plastic content. However, the study also noted that the reduction in strength was not significant enough to disqualify the use of plastic waste in non-load-bearing applications. Admile and Nemade (2020) further supported these findings, highlighting that while there is a decrease in compressive strength, the material still meets the minimum requirements for certain structural applications.

C. Physical Properties and Workability

The density and workability of concrete are important factors in its application and performance. Vadivel et al. (2016) found that the density of concrete decreases with the addition of plastic aggregates due to the lower density of plastic compared to natural aggregates. This reduction in density can be advantageous for lightweight concrete applications. Additionally, Islam (2022) reported that the workability of concrete mixes decreases with the inclusion of plastic waste, which can be managed by adjusting the water-cement ratio and the use of chemical admixtures.

D. Environmental and Economic Benefits

The environmental benefits of using plastic waste in concrete are well-documented. Elango et al. (2021) emphasized that incorporating plastic waste into concrete reduces the amount of plastic that ends up in landfills and oceans, thereby mitigating environmental pollution. Furthermore, Ramesan et al. (2015) highlighted the potential cost savings associated with using recycled materials, though they also noted the need for further research to optimize the economic viability of such practices.

E. Gaps and Future Research Directions

Despite the promising results, several gaps remain in the research on plastic-modified concrete. Most studies have focused on the mechanical properties, with limited research on the long-term durability and performance of plastic-modified concrete under various environmental conditions. Additionally, there is a need for more comprehensive economic analyses to assess the feasibility of large-scale implementation. Future research should also explore the potential for using different types of plastic waste and the effects of various additives to enhance the properties of plastic-modified concrete.

In summary, the literature indicates that plastic waste can be successfully incorporated into concrete, offering environmental and economic benefits. However, careful consideration of the proportion of plastic aggregates and the use of appropriate additives is crucial to maintaining the desired properties of concrete. This study aims to build on these findings by evaluating the specific use of polypropylene plastic waste in M-25 grade concrete and assessing its impact on the mechanical and physical properties of the concrete.

III. MIX PROPORTION

The mix proportion for the concrete was designed to evaluate the impact of replacing natural coarse aggregates with polypropylene plastic aggregates at various levels. The aim was to determine an optimal mix that maintains the structural integrity and strength of M-25 grade concrete while incorporating plastic waste. This section details the materials used, the mix design, and the preparation process.

A. Materials Used

The materials used in this study are outlined in Table 1. Each material was chosen for its specific properties to contribute to the overall performance of the concrete mix.

Table 1. Material Specifications

Material	Specifications
Cement	Ordinary Portland Cement (OPC) 53 grade
Fly Ash	Class F fly ash
Fine Aggregate	River sand conforming to Zone II
Coarse Aggregate	Crushed stone with a maximum size of 20 mm
Plastic Aggregate	Polypropylene plastic waste, processed
Admixture	Superplasticizer (1% by weight of cement)

B. Mix Design

The mix proportions were developed based on guidelines provided by IS 10262: 2009 for M-25 grade concrete. The target was to achieve a mix that incorporates plastic aggregates at varying replacement levels without compromising the structural requirements. The replacement levels of plastic aggregates were set at 0%, 10%, 15%, and 20%.

Table 3. Mix Proportion PA Replacement

Replacement Level	Cement (kg)	Fly Ash (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Plastic Aggregate (kg)	Water (L)	Admixture (%)
0% (Control)	300	70	777.69	1083.94	0	150	1
10%	300	70	777.69	975.55	121.7	150	1
15%	300	70	777.69	921.35	182.55	150	1
20%	300	70	777.69	867.15	243.4	150	1

Pic. 3: Mix Proportion

C. Preparation of Concrete Mixes

The concrete mixes were prepared using a standard mixing procedure to ensure uniformity and consistency across all batches.

Material Preparation: The materials were weighed accurately according to the mix proportions. The polypropylene plastic waste was shredded to match the size of natural aggregates.

Mixing Process: The mixing was carried out in a rotating drum mixer. First, the dry materials (cement, fly ash, fine aggregate, and coarse aggregate) were mixed thoroughly for about 2 minutes. Following this, the plastic aggregates were added, and the mixing continued for another 2 minutes.

Addition of Water and Admixture: Water and the superplasticizer were added to the dry mix gradually, ensuring even distribution. The mixing was then continued for an additional 3 minutes to achieve a homogeneous mixture.

Pic. 4: Cube Oiling

Pic. 5: Cube Casting

Casting and Curing: The mixture of concrete was transferred into oiled molds, resulting in 150 mm x 150 mm x 150 mm cubes. To guarantee compaction and get rid of air bubbles, the molds were vibrated. After a day, the specimens were demolded and allowed to cure in water at a temperature of 27 ± 2°C for a total of 28 days.

The mix proportions and preparation procedures aimed to produce concrete with consistent quality and properties, enabling a reliable comparison of the performance of concrete with varying levels of plastic aggregate replacement. This foundational work sets the stage for subsequent testing and analysis of the mechanical and physical properties of the resulting concrete mixes.

IV. TESTING

The testing phase is crucial for evaluating the mechanical and physical properties of the concrete mixes with varying levels of plastic aggregate replacement. This section details the specific tests conducted and their methodologies, including the density test, water absorption test and compressive strength test.

A. Density Test

The density test was conducted to determine the dry density of the concrete samples.

Procedure:

The concrete cubes, after being cured for 28 days, were weighed to determine their mass.

The volume of each cube was calculated based on its dimensions (150 mm x 150 mm x 150 mm).

The dry density was then calculated using the formula:

$$\text{Density} = \text{Mass} / \text{Volume}$$

Results:

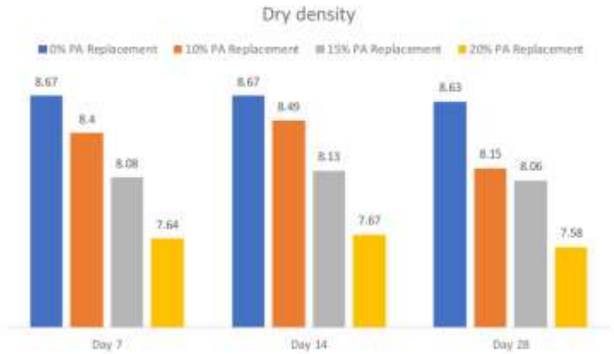
The densities of the different concrete mixes were recorded and analyzed.

The impact of plastic aggregate on the density of the concrete was assessed.

Table 4: Dry Density

Material	0% PA Replacement	10% PA Replacement	15% PA Replacement	20% PA Replacement
Day 7	8.67	8.40	8.08	7.64
Day 14	8.67	8.49	8.13	7.67
Day 28	8.67	8.15	8.06	7.58

Fig. 1: Graph of the result of dry density



B. Compressive Strength Test

The concrete's ability to support a given load was assessed using the compressive strength test.

Procedure:

A universal testing equipment was used to apply compressive force to the 28-day-cured concrete cubes.

The load was progressively increased until the specimen failed.

The cube's maximum load at which it failed was noted.

Calculation:

The compressive strength was calculated using the formula:

Compressive Strength = Maximum Load / Cross-sectional Area

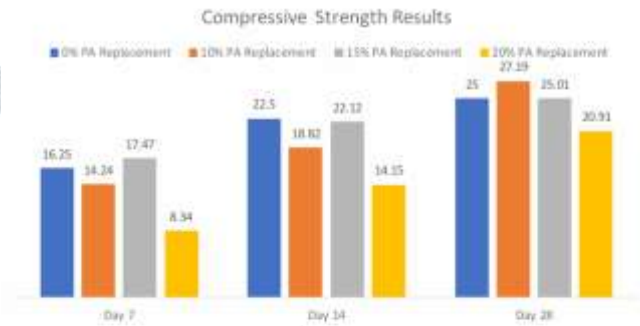
Results:

The compressive strengths of the concrete mixes with 0%, 10%, 15%, and 20% plastic aggregate replacement were recorded.

The effect of increasing plastic aggregate content on compressive strength was analyzed.

Table 5: Compressive Strength Results

Fig. 2: Graph of the result of the compressive test



C. Water Absorption Test

The water absorption test was conducted to assess the porosity and durability of the concrete.

Procedure:

The concrete cubes were dried at 105°C in an oven until they reached a consistent weight.

After that, the dried cubes were submerged in water for a whole day.

To ascertain the mass of the absorbed water, the cubes were weighed once more after a 24-hour period.

Calculation:

The water absorption was calculated using the formula:

Water Absorption (%) = (Wet Weight − Dry Weight / Dry Weight) × 100

Results:

The water absorption percentages for the different concrete mixes were recorded.

The correlation between plastic aggregate content and water absorption was analyzed.

D. Cost-to-Benefit Analysis

A cost-benefit analysis was done to see if it would be financially feasible to use plastic trash in concrete.

Procedure:

The cost of materials for each mix proportion was calculated, including the cost of plastic waste.

The total cost for producing one cubic meter of each concrete mix was determined.

The compressive strength to cost ratio was calculated to assess the economic viability.

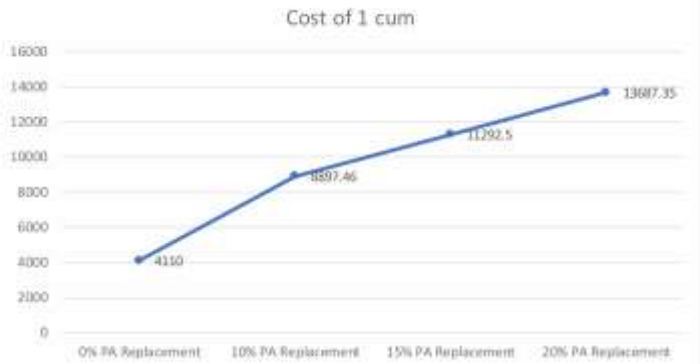
Results:

The costs for 0%, 10%, 15%, and 20% plastic aggregate replacement mixes were compared.

The cost difference between conventional concrete and plastic aggregate concrete was analyzed.

Table 6: Cost-to-Benefit Analysis of M-25 Grade Concrete

Fig. 3: Graph of Cost (In INR) to Benefit Analysis of M-25 Grade Concrete



We were able to thoroughly assess the effects of replacing concrete aggregate with plastic on its characteristics and economic viability by carrying out these experiments. The findings offer insightful information on the possibility of utilizing plastic waste as a sustainable substitute in the manufacturing of concrete.

V. RESULTS AND DISCUSSION

The outcomes of the several experiments carried out on concrete mixtures with varying percentages of plastic aggregate substitution are shown in this section. It contains a thorough examination and discussion of the results, emphasizing how flexible particles affect the concrete's mechanical qualities, physical characteristics, and viability from an economic standpoint.

A. Compressive Strength

Results:

The outcome is the compressive strength for concrete mixes with 0%, 10%, 15%, and 20% plastic aggregate replacement are summarized in Table 5.

As the percentage of plastic aggregate increases, the compressive strength decreases.

The 0% plastic aggregate mix had the highest compressive strength, followed by the 10%, 15%, and 20% mixes.

Table 5: Compressive Strength Result

Timeline	0% PA Replacement	10% PA Replacement	15% PA Replacement	20% PA Replacement
Day 7	16.25	14.24	17.47	8.34
Day 14	22.5	18.82	22.12	14.15
Day 28	25	27.19	25.01	20.91

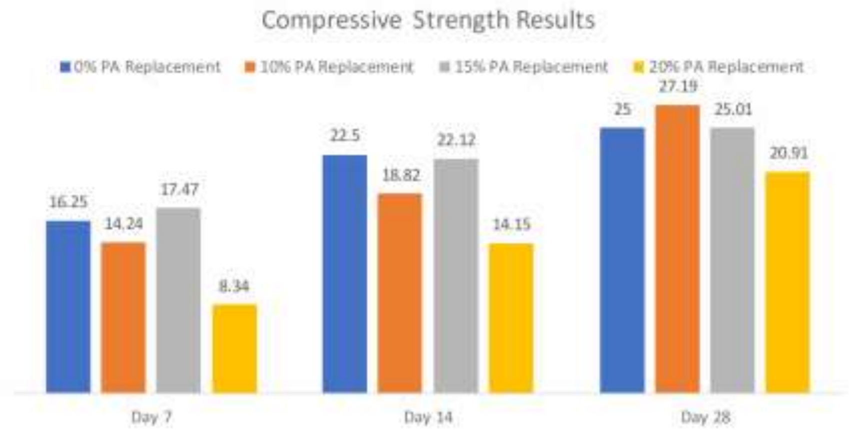
Discussion:

The decrease in compressive strength with increasing plastic aggregate content can be attributed to the lower density and strength of plastic compared to natural aggregates.

Despite the reduction in strength, the mix with up to 15% plastic aggregate still meets the standard requirements for structural concreting.

Beyond 15% replacement, the strength falls below acceptable levels for structural applications.

Fig. 2: Graph of the result of the compressive test



B. Density

Results:

The dry density results for the different concrete mixes are presented in Table 4.

The density of the concrete decreases as the plastic aggregate content increases.

Table 4: Dry Density

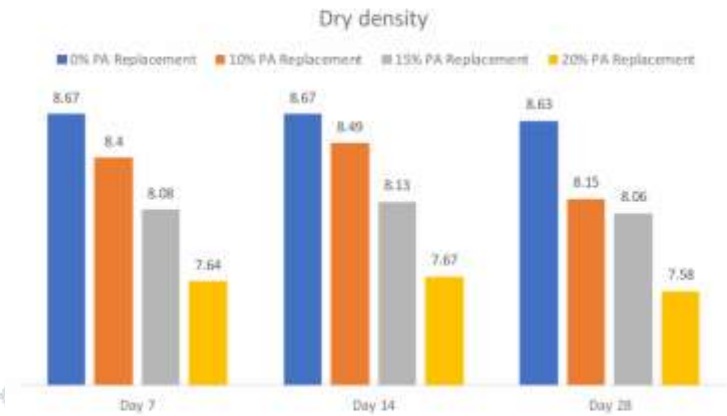
Material	0% PA Replacement	10% PA Replacement	15% PA Replacement	20% PA Replacement
Day 7	8.67	8.40	8.08	7.64
Day 14	8.67	8.49	8.13	7.67
Day 28	8.67	8.15	8.06	7.58

Discussion:

The reason for the decrease in density is because plastic aggregates have a lower density than natural aggregates.

This makes the concrete lighter, which could be advantageous for applications where weight reduction is beneficial.

Fig. 1: Graph of the result of dry density



C. Water Absorption

Results:

The water absorption percentages for the concrete mixes are presented.

An increase in plastic aggregate content leads to higher water absorption.

Discussion:

Higher water absorption indicates increased porosity in the concrete mixes with plastic aggregates.

This could affect the durability of the concrete, making it more susceptible to water-related damage over time.

D. Cost-to-Benefit Analysis

Results:

The cost analysis for different concrete mixes is detailed in Table 6.

The total costs for mixes with 10%, 15%, and 20% plastic aggregate replacement were significantly higher than conventional concrete.

Table 6: Cost-to-Benefit Analysis of M-25 Grade Concrete

Material	10% PA Replacement	Cost	15% PA Replacement	Cost	20% PA Replacement	Cost
CEMENT	300	1737	300	1737	300	1737
FLYASH	70	140	70	140	70	140
C.SAND	777.69	505.5	777.69	505.5	777.69	505.5
PLASTIC	121.7	4868	182.55	7302	243.4	9736
10 MM	405.86	263.81	345.92	224.85	285.69	185.7
20 MM	678.08	440.75	678.08	440.75	678.08	440.75
ADMIXTURE (%)	2.96	192.4	2.96	192.4	2.96	192.4
Misc.		750		750		750
TOTAL		8897.46		11292.5		13687.35
Conv. Concrete		4110		4110		4110
Difference (Rs)		4787.46		7182.5		9577.35
Difference (%)		116.50%		174.80%		233%

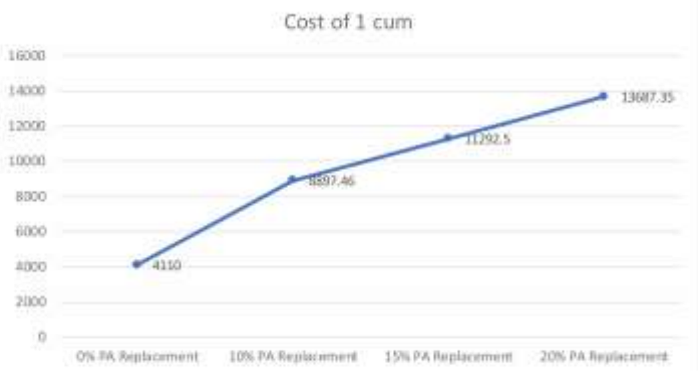
Discussion:

The higher costs are primarily due to the external sourcing of plastic waste.

If plastic waste can be processed in-house, the cost could be reduced, making plastic aggregate concrete economically viable.

The compressive strength to cost ratio was calculated to evaluate the economic feasibility.

Fig. 3: Graph of Cost (In INR) to Benefit Analysis of M-25 Grade Concrete



Strength vs. Density:

The results indicate a trade-off between strength and density. While plastic aggregates reduce the overall weight of the concrete, they also decrease its compressive strength.

Economic Feasibility:

The cost-to-benefit analysis shows that while plastic aggregate concrete is currently more expensive than conventional concrete, the cost could be reduced with in-house processing of plastic waste.

Environmental Impact:

Using plastic waste in concrete helps in reducing plastic pollution and promoting sustainability in construction.

The findings demonstrate that plastic waste can be used as a partial replacement for natural aggregates in concrete production, offering a sustainable alternative with minimal impact on strength and significant weight reduction. However, economic considerations need to be addressed to make this approach more feasible for widespread adoption.

VI. CONCLUSION

The experimental study on using plastic waste as a partial replacement for aggregate in structural concrete has led to several key findings:

Feasibility of Plastic Waste in Concrete: The use of plastic waste as a replacement for coarse aggregate up to 15% in M-25 grade concrete meets the standard compressive strength requirements for structural applications. Beyond this percentage, the compressive strength decreases, making it unsuitable for structural concreting.

Lightweight Concreting: The concrete mix containing plastic waste exhibits a significant reduction in weight compared to conventional concrete. This reduction in density suggests potential applications in lightweight concreting, offering benefits in terms of ease of handling and reduced structural loads.

Environmental Impact: Incorporating plastic waste into concrete provides a sustainable solution for managing plastic waste, reducing environmental pollution, and contributing to the circular economy. This approach not only mitigates waste disposal issues but also conserves natural aggregate resources.

Cost Analysis: The cost analysis revealed that the experimented concrete with plastic aggregates is more expensive than conventional concrete. However, the higher cost is attributed to the outsourcing of processed plastic waste. If plastic waste is processed in-house, the cost could be significantly reduced, potentially making it competitive with or even cheaper than conventional concrete.

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