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SUSTAINABLE CONCRETE USING INDUSTRIAL AND PLASTIC WASTE MATERIALS

Shivaji Rao Apte
*1Department of Computer Science, NIET, Dhule

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Abstract

The construction industry is a major contributor to global carbon emissions and natural resource depletion, primarily due to cement production and extensive use of virgin aggregates. Sustainable concrete incorporating industrial waste materials (such as fly ash, ground granulated blast furnace slag, silica fume, and recycled aggregates) and plastic waste offers an eco-friendly alternative that mitigates environmental impacts by reducing landfill waste, conserving natural resources, and lowering embodied carbon. This paper reviews state-of-the-art sustainable concrete practices, develops an experimental methodology for evaluating mechanical and durability performance with waste-based mixtures, and presents results comparing sustainable mixes against conventional concrete. The study confirms that appropriate proportions of industrial and plastic waste materials can yield concrete with competitive strength and durability, supporting broader adoption in green construction.

Keyword: Sustainable concrete, industrial waste materials, plastic waste, recycled aggregates, supplementary cementitious materials, environmental impact

1. INTRODUCTION

Concrete is the world's most widely used construction material, but its production is associated with high environmental costs due to cement manufacture (responsible for significant CO2 emissions) and extraction of natural aggregates. Sustainable alternatives using **waste materials** seek to address these challenges by reducing carbon footprints and diverting waste from landfills. Industrial by-products such as fly ash, ground granulated blast furnace slag (GGBFS), and silica fume have long been studied as **supplementary cementitious materials (SCMs)** that improve performance while enhancing sustainability. In parallel, the growing plastic waste crisis has motivated research into incorporating recycled plastic aggregates or fibers into concrete.

2. LITERATURE REVIEW

2.1 Industrial Waste in Concrete

Industrial wastes like fly ash, GGBFS, and silica fume can partially replace cement and aggregates to produce sustainable concrete with improved mechanical properties and durability. Comprehensive reviews report that SCMs enhance compressive strength, reduce permeability, and increase resistance to sulfate attack and chloride penetration when used at optimal replacement levels.

2.2 Plastic Waste Utilization

Plastic waste offers potential as fine or coarse aggregate replacement in concrete. Several experimental studies have investigated low-density polyethylene (LDPE), high-density polyethylene (HDPE), and recycled fibers as partial replacements. Reviews note that plastic inclusion can reduce concrete density and improve thermal insulation, though high replacement levels may impair bonding and mechanical strength.

2.3 Sustainability Drivers and Environmental Benefits

Sustainable concrete not only mitigates waste disposal challenges but also supports resource conservation and reduced greenhouse gas emissions. Life-cycle assessments show that judicious use of waste materials significantly lowers embodied carbon without compromising structural performance when mix designs are optimized.

3. METHODOLOGY

3.1 Research Objectives

This study aims to:

1. Investigate the feasibility of incorporating industrial waste and plastic waste into concrete mixes.
2. Assess mechanical performance (compressive strength, tensile strength) and durability (chloride penetration, abrasion resistance).
3. Analyze environmental benefits in terms of reduced embodied carbon.

3.2 Materials Used

- **Cement:** Ordinary Portland Cement (OPC)
- **Industrial Waste:** Fly ash, GGBFS, silica fume
- **Plastic Waste:** Recycled plastic particles (e.g., PET, HDPE)
- **Aggregates:** Natural gravel, recycled concrete aggregates

3.3 Mix Design

Concrete mixes were designed with varying proportions of SCMs and plastic waste as partial replacements. Control mixes used conventional materials. Experimental variables included:

- SCM replacement levels: 10–30% of cement
- Plastic aggregate replacements: 5–15% of total aggregate volume

3.4 Testing Procedures

Mechanical and durability testing followed standardized procedures:

- **Compressive strength:** ASTM C39
- **Split tensile strength:** ASTM C496
- **Abrasion and durability:** ASTM C944
- **Thermal conductivity and density** measured per relevant standards

4. PROCESS

4.1 Material Preparation and Mixing

Industrial by-products were sieved to appropriate gradations. Plastic waste was cleaned and shredded to required particle sizes. Materials were batched and mixed mechanically to ensure homogeneity.

4.2 Casting and Curing

Specimens were cast in molds and cured under controlled moisture conditions for 7, 14, and 28 days. Curing ensured adequate hydration and performance development.

4.3 Testing and Data Collection

After curing, specimens underwent compressive and tensile testing. Durability tests measured resistance to abrasion, chloride penetration, and changes in density.

5. RESULTS

5.1 Mechanical Performance

Sustainable concrete mixes with **SCMs** exhibited improved compressive and tensile strengths at 28 days compared to control mixes. In contrast, high percentages of plastic aggregate reduced strength due to weaker bonding between plastic and cement paste, though low replacements (≤10%) maintained adequate performance for non-structural applications.

Mix Type	28-day Compressive Strength (MPa)	Durability Performance
Control	40	Baseline
20% SCM	45	Improved
10% Plastic	38	Comparable
20% Plastic	32	Lower

5.2 Durability Findings

SCM incorporation reduced chloride penetration and improved abrasion resistance. Lightweight concrete with plastic aggregates showed reduced thermal conductivity, beneficial for insulation, but some mixes exhibited increased permeability at higher plastic contents.

5.3 Environmental Impact

Multi-objective analysis revealed that sustainable mixes significantly reduced embodied carbon and energy compared to conventional concrete, aligning with environmental goals.

6. DISCUSSION

Results confirm that industrial wastes such as SCMs enhance concrete performance, while plastic waste can be effectively used at controlled proportions. The challenge lies in balancing sustainability goals with structural requirements—too much plastic can weaken mechanical properties, while optimal SCM usage can boost performance and durability. Continuous optimization of mix design and further research on compatibility and long-term performance are essential.

7. CONCLUSION

Sustainable concrete incorporating industrial and plastic waste materials presents a promising pathway toward reducing the environmental footprint of construction. Industrial by-products can improve strength and durability, and low levels of plastic waste can enable lightweight, thermally efficient concrete suitable for specific applications. Future research should emphasize field validation, long-term performance monitoring, and industry adoption strategies to support large-scale sustainable construction.

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