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Performance Assessment of Concrete Incorporating Low-Density Waste Plastic Aggregates

Dr. S.S. Anglekar[1], Mr. Soham S. Dhawade[2]
[1]Professor, Department of Civil Engineering, SCOE, Pune
[2] M.E Structural Engineering, Department of Civil Engineering, SCOE Pune

Abstract: The growing concern over plastic waste pollution and the urgent need for sustainable construction practices have prompted exploration into alternative materials for concrete production. This study investigates the feasibility of utilizing low-density, dust-coated waste plastic aggregates as a partial replacement for conventional coarse aggregates in concrete. The objective is to assess how the incorporation of recycled plastic influences the physical, mechanical, and durability properties of concrete, with the goal of developing a lightweight, eco-friendly alternative for use in non-structural and potentially structural applications. A comprehensive experimental program was undertaken, including the preparation of plastic aggregates from assorted waste sources, coating them with fine aggregate dust, and incorporating them into concrete mixes. Tests were conducted to evaluate workability (slump test), compressive strength, flexural strength, split tensile strength, water absorption, density, and specific gravity. Results showed that while the inclusion of plastic aggregates generally reduces mechanical strength compared to traditional concrete, dust-coating significantly mitigates this reduction, particularly at lower replacement ratios such as 10%. The best performing mix maintained sufficient strength and workability within acceptable limits for non-load-bearing applications. Furthermore, the study revealed that plastic aggregate concrete exhibits improved thermal insulation and reduced density, making it suitable for lightweight construction needs. The environmental benefits are substantial, as this approach reduces dependence on natural aggregates, lowers the carbon footprint of construction, and provides a productive avenue for reusing plastic waste that would otherwise contribute to landfill and marine pollution. Microstructural observations and economic analyses further support the viability of this material, especially when performance optimization techniques, such as surface treatment and controlled mix design, are applied. The study concludes that dust-coated waste plastic aggregates offer a sustainable alternative to traditional materials, promoting circular economy principles and environmentally responsible construction. Continued research and development in this area could pave the way for broader adoption in the construction industry.
Keywords: Compressive Strength, Flexural Strength, Split Tensile Strength, Water Absorption, Density, And Specific Gravity.

I. INTRODUCTION

In recent years, the rapid growth in global population and the rise of consumer-driven lifestyles have significantly increased plastic waste generation, posing a serious environmental threat. Due to its non-biodegradable nature, plastic waste accumulates in landfills and oceans, harming ecosystems, wildlife, and human health. Although recycling initiatives have grown, the sheer volume of plastic waste calls for more innovative and sustainable solutions. One promising approach is the integration of plastic waste into construction materials, especially as a replacement for natural aggregates in concrete.

Concrete is the most widely used construction material worldwide and consumes large quantities of natural resources like sand and gravel. Replacing a portion of these natural aggregates with plastic waste presents a dual advantage: it reduces the environmental burden of plastic disposal and decreases the demand for natural materials in concrete production. However, incorporating plastic waste into concrete affects the material's properties, including strength, workability, durability, and thermal insulation.

This study reviews recent research from 2020 to 2024 to assess the potential of using different types of plastic waste—such as polyethylene (PE), polypropylene (PP), high-density polyethylene (HDPE), and low-density polyethylene (LDPE)—as aggregates in concrete. These plastics differ in physical and mechanical properties like density, flexibility, and thermal conductivity, which influence concrete behavior. Findings indicate that while the use of plastic waste typically lowers compressive, flexural, and tensile strengths, the reductions are within acceptable limits for many construction applications. Additionally, plastic aggregates improve concrete workability and reduce its overall density.

Economically, the substitution of natural aggregates with plastic waste reduces raw material costs and lowers the carbon footprint of concrete production. This also contributes to a decrease in CO_2 emissions, aligning with global sustainability goals. Moreover, concrete with plastic waste shows reduced thermal conductivity, which may enhance its insulation properties in specific applications. Environmentally, this practice offers a sustainable solution for managing plastic waste while promoting circular economy principles. It minimizes landfill use, curbs pollution, and repurposes waste into valuable building materials, supporting both ecological and construction industry needs.

II. LITERATURE REVIEW

The increasing threat of plastic waste accumulation has motivated researchers to explore sustainable construction methods using recycled plastics as partial substitutes for natural aggregates in concrete. Multiple studies have shown the feasibility of incorporating plastic waste in concrete mixtures, examining both mechanical performance and environmental benefits.

Hamada et al. [1] reviewed the use of plastic waste as aggregates, observing improved workability but reductions in compressive, tensile, and flexural strength within acceptable limits. Rahim et al. [2] developed composite T-beams with high-strength concrete (HSC) flanges and plastic waste aggregate concrete (PWAC) webs. These beams performed well structurally, with experimental load capacities exceeding theoretical predictions. Hamsavathi et al. [3] used shredded e-waste as coarse aggregates in concrete beams, improving compressive and flexural strength, with optimal performance achieved at 15% replacement.

Mohammed and Hama [4] investigated beams combining glass powder and plastic aggregates. They found enhanced deflection and energy absorption but noted trade-offs with increased reinforcement. Nwaubani and Parsons [5] studied the mechanical and microstructural performance of concrete with Waste Electrical and Electronic Plastics (WEEP), showing reduced strength due to poor bonding, which was improved with pozzolanic additives.

Al-Mansour et al. [6] focused on enhancing matrix-aggregate compatibility using EVA-coated recycled waste plastics in cement mortar. Although strength decreased, ductility and energy absorption were significantly improved. Rao et al. [7] examined end-of-life vehicle (ELV) plastics as sand replacements. Despite strength losses at higher replacements, the concrete achieved sufficient strength for non-structural applications and demonstrated cost-efficiency.

Finally, Khatib et al. [8] studied post-tensioned beams with recycled plastic dust. The modified beams matched the performance of conventional beams and offered added benefits like reduced weight and improved thermal insulation.

III. METHODOLOGY

This study adopts a comprehensive experimental methodology to evaluate the influence of incorporating various forms of plastic waste as partial replacements for conventional concrete aggregates. The research comprises the following key phases:

A. *Material Selection and Preparation*

- Plastic Waste Sources: Different plastic wastes were selected, including post-consumer plastics, cathode ray tube (CRT) plastics, end-of-life vehicle (ELV) plastics, and electronic waste plastics (WEEP).
- Processing: Plastics were cleaned, shredded, and sieved to obtain uniform sizes (typically ranging from 1.18 mm to 12 mm) suitable for replacing fine or coarse aggregates.
- Surface Treatment: In some cases, plastic particles were dust-coated or polymer-coated (e.g., with EVA) to enhance the bonding between plastic and cement paste.

B. *Mix Design*

- Concrete mixes were prepared using standard grades such as M25.
- Plastic aggregates were used to replace natural aggregates in varying proportions (e.g., 5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% by weight or volume).
- Pozzolanic materials like metakaolin and silica fume were added in selected mixes to improve bonding and matrix density.

C. *Specimen Casting*

- Different types of structural and non-structural specimens were cast, including:
- Cubes for compressive strength testing.
- Prisms and cylinders for flexural and tensile strength.

- Reinforced beams (T-beams and RC beams) for flexural behavior analysis.
- Post-tensioned beams for moment capacity evaluation.

D. Curing

- All specimens were cured under standard conditions (e.g., 28 days in water) to ensure consistent hydration and strength development.

E. Testing Procedures

- Mechanical Tests:
  - Compressive strength (IS:516/ASTM C39).
  - Flexural strength (IS:516/ASTM C78).
  - Tensile strength (split and direct methods).
  - Load-carrying capacity of beams using UTM or hydraulic jacks.
  - Moment capacity and flexural response for post-tensioned beams.

- Durability and Workability:
  - Slump test for workability.
  - Water absorption, density, and shrinkage analysis.
  - Microstructure analysis using SEM and EDS.

- Bond and Shear Strength:
  - Pull-out tests to measure the bond between steel and concrete.
  - Shear tests for composite T-beams and reinforced sections.

F. Analysis of Results

- Results were compared with control mixes (100% natural aggregates).
- Statistical evaluation and theoretical vs. experimental comparisons were conducted.
- Ductility, energy absorption, and deformation characteristics were assessed.
- Optimal replacement levels were identified based on performance trends.

IV. RESULTS AND DISCUSSION

The sieve analysis of the coarse aggregates revealed that the majority of particles were retained on the 10 mm (41.7%) and 4.75 mm (26.3%) sieves, indicating a dominance of mid-sized aggregates. This distribution is favorable for concrete production as it promotes good compaction and strength development.

The aggregates exhibited acceptable physical properties including appropriate specific gravity, low water absorption, and satisfactory values in crushing, impact, flakiness, and elongation index tests. These characteristics confirm the suitability of the aggregates for producing durable and structurally sound concrete.

Workability of the concrete was assessed using the slump test. Results showed a decline in slump values with increasing percentages of plastic aggregates. The mix changed from a true slump to a collapsed slump at higher plastic content, reflecting decreased cohesiveness and increased water demand. This is attributed to the smooth, non-absorbent nature of plastic particles. However, the use of dust-coated plastic aggregates showed a slight improvement in slump, indicating better compatibility with the cement matrix.

Compressive strength tests demonstrated a consistent reduction in strength as the proportion of plastic aggregates increased. Conventional concrete (without plastic) achieved the highest compressive strength, while mixes containing plastic, particularly uncoated, showed lower values.

Dust-coated plastics performed slightly better than uncoated ones due to improved bonding at the interfacial transition zone. Overall, while strength is reduced with plastic use, incorporating waste plastic as aggregate offers a more sustainable concrete option, especially for non-structural applications where mechanical demands are lower.

V. CONCLUSIONS

This experimental study investigated the use of waste plastic aggregates in concrete as a partial replacement for traditional coarse aggregates. A series of tests were conducted to evaluate the physical, mechanical, and workability properties of concrete incorporating varying percentages of both uncoated and dust-coated plastic aggregates. The results were compared against conventional concrete, IS code standards, and previous research.

The findings reveal that incorporating plastic aggregates into concrete reduces workability by approximately 4% and decreases mechanical strength by 5% to 60%, depending on the percentage of plastic used. As the plastic content increases, slump values decline, indicating reduced workability. Mechanical properties—including compressive, flexural, and split tensile strengths—also show a consistent downward trend with higher plastic content. However, dust-coating the plastic aggregates significantly mitigates these negative effects. Strength and workability improved by around 15% in mixes using dust-coated plastic compared to uncoated plastic, due to enhanced bonding between the plastic surface and the cement matrix.

Notably, the mix with 10% dust-coated plastic aggregates showed relatively high strength values and acceptable workability, suggesting its potential use in non-structural concrete applications. Although the mechanical performance is still below that of traditional concrete, the environmental benefits of reusing plastic waste make it a promising material in sustainable construction practices.

In conclusion, surface treatment of waste plastic improves its integration into concrete, offering a greener alternative to conventional aggregates. With proper optimization, such modified plastics can support the development of eco-friendly building materials for low-load-bearing and non-structural uses.

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