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Utilizing Waste Plastic in Concrete for Partial Substitution of Fine Aggregate

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Abstract
This study explores the viability of integrating waste plastic materials as a partial substitute for fine aggregate in concrete, aiming to mitigate environmental concerns while potentially enhancing concrete properties. Through various laboratory experiments, including normal consistency tests and slump cone tests, the research evaluates the effects of waste plastic on concrete characteristics. Findings indicate that the addition of waste plastic has negligible impacts on concrete setting time, but it reduces workability as plastic content increases, potentially leading to bleeding or segregation. Compressive strength tests reveal a decline in strength at 14 days for concrete containing 10% and 15% waste plastic, accompanied by decreasing densities with higher plastic content. Nonetheless, incorporating waste plastic results in cost savings and reduces reliance on natural aggregates. Concrete cubes demonstrate maximum compressive strengths of 17.31 N/mm² (0% plastic waste), 18.32 N/mm² (15% plastic waste), and 17.48 N/mm² (20% plastic waste), indicating a diminishing strength trend with increased plastic content. Future research could focus on improving the bond between plastic and cement particles to enhance cohesion and expand the applicability of waste plastic-concrete mixtures.
Keywords: Waste plastic, Concrete, Fine aggregate, Partial replacement, Sustainable construction

1. Introduction

In our country, concrete is widely and extensively utilized as the cornerstone of the nation's infrastructure due to its ability to provide maximum strength, support, and durability. It is both technically and economically dynamic, making it readily accessible. However, with the increasing demand for these chemical products, it is adversely affecting our environment, and it is also a costly medium. Fortunately, there are alternative materials that can replace these chemical products, offering both environmental benefits and cost-effectiveness. Materials such as waste plastic, waste paint, broken glass, paper pulp, etc., are being used in place of traditional concrete, contributing to a more sustainable and affordable construction approach. Plastic waste can be used as a building material for hot and cold countries, as it is impermeable and does not conduct heat. Some companies are turning plastic waste into raw materials like waterproof planks that can be used to construct classrooms, houses, and shelters. This way, plastic waste can be recycled and reused, reducing its environmental impact. The utilization of plastic is every day expanding and it is helpful just as a perilous material. At the period of scarcity, plastic although is of great importance and value however on using it, it is basically disposed of leading to a huge number of problems. Plastic is non-biodegradable, with the remaining parts as a risky material for more than hundreds of years. The amount of plastic waste in Municipal Solid Waste (MSW) is expanding quickly. This is because of the quick development of populace, urbanization, developmental activities, and changes in lifestyle. They are non-biodegradable and furthermore analysts have discovered that plastic materials can stay on earth for a long time without debasement (around 4500 years). In India around 40 million tons of the civil strong waste is produced every year, with assessed expanding at a pace of 1.5 to 2% consistently. Land filling of plastic is also dangerous due to its slow degradation rate and bulky nature. The waste mass may hinder the ground water flow and can also be the movement to foot. Plastic waste also contains various toxic elements, especially cadmium and lead, which can mix with rainwater and pollute soil and water. Recycling plastics is a possible option. As plastic is an organic hydrocarbon-based material, its high calorific value can be used for incineration or in other high temperature processes. But, burning plastics releases a variety of poisonous chemicals into the air, including dioxins, one of the most toxic substances. Plastic waste can also be used to produce new plastic-based products after processing. However, it is not an economical process as there cycled plastic degrades in quality and necessitates new plastic to make the original product. Scientists are investigating the integration of plastic waste into concrete, recognizing that concrete ranks as the second most in-demand material by humans, following water. The use of post-consumer plastic waste in concrete not only provides a safe disposal method but may also enhance concrete properties such as tensile strength, chemical resistance, drying shrinkage, and creep over both short and long- term periods.

1.1 Significance of the Work

The significance of this research lies in its potential to address significant environmental challenges associated with plastic waste pollution on a global scale. By exploring the integration of plastic waste into concrete, this study contributes to recycling efforts and mitigates environmental degradation caused by plastic pollution. Furthermore, the purposeful utilization of plastic waste in concrete offers a constructive solution for managing plastic waste, diverting it from landfills, and potentially reducing overall plastic pollution volumes. Through the conservation of natural resources and promotion of sustainable practices in the construction industry, this research aims to foster environmental stewardship and contribute to a more sustainable future.

1.2 Scope of the Work

The scope of this research encompasses several key areas. Firstly, it focuses on investigating the mechanical properties of concrete enhanced with plastic waste, including compressive strength and durability. Additionally, the study explores the economic aspects of incorporating plastic waste into concrete mixtures, assessing its cost-effectiveness compared to traditional construction materials. Furthermore, this research contributes to the development of innovative construction materials aligned with sustainable practices, potentially opening up new avenues for designing and constructing buildings with reduced environmental impact. Finally, the study aims to provide insights into regulatory compliance related to the use of recycled materials in construction, ensuring the safety and efficacy of plastic-reinforced concrete in compliance with existing building codes and regulations.

2. Objectives of the current study

The objectives of this study aim to investigate the feasibility and benefits of incorporating plastic waste into concrete. Through these objectives, the research seeks to provide insights into the environmental, mechanical, and economic aspects of using plastic waste in concrete production.

1. To determine the impact of incorporating plastic waste on concrete's mechanical properties, including compressive strength, flexural strength, and durability.
2. To evaluate the cost-effectiveness of using plastic waste as a partial replacement for fine aggregate in concrete, considering material availability, production costs, and potential savings compared to traditional materials.

3. Literature Review

3.1 Overview of Concrete Composition

Concrete is a composite material composed primarily of aggregates, cement, and water, with supplementary materials such as admixtures often included to enhance specific properties. The composition of concrete plays a crucial role in determining its strength, durability, workability, and other engineering properties. Here is a breakdown of the main components:

- Aggregates: Aggregates constitute the bulk of concrete volume and consist of coarse and fine particles. Coarse aggregates, typically gravel or crushed stone, provide strength and stability to the concrete mix. Fine aggregates, such as sand, fill the voids between coarse particles, contributing to workability and density. The quality and grading of aggregates significantly influence concrete properties.
- Cement: Cement acts as the binding agent in concrete, holding the aggregates together. Portland cement is the most used type of cement in concrete production, composed primarily of calcium

silicates. When mixed with water, cement undergoes a chemical reaction called hydration, forming a paste that binds the aggregates into a solid mass.

- Water: Water is essential for the hydration of cement and the formation of the concrete paste. The water-to-cement ratio (w/c ratio) is a critical parameter that affects concrete strength, workability, and durability. Proper control of water content is necessary to achieve the desired concrete properties while avoiding issues such as segregation and shrinkage.
- Admixtures: Admixtures are additional materials added to concrete mixtures to modify its properties or improve performance. They can enhance workability, accelerate or retard setting time, increase strength, or enhance durability. Common types of admixtures include plasticizers, superplasticizers, air-entraining agents, and set-retarding agents.
- Supplementary Cementitious Materials (SCMs): SCMs, such as fly ash, slag, and silica fume, are by-products of industrial processes that can be used as partial replacements for cement in concrete mixtures. Incorporating SCMs can improve concrete durability, reduce permeability, and decrease environmental impact by reducing the consumption of cement.

Overall, the proper proportioning and mixing of these components are essential for producing high-quality concrete with the desired properties for various construction applications. Understanding the role of each component and their interactions is crucial for achieving optimal concrete performance and durability in structures.

3.2 Environmental Impact of Concrete Production

Concrete production is associated with significant environmental implications due to its high energy consumption, raw material extraction, and greenhouse gas emissions. The process of cement production, a key component of concrete, involves high temperatures and releases substantial amounts of carbon dioxide (CO_2) into the atmosphere, contributing to climate change. Additionally, the extraction of raw materials such as limestone and sand can lead to habitat destruction and biodiversity loss. Furthermore, transportation of materials to concrete production sites generates emissions, adding to the overall environmental footprint. To mitigate these impacts, efforts are underway to develop sustainable practices in concrete production, including the use of alternative materials, energy-efficient technologies, and carbon capture and storage techniques.

3.3 A Critical Review on Previous Studies

Conducting a critical review on previous studies is crucial as it provides insights into existing knowledge gaps, methodologies, and findings. It helps researchers identify strengths and weaknesses, refine research questions, and build upon existing literature, ultimately contributing to the advancement of knowledge in the field.

Gopi, K.S. and Srinivas, T. (2020) investigate the feasibility of using recycled plastic waste as fine aggregate in concrete production. Testing with M30 grade concrete shows decreased workability with higher plastic waste percentages. Optimum PET replacement is 10%, while PP exhibits marginal compressive strength reduction at 5% replacement.

Manjunath, B.A. (2016) explores the management and recycling potential of E-plastic waste, a valuable yet hazardous resource from IT industries, with low recycling rates. Utilizing E-plastic waste as partial replacement for aggregates in concrete offers environmental benefits, reduces costs, and provides structural strength. Experimental study on M20 concrete reveals optimal performance with 10% E-plastic replacement for coarse aggregates.

Lokeshwari, M. et al. (2019) investigate the utilization of recycled plastic aggregate (RPA) made from shredded Polypropylene (PP) plastic waste as a partial replacement for both fine and coarse aggregates in concrete production. Testing on M-40 grade concrete reveals reduced properties but suggests RPA as a sustainable alternative for lower grade applications.

Ullah, K. et al. (2022) investigate the substitution potential of electronic plastic waste (EPW) as fine aggregate in eco-friendly concrete. Four M20 grade concrete mixes replace natural fine aggregates with plastic fine aggregates (PFA) at 0%, 10%, 15%, and 20% levels. Results show reduced compressive and tensile strength with increased PFA incorporation but satisfactory performance in durability tests, indicating EPW concrete's potential for sustainable applications.

Dharmaraj, R. and Iyappan, G. (2016) address the pressing issue of plastic disposal by exploring the feasibility of utilizing Low Density Polyethylene (LDPE) bags as a partial replacement for fine aggregate in concrete. Through meticulous methods involving pulverization and granulation, they investigate concrete properties with varying LDPE replacement percentages. Results indicate improved compressive strength with up to 15% LDPE replacement, offering a sustainable solution to conserve natural resources.

Sabău, M. and Vargas, J.R. (2018) explore the utilization of e-plastic waste as a partial replacement for coarse mineral aggregate in concrete production. Their research introduces a concrete mix incorporating ground e-plastic waste from electronic device housings, aimed for social housing wall construction. Findings reveal a reduction in compressive strength, with a maximum decrease of 44% at 60% e-plastic waste. Good workability in fresh state is observed, yet adhesion issues require pre-processing for enhanced bond strength with cementitious material. Proposed equations offer estimations for compressive strength reduction. Cost savings of up to 15% in masonry wall construction are possible with e-plastic waste incorporation.

4. Methodology and Materials

4.1 Collection and Sorting

- Collect PVC waste materials from various sources such as discarded pipes, cable insulation, or packaging.
- Sort the collected materials based on PVC content and relevant characteristics.

4.2 Cleaning and Shredding

- Clean the sorted PVC waste to remove contaminants like dirt, labels, or other PVC materials.
- Shred the cleaned PVC waste into small particles suitable for concrete.

4.3 Separation of PVC and Suitable Fibers

- Use separation techniques, such as density-based methods, to separate PVC from other plastics in mixed waste.
- Transform PVC waste into fibers suitable for concrete preparation.

4.4 Experimental Design

- Replace 15% and 20% of fine aggregate in M20 grade concrete with PVC waste.
- Cast cube specimens of 150 mm x 150 mm x 150 mm and test after 7 and 14 days of curing.

4.5 Mixing

- Accurately measure and combine cement, sand, aggregates, and PVC waste fibers.
- Gradually add water to achieve the desired consistency without over-mixing.

4.6 Casting

- Prepare molds and compact concrete in layers.
- Cure specimens for the specified period before demolding.
- Repeat the process for conventional concrete blocks without PVC waste.

5. Materials used in the current study:

5.1 Waste Plastic (PVC Waste)

Utilization of PVC waste plastic in concrete offers an eco-friendly solution to plastic disposal issues. PVC waste, sourced from discarded items like pipes and packaging, enhances concrete flexibility and impact resistance, particularly beneficial for structures in stress-prone areas.

5.2 Cement

Portland cement, the primary binder in concrete, undergoes calcination to form clinker. Blended with gypsum, it produces standard OPC grade-43 cement, extensively used in construction.

5.3 Coarse Aggregate

Essential for concrete strength, coarse aggregate, including gravel, crushed stone, or recycled concrete, fills voids, interlocks particles, and reduces shrinkage. Common sizes range from 5mm to 20mm, selected based on structural requirements.

5.4 Fine Aggregate (Sand)

Concrete sand, passing through a 4.75 mm sieve, enhances workability and cohesion. Notably, beach or dune sand is unsuitable due to rounded particles and high salt content, impacting concrete performance.

6. Experimental results

6.1 Normal Consistency Test

- Determines water requirement for standard consistency of cement paste.

- Importance: Essential for assessing workability and water-cement ratio.

6.2 Initial and Final Setting Time Test

- Determines time durations for initial and final setting of cement paste.
- Importance: Crucial for understanding cement behavior and workability.

6.3 Slump Cone Test

- Evaluates workability and consistency of freshly mixed concrete.
- Importance: Assesses concrete's ability to flow and deform.

6.4 Compressive Strength Test

- Determines concrete's ability to withstand compressive loads.
- Importance: Ensures quality and durability of concrete structures.

7. Results and discussion

The test results reveal significant insights into the properties of materials used in concrete casting. Normal consistency of the cement was found to be 25%, with a final setting time of 464 minutes. Slump tests showed a reduction in slump size with increasing percentages of waste plastic, indicating decreased workability. Compression tests after 7 days of curing demonstrated an average compressive strength of 17.31 N/mm² for conventional blocks, rising to 18.32 N/mm² with 15% waste plastic and slightly lower at 17.48 N/mm² with 20% waste plastic. At 14 days, the average compressive strength for conventional blocks increased to 18.78 N/mm², while blocks with 15% waste plastic exhibited a slightly lower average strength of 18.25 N/mm², and those with 20% waste plastic showed a further decrease to 16.83 N/mm². These findings suggest a negative correlation between waste plastic content and compressive strength, likely due to reduced cohesion between plastic and cement, potentially leading to cracks during testing. Moreover, the decrease in slump size hints at decreased workability, posing challenges such as bleeding and segregation in concrete blocks with higher waste plastic content. The complete results are summarized in below tables 1-3 and the compressive strength is shown in figure 1.

Table 1: **Consistency of Cement**

Weight of cement (g)	Percentage of Water added (in terms of weight of cement)	Volume of Water added (ml)	Reading on Gauge (mm)
400	25	100	35
400	28	112	17
400	29	116	16
400	30	120	11
400	**31**	**124**	**7**

Table 2: slump cone test

S. No	Percentage of replacement asplastic	W/C Ratio	Quantity of water in ml	Slump in mm
1.	0	0.55	1375	95
2.	15	0.55	1375	91
3.	20	0.55	1375	87

Table 3: conventional Block after 7 days

Trial	Load (KN)	Area	Compressive Strength(N/mm^2)	Average (N/mm^2)
1	388	150 x 150	17.26	

2	390	150 x 150	17.37	17.31

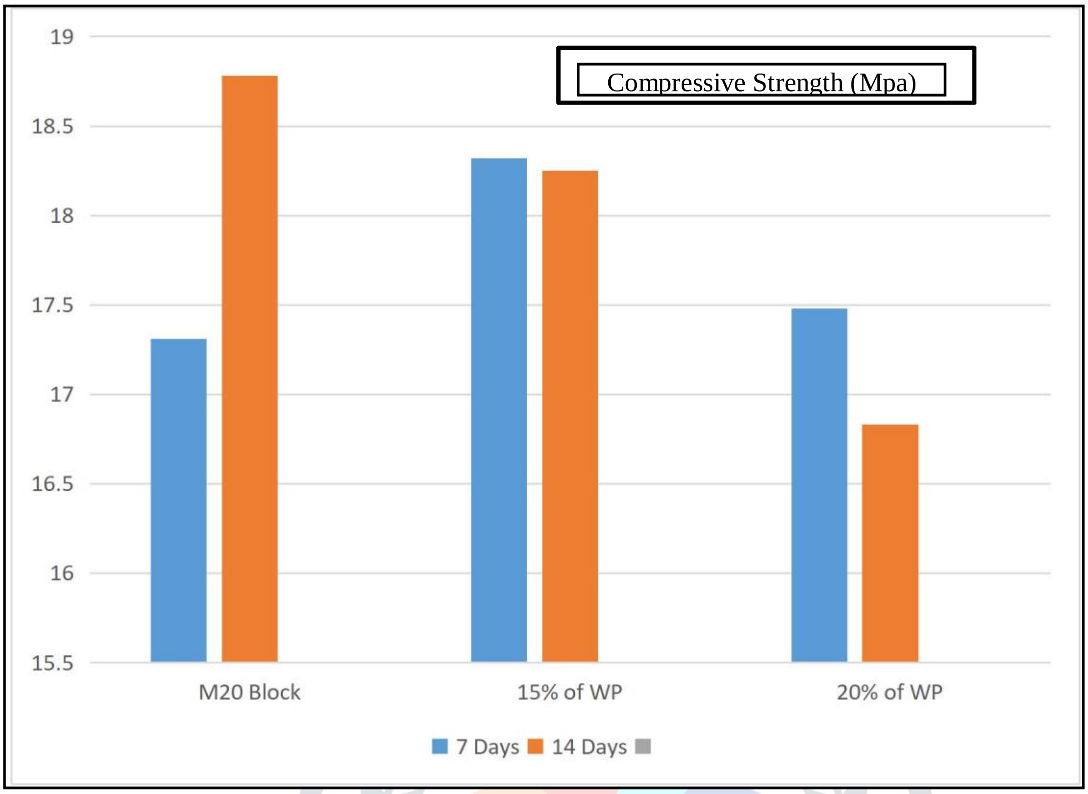

figure 1: compressive strength (Mpa)

8. Conclusions

The research undertaken aimed to explore the feasibility of substituting a portion of fine aggregate in concrete with waste plastic materials, offering potential benefits for both environmental sustainability and concrete properties enhancement. Through a series of experiments, the study assessed mechanical, structural, and durability characteristics of concrete mixtures containing varying percentages of waste plastic. The findings suggest that while waste plastic incorporation does not significantly impact the setting time of concrete, it does lead to reduced workability, potentially causing bleeding or segregation, indicating poor cohesion between plastic and cement particles. Moreover, a decrease in compressive strength was observed in concrete containing higher percentages of waste plastic, highlighting potential issues such as cracking due to lack of cohesiveness. However, there were notable benefits observed, including a reduction in construction and maintenance costs and decreased reliance on natural aggregates. The study demonstrated that as the percentage of waste plastic increased, the overall strength of the concrete decreased, with maximum compressive strength observed at 17.31 N/mm² for zero percent plastic waste. This decline in strength suggests that waste plastic-concrete mixtures may be most suitable for applications where minimum workability is required, such as precast bricks or partition wall panels. Future research avenues could explore methods to improve the bond between plastic and cement particles, potentially through finer grinding of waste plastic or the addition of plasticizers to enhance cohesion.

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