Lightweight Aggregate Concrete (LWAC) Incorporating Plastic Waste as Partial Aggregate Replacement

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Abstract-*The continuous increase in plastic waste generation and depletion of natural aggregate resources have become major environmental and sustainability concerns worldwide. Disposal of plastic waste in landfills and open environments leads to soil pollution, water contamination, and ecological imbalance because plastics are non-biodegradable in nature. At the same time, the construction industry consumes enormous quantities of natural aggregates for concrete production, resulting in excessive exploitation of natural resources. In this context, the utilization of plastic waste in Lightweight Aggregate Concrete (LWAC) has emerged as a promising sustainable solution. This study reviews the potential application of waste plastic materials such as Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polypropylene (PP), and Expanded Polystyrene (EPS) as partial replacement for conventional aggregates in concrete. The influence of plastic aggregates on workability, density, compressive strength, tensile strength, flexural strength, thermal insulation, and durability properties of LWAC is discussed in detail. Previous studies indicate that optimum replacement levels can significantly reduce concrete density while maintaining acceptable structural performance for non-structural and selected structural applications. The incorporation of plastic waste in concrete also contributes toward sustainable waste management, reduction in landfill burden, and conservation of natural aggregates. However, excessive replacement percentages may negatively affect mechanical properties because of weak interfacial bonding between plastic particles and cement paste. Therefore, optimization of replacement levels and enhancement of bonding characteristics are important for achieving durable and structurally efficient lightweight concrete. The study also highlights major research gaps, challenges, and future research opportunities related to plastic-based LWAC. The findings may support development of environmentally sustainable construction materials and contribute toward circular economy practices in the construction industry.*

Key Words: Lightweight Aggregate Concrete, Plastic Waste, Sustainable Concrete, PET, HDPE, Aggregate Replacement, Durability.

1. INTRODUCTION

Plastic waste accumulation has become one of the most serious environmental challenges due to rapid industrialization, urbanization, and increasing consumer demand for plastic products. Plastics are extensively used in packaging, household materials, electronic devices, automotive industries, and construction applications because of their lightweight nature, durability, flexibility, and low manufacturing cost. However, improper disposal of plastic waste has resulted in severe environmental pollution, including blockage of drainage systems, contamination of water bodies, and generation of microplastics.

According to recent environmental studies, millions of tons of plastic waste are generated every year worldwide, while only a small portion is effectively recycled. Most plastic waste is either dumped in landfills or burned in open environments, leading to harmful greenhouse gas emissions and long-term ecological damage. Therefore, sustainable methods for plastic waste utilization and recycling have become an urgent necessity.

Concrete remains one of the most widely used construction materials because of its high compressive strength, durability, versatility, and economic feasibility. Aggregates constitute approximately 60–75% of the total volume of concrete and significantly influence its physical, mechanical, and durability properties [10]. The growing demand for concrete production has increased consumption of natural aggregates, leading to depletion of natural resources and environmental degradation caused by quarrying activities.

Lightweight Aggregate Concrete (LWAC) is a specialized type of concrete produced using lightweight aggregates having lower density compared to conventional aggregates. The density of LWAC generally ranges below 2000 kg/m^3. Lightweight concrete offers several advantages such as reduction in dead load of structures, improved thermal insulation, better fire resistance, easier handling, and lower transportation costs.

Conventional lightweight aggregates include expanded clay, pumice, shale, vermiculite, perlite, and fly ash aggregates. In recent years, researchers have focused on utilizing industrial by-products and recycled waste materials as lightweight aggregate alternatives to improve sustainability and reduce environmental impact.

Waste plastic materials such as PET, HDPE, PP, and EPS have shown significant potential for use as partial aggregate replacement materials in concrete [7], [8], [9]. The lightweight nature of plastic aggregates contributes toward reduction in concrete density and improvement in thermal insulation characteristics. Furthermore, utilization of waste plastic in concrete provides an environmentally friendly solution for recycling non-biodegradable waste materials.

Several researchers have reported that moderate replacement levels of plastic aggregates can produce lightweight concrete with acceptable compressive strength and durability properties suitable for non-structural and selected structural applications. In addition, plastic aggregates may improve impact resistance and energy absorption capacity because of their flexible nature.

Despite these advantages, incorporation of plastic waste in concrete also presents certain challenges. Excessive replacement levels may reduce compressive strength, tensile strength, and bond characteristics because plastic surfaces are generally smooth and hydrophobic. Weak interfacial bonding between plastic particles and cement paste may increase porosity and reduce durability performance [11]. Therefore, optimization of replacement percentage and surface treatment techniques are necessary for improving the engineering performance of plastic-based LWAC.

The present study focuses on reviewing the properties, advantages, limitations, and future possibilities of Lightweight Aggregate Concrete containing plastic waste as partial aggregate replacement. The study also identifies important research gaps and provides recommendations for future research in sustainable concrete technology.

1.1 SIGNIFICANCE OF THE STUDY

The utilization of waste plastic in Lightweight Aggregate Concrete is important from environmental, economic, and technical perspectives. Incorporation of recycled plastic into concrete helps reduce landfill disposal and conserves natural aggregate resources.

From a sustainability viewpoint, plastic-based LWAC can reduce the environmental impact associated with aggregate quarrying and concrete production. The lightweight nature of plastic aggregates decreases concrete density, thereby reducing dead load and transportation costs.

Technically, the study contributes toward understanding the influence of plastic aggregates on workability, compressive strength, tensile strength, durability, thermal conductivity, and density of concrete. The findings may support development of eco-friendly and lightweight construction materials suitable for modern infrastructure.

2. LITERATURE REVIEW

Several researchers have investigated the use of waste plastic in lightweight concrete production. Hamada et al. [9] reviewed the application of plastic waste as aggregate material and reported that plastic aggregates significantly reduce concrete density and improve sustainability.

Del Rey Castillo et al. [8] developed artificial lightweight aggregates manufactured from recycled plastic waste and observed improvements in thermal insulation properties and reduction in unit weight of concrete.

Basha et al. [7] investigated the mechanical and thermal behavior of recycled plastic aggregate concrete and reported that moderate replacement levels maintained acceptable compressive strength while improving lightweight characteristics.

Studies involving PET waste aggregates demonstrated reductions in compressive and tensile strength at higher replacement levels because of weak interfacial bonding and increased porosity [15]. Parsons and Nwaubani [11] also reported reduction in durability performance with increased plastic aggregate content.

Recent research by Amjad et al. [6] indicated that incorporation of nano-iron oxide and sisal fibers can improve mechanical and durability performance of plastic aggregate concrete.

Overall, previous studies confirm that waste plastic can be effectively utilized in LWAC; however, optimization of replacement percentage and durability enhancement remains necessary.

Table1. Comparison of Previous Studies on Plastic-Based LWAC

Researcher	**Type of Plastic Used**	**Replacement Level**	**Major Findings**	**Limitation**
Hamada et al. [9]	Mixed Plastic Waste	5–30%	Reduced density and improved sustainability	Reduced strength at higher replacement
Basha et al. [7]	Recycled Plastic Aggregate	10–20%	Improved thermal insulation	Weak bonding characteristics
Del Rey Castillo et al. [8]	Artificial Plastic Aggregate	10–25%	Lower unit weight and better insulation	Reduced compressive strength
Dawood et al. [15]	PET Waste	5–20%	Lightweight concrete production	Increased porosity
Parsons et al. [11]	ABS Plastic Aggregate	10–30%	Sustainable aggregate alternative	Durability reduction
Amjad et al. [6]	Plastic Aggregate + Fibers	30%	Improved durability and strength	Complex mix design

3. RESEARCH GAP

Although considerable research has been carried out on plastic aggregate concrete, several important research gaps still exist:

1. Limited information is available regarding long-term durability performance of plastic-based LWAC.
2. Standard guidelines for plastic aggregate gradation and surface treatment are not yet established.
3. Most studies focus only on compressive strength, while limited work has been conducted on thermal conductivity, shrinkage, and fire resistance.
4. The optimum percentage of plastic replacement for structural-grade LWAC is still uncertain.
5. Limited studies are available on life-cycle assessment and large-scale field applications.
6. The effect of combined curing environments such as saline and alkaline conditions requires further investigation.

4. OBJECTIVES

1. To develop Lightweight Aggregate Concrete using plastic waste as partial aggregate replacement.
2. To determine the optimum percentage of plastic aggregate replacement.
3. To evaluate compressive, tensile, and flexural strength of plastic-based LWAC.
4. To study durability characteristics including water absorption and chloride penetration resistance.
5. To evaluate density reduction and thermal performance.
6. To assess sustainability and environmental benefits of plastic aggregate utilization.

5. MATERIALS USED

1. Ordinary Portland Cement (OPC)

Ordinary Portland Cement was used as the primary binding material for concrete production.

2. Fine Aggregate

Natural river sand conforming to standard grading requirements was used as fine aggregate.

3. Lightweight Aggregate

Lightweight aggregates such as expanded clay and pumice were used to reduce concrete density.

4. Plastic Waste Aggregates

Plastic wastes including PET, HDPE, and PP were collected, cleaned, shredded, crushed, and graded before use in concrete.

5. Admixtures

Superplasticizers were used to improve workability and consistency of concrete mixes.

6. Water

Clean potable water was used for mixing and curing of concrete specimens.

6. METHODOLOGY

The proposed methodology consists of the following stages:

1. Literature review and identification of research gaps.
2. Selection and characterization of materials.
3. Preparation of plastic aggregates.
4. Mix design of LWAC with different replacement levels.
5. Casting and curing of concrete specimens.
6. Mechanical testing of hardened concrete.
7. Durability evaluation.
8. Statistical analysis and interpretation of results.

7. TESTS CONDUCTED

Fresh Concrete Tests

- Slump Cone Test
- Density Test

Mechanical Tests

- Compressive Strength Test
- Split Tensile Strength Test
- Flexural Strength Test
- Modulus of Elasticity Test
- Pull-Out Bond Strength Test
- Ultrasonic Pulse Velocity Test

Durability Tests

- Water Absorption Test
- Sorptivity Test
- Rapid Chloride Penetration Test (RCPT)
- Acid Resistance Test
- Alkali Resistance Test

Thermal Test

- Thermal Conductivity Test

Table 2. Advantages and Limitations of Plastic-Based LWAC

Advantages	**Limitations**
Reduces plastic waste disposal	Reduced compressive strength at higher replacement
Conserves natural aggregates	Weak bonding with cement paste
Reduces concrete density	Increased porosity
Improves thermal insulation	Durability concerns
Supports sustainable construction	Lack of standard specifications
Reduces dead load of structures	Limited field applications

8. FUTURE SCOPE

The future scope of plastic-based Lightweight Aggregate Concrete is extensive due to growing environmental concerns and increasing emphasis on sustainable infrastructure development. Although several studies have demonstrated the feasibility of utilizing waste plastic in concrete, many aspects still require detailed investigation.

Future research may focus on improving the interfacial bonding between plastic aggregates and cement paste through chemical treatment, surface roughening, and coating techniques. Such modifications may help improve compressive strength and durability performance.

Further studies are also required on long-term durability properties such as creep, shrinkage, carbonation resistance, freeze-thaw resistance, sulfate attack resistance, and chloride penetration behavior under aggressive environmental conditions.

The incorporation of supplementary cementitious materials, nanomaterials, fibers, and hybrid reinforcement systems may further enhance the mechanical and durability performance of plastic-based LWAC. Advanced materials such as nano-silica, graphene oxide, and fiber-reinforced polymers can be explored for improving microstructural characteristics.

Another important future research area involves thermal insulation, acoustic performance, and fire resistance behavior of plastic aggregate concrete. Since plastic materials are sensitive to temperature, detailed fire performance analysis is necessary before large-scale structural applications.

Life-cycle assessment and cost-benefit analysis should also be performed to evaluate the environmental and economic feasibility of plastic-based lightweight concrete. In addition, large-scale field implementation and real-time structural monitoring can provide valuable practical data regarding performance under actual service conditions.

Artificial intelligence and machine learning techniques may also be applied for optimization of concrete mix design, prediction of strength properties, and durability modeling of plastic-based LWAC.

9. CONCLUSIONS

The utilization of waste plastic as partial aggregate replacement in Lightweight Aggregate Concrete offers a sustainable solution for addressing environmental pollution and depletion of natural resources. Plastic-based LWAC can significantly reduce concrete density while improving thermal insulation characteristics. Previous studies indicate that moderate replacement levels provide acceptable mechanical and durability performance. However, higher replacement percentages may reduce strength because of weak interfacial bonding and increased porosity.

Further research is required to optimize mix proportions, improve bonding mechanisms, and evaluate long-term durability performance. The successful implementation of plastic-based LWAC may contribute significantly toward sustainable infrastructure development and circular economy practices.

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