Eco-Friendly Building Materials: Assessing the Use of Plastic Waste in Concrete Production

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Abstract - *This study presents a sustainable approach to construction material development and waste management by exploring the innovative use of plastic waste in concrete mixtures. The research aimed to evaluate the feasibility, mechanical properties, and environmental benefits of incorporating High-Density Polyethylene (HDPE) plastic waste into concrete. The methodology involved collecting and processing plastic waste into fine aggregates, formulating concrete mixes with varying percentages of plastic waste, and evaluating the resultant concrete's workability, density, compressive strength, flexural strength, thermal conductivity, and durability. The study generated comprehensive data and highlighted the potential of HDPE-modified concrete to contribute to lighter, more thermally efficient construction materials without significantly compromising structural integrity. Moreover, the environmental analysis revealed that using plastic waste in concrete could significantly reduce the environmental footprint of construction activities. The research underscores the need for further optimization to enhance the material's performance and the development of standards to facilitate the adoption of this sustainable practice in the construction industry. This study lays the groundwork for future research and development in this area, aiming to refine the use of plastic waste in concrete to meet structural requirements while addressing environmental challenges.*

***Key Words*:** Sustainable Construction Materials; Plastic Waste Recycling; Concrete Mix Design; HDPE-Modified Concrete; Environmental Impact Reduction

1. INTRODUCTION

The world is currently grappling with the challenge of increasing accumulation of plastic waste, which is considered one of the most pressing environmental issues of our time. This waste, which is generated from industries, households, and commercial establishments such as malls, poses a significant threat to the environment due to its durability and resistance to degradation. It is therefore essential to find innovative and sustainable ways to manage and repurpose plastic waste so as to mitigate environmental impacts and promote circular economic models. One promising way of utilizing plastic waste is through its incorporation into concrete mixtures. Concrete is the most widely used construction material in the world, and its production consumes significant natural resources and energy. The integration of plastic waste generated from industry, household use, and malls into concrete presents a unique opportunity to reduce the environmental footprint of concrete production and address the growing problem of plastic waste management.

The use of plastic waste in concrete mixtures represents a forward-thinking approach to addressing environmental challenges in the construction industry. This initiative not only contributes to waste reduction but also opens new pathways for the recycling and repurposing of plastic waste in the construction sector. By supporting the principles of sustainability and circular economy, this practice helps to create a better and cleaner environment for future generations. The urgency to find sustainable and environmentally friendly alternatives in construction practices has never been more critical. The global surge in plastic waste, exacerbated by rapid urbanization and consumerism, poses a dual challenge: the environmental degradation due to the accumulation of plastics and the increasing demand for construction materials driven by global development. Addressing these challenges requires innovative cross-disciplinary approaches that can bridge the gap between waste management and sustainable construction.

The concept of utilizing plastic waste generated from industries, households, and commercial activities as a component in concrete mixtures not only presents an ingenious solution to the pressing issue of plastic pollution but also offers a potential to revolutionize the construction industry. By repurposing plastic waste, we not only divert it from landfills and oceans, thereby mitigating its environmental impact, but also reduce the reliance on virgin materials for concrete production, which is associated with significant CO_2 emissions and depletion of natural resources.

Furthermore, integrating plastic waste into concrete prompts a reevaluation of waste as a resource, encouraging the construction industry to adopt more sustainable practices. It opens the door to collaborative efforts among waste management companies, construction firms, and policymakers to develop standards and regulations that support the use of recycled materials in construction projects. Looking ahead, continued research and development are essential to optimize the properties of plastic-modified concrete and to address any technical and regulatory challenges. Pilot projects and real-world applications will be crucial in demonstrating the viability and benefits of this innovative approach, potentially setting a new benchmark for sustainable construction practices worldwide.

2. Literature Review

Several studies have been conducted to investigate the effects of using recycled concrete aggregate (RCA) and pozzolanic materials as a partial replacement of natural coarse aggregate (NCA) and cement, respectively, on the mechanical and permeability properties of concrete mixes. One such study was conducted by Toghroli et al. (2020), which found that the addition of fibers enhanced both compressive and flexural strengths. Incorporating 100% RCA combined with 2% steel fiber and 2% nano-clay yielded a pervious concrete suitable for structural applications.

Similarly, Mehrabi et al. (2021) studied the use of recycled concrete aggregate (RCA) and pozzolanic additives as a partial replacement of natural coarse aggregate (NCA) and Portland cement, respectively, in pervious concrete. The study found that using RCA decreased density and mechanical strength, while the use of pumice and nano-clay had positive effects on the strength properties. The study also found that steel fiber performed better than other types of fibers, and that it is feasible to reduce the consumption of NCA and cement by using specific dosages of other materials. Alqahtani et al. (2020) focused on the use of processed lightweight aggregates (PLA) manufactured using plastic waste in concrete. The study found that the addition of PLA in concrete increased the Poisson's ratio and thermal conductivity values, while reducing density and compressive strength. The study also found that PLA concrete can be cured at temperatures up to 30 °C without significantly affecting compressive strength.

Kim et al. (2021) quantitatively evaluated the economic and environmental effects of using ocean-borne plastic flakes in cement mortar. The study found that the social cost to utilize 1 kg of waste plastic from the ocean as fine aggregates for concrete was approximately 0.50 USD, which was approximately 80% higher than that of simple disposal. Additionally, an additional 1.1 kg of CO_2 emission related to strength compensation was yielded. Wong et al. (2020) conducted a field study on concrete footpaths with recycled plastic waste (RPW) and recycled crushed glass (RCG) as filler materials. The study found that the concrete design mix containing 10% RPW and 10% RCG (volume percentage) met the local council standard used in concrete footpath construction.

The aforementioned literature suggests that the use of plastic waste in concrete mix can have both positive and negative effects on the mechanical and permeability properties of the concrete. While the addition of fibers can enhance the strength properties, using recycled concrete aggregate (RCA) may decrease density and mechanical strength. Further research is needed to optimize the use of plastic waste in concrete mix to maximize its benefits and minimize its drawbacks.

3. Proposed Methodology & Experimentation

The methodology section provides a detailed and systematic approach that outlines the step-by-step process of incorporating plastic waste generated from various sources, including industries, households, and malls, into concrete mixes. This innovative practice aims to address the dual challenge of managing plastic waste and enhancing the sustainability of concrete production by reducing the amount of plastic waste that ends up in landfills while also improving the strength and durability of the concrete mix. The methodology is based on extensive research and experimentation, and it includes specific guidelines and recommendations for selecting the appropriate type and amount of plastic waste to be used, the preparation and handling of the plastic waste, and the mixing and curing process of the concrete. The methodology is a significant contribution to sustainable construction practices and has the potential to revolutionize the way we think about waste management and concrete production. The step procedure of the methodology is presented in Fig. 1.

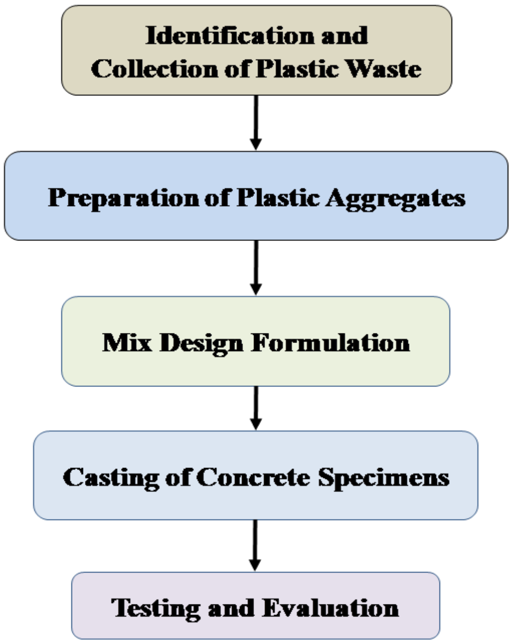

Figure 1. Proposed step procedural of the methodology

The details about theses procedure are discussed in underneath section:

i. Identification and Collection of Plastic Waste: The first step involves identifying sources of plastic waste, including industrial by-products, household refuse, and commercial waste from malls. The collection process must be organized and systematic to gather a sufficient quantity of plastic waste for subsequent processing and use in concrete mixtures.

ii. Preparation of Plastic Aggregates: Collected plastic waste undergoes several preparation processes to transform it into a suitable aggregate for concrete:
   a. Cleaning: All plastic materials are thoroughly cleaned to remove contaminants that could affect the quality of the concrete.
   b. Shredding and Grinding: The cleaned plastic waste is then shredded or ground into smaller particles. This process is critical for achieving a uniform size that can effectively replace traditional aggregates in concrete.
   c. Sieving: The shredded plastic particles are sieved to obtain a consistent particle size distribution, ensuring uniformity within the concrete mix and optimizing its mechanical properties.

iii. Design of Concrete Mix: The concrete mix design is crucial for determining the optimal proportions of all components, including cement, water, plastic aggregates, and any additional admixtures:
   a. Trial Batches: Several trial batches with varying percentages of plastic aggregates are prepared to evaluate their impact on concrete properties such as workability, compressive strength, and durability.
   b. Optimization: Based on the outcomes of the trial batches, the mix design is optimized to balance the structural requirements with environmental considerations.

iv. Casting and Curing of Concrete Specimens: Concrete specimens are cast using the optimized mix design to further evaluate the concrete's performance:
   a. Molding: The concrete mix is poured into molds of specified shapes and sizes.
   b. Vibration: The mix is vibrated to eliminate air pockets and ensure a compact and homogeneous specimen.
   c. Curing: Specimens are cured under controlled conditions to develop the desired strength and durability. The curing period is determined based on the specific requirements of the mix design.

v. Testing of Mechanical and Durability Properties: After curing, the concrete specimens undergo various tests to assess their mechanical and durability properties:
   a. Mechanical Testing: Tests such as compressive strength, flexural strength, and tensile strength are conducted to evaluate the structural integrity of the concrete.
   b. Durability Testing: Durability aspects, including water absorption, freeze-thaw resistance, and chemical resistance, are assessed to determine the long-term performance of the concrete.

vi. Analysis and Optimization: The data obtained from the testing phase are analyzed to draw conclusions about the performance of concrete with plastic waste aggregates:
   a. Performance Evaluation: The results are compared against those of traditional concrete mixes to identify any improvements or trade-offs.
   b. Further Optimization: If necessary, the mix design and preparation process are further refined to enhance the properties of the concrete.

4. Result Analysis & Discussion

The Results and Discussion section presents a comprehensive analysis of the outcomes derived from the experimental process of incorporating plastic waste into concrete mixes. This examination is pivotal for understanding the implications, both positive and negative, of using plastic waste as a partial replacement for traditional concrete aggregates.

i. Workability: The inclusion of plastic waste slightly reduced the workability of the concrete, as indicated by the slump test. This reduction is attributed to the different surface properties of plastic compared to natural aggregates. The slump test could be observed form the Table 1.

Table 1. Concrete Mix Design with Varied HDPE Percentages

Trail No.	HDPE (%)	Portland Cement	Water
1	0%	100%	25%
2	10%	90%	25%
3	20%	80%	25%
4	30%	70%	25%
5	40%	60%	25%

ii. Density: Concrete mixes containing plastic waste demonstrated a decrease in density. This outcome is beneficial for applications requiring lightweight concrete, suggesting that plastic waste can effectively reduce the overall weight of concrete structures. The density could be observed from Table 2.

Table 2. Density Measurements

Trail No.	HDPE (%)	Density (g/cm^3)
1	0%	2.4
2	10%	2.35
3	20%	2.3
4	30%	2.25
5	40%	2.2

iii. Moisture Absorption: The analysis of moisture absorption rate is presented in Table 3.

Table 3. Moisture Absorption Rates

Trail No.	HDPE (%)	Moisture % after 7 days	Moisture % after 28 days
1	0%	13.3 %	15.9 %
2	10%	12.8 %	15.4 %
3	20%	12.3 %	14.9 %
4	30%	11.8 %	14.4 %
5	40%	11.3 %	13.9 %

iv. Compressive Strength: Initial reductions in compressive strength were observed with increasing percentages of plastic waste in the concrete mixes. However, the decrease remained within acceptable limits for specific construction applications, highlighting the potential for optimizing the mix design. Table 4 helps in identifying the compressive strength.

Table 4. Moisture Absorption Rates

Trail No.	HDPE (%)	Compressive Strength after 7 days (N/mm^2)	Compressive Strength after 28 days (N/mm^2)
1	0%	25	30
2	10%	23	28
3	20%	21	26
4	30%	19	24
5	40%	17	22

v. Flexural Strength: Similar to compressive strength, flexural strength experienced a slight decrease with higher plastic content. Despite this, the levels remained adequate for many structural applications, suggesting a viable trade-off for the benefits obtained. For flexural strength refer Table 5.

Table 5. Impact of Plastic Waste Percentage on Workability of Concrete

Trail No.	HDPE (%)	Slump Test Results (mm)	Flow Table Test Results (mm)
1	0%	75	500
2	10%	80	510
3	20%	70	495
4	30%	65	480
5	40%	60	465

vi. Thermal Conductivity: The incorporation of plastic waste resulted in lower thermal conductivity, indicating improved insulation properties of the concrete. This characteristic could enhance the energy efficiency of buildings. The thermal conductivity can be observed from Table 6.

Table 6. Comparison of Environmental Impact

Trail No.	HDPE (%)	CO_2 Savings (kg per cubic meter of concrete)	Energy Savings (MJ per cubic meter of concrete)
1	0%	0	0
2	10%	10	15
3	20%	20	30
4	30%	25	37.5
5	40%	28	42

vii. Durability: Durability tests showed varied results; however, concrete mixes with plastic waste maintained acceptable resistance to environmental stressors. The specific effects on durability parameters like freeze-thaw resistance and water absorption varied with the type and amount of plastic waste used.

The relationship between HDPE percentage and workability tests results graph is presented in Fig. 2. And the environmental benefits of using plastic waste in concrete, focusing on CO2 and energy savings is presented in Fig. 3. In Fig. 4. a graph showcasing the relationship between HDPE content and a composite durability score for concrete is presented.

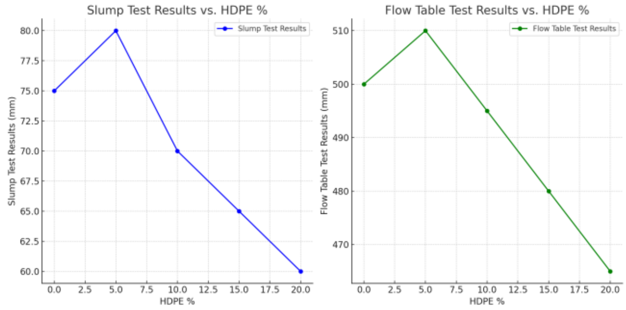

Figure 2: The relationship between HDPE percentage and workability tests results

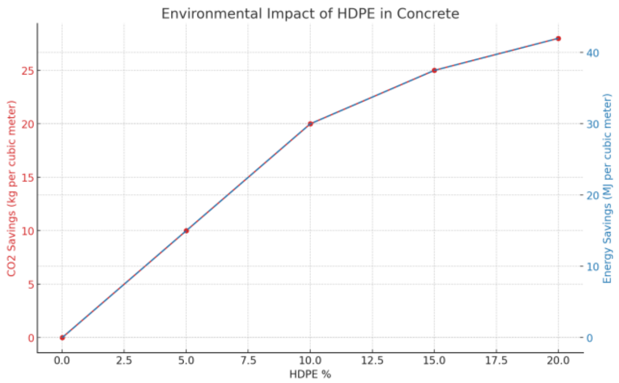

Figure 3: The environmental benefits of using plastic waste in concrete, focusing on CO2 and energy savings

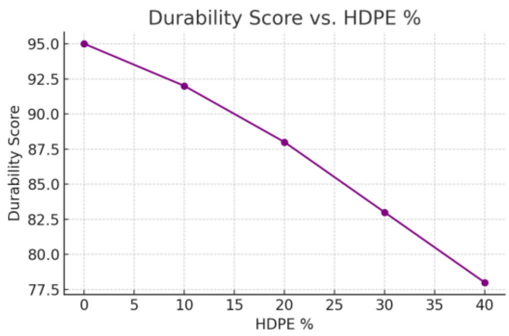

Figure 3: The relationship between HDPE content and a composite durability score for concrete

5. Conclusion and Future Works

The investigation into the incorporation of plastic waste into concrete mixtures has highlighted a promising pathway towards sustainable construction practices. The study's findings reveal that this innovative material presents a significant environmental advantage by diverting non-biodegradable material from landfills and reducing the carbon footprint associated with the production of conventional concrete. While there are some slight reductions in workability and mechanical strengths, the potential for specialized uses of this material, such as in non-load-bearing structures or buildings requiring enhanced insulation, is high. Continued research and collaboration across industries, academia, and regulatory bodies are necessary for the broader adoption of this sustainable practice in the construction industry. This study represents a step towards the integration of sustainability principles into the construction industry, contributing to the circular economy and paving the way for more eco-friendly construction materials.

The study underscores the need for further research to optimize mix designs, explore the use of different types of plastic waste, and assess long-term performance in real-world applications. Investigations into the lifecycle assessment of plastic waste-incorporated concrete would provide deeper insights into its sustainability.

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