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Use of Plastic Waste as Partial Replacement of Coarse Aggregate in Concrete: A Review

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Abstract- The increasing generation of plastic waste and the continuous extraction of natural aggregates have become major environmental concerns. The construction industry offers an opportunity to address these challenges by incorporating processed waste plastic into concrete as a partial replacement for natural coarse aggregates. This review paper examines the potential use of recycled plastic waste, particularly polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene (PP), in concrete production. The effects of plastic aggregate replacement on workability, density, compressive strength, split tensile strength, flexural strength, and durability are reviewed based on published research. The available literature generally indicates that incorporating plastic aggregates can reduce the density of concrete and contribute to waste management. However, increasing the replacement percentage may reduce mechanical strength because of the relatively low stiffness of plastic and inadequate bonding between plastic particles and the cement matrix. Some studies indicate that small replacement percentages can retain acceptable strength, while higher percentages may be more appropriate for non-structural and lightweight applications. The review also identifies research gaps related to long-term durability, fire resistance, environmental safety, and standardization of plastic aggregate processing. It is concluded that waste plastic can be a promising supplementary construction material when its properties, replacement level, and intended application are carefully evaluated

Keywords: Plastic waste, coarse aggregate, recycled plastic aggregate, concrete, compressive strength, sustainable construction, lightweight concrete, waste management.

I. INTRODUCTION

Concrete Concrete is one of the most widely used construction materials in the world because of its strength, durability, availability and versatility. It is used in buildings, roads, bridges, pavements, foundations and many other infrastructure projects. The production of concrete requires large quantities of cement, fine aggregate and coarse aggregate. Continuous demand for natural aggregates increases pressure on quarries and other natural resources, making the search for alternative construction materials increasingly important.

Plastic is another material that has become an essential part of modern life. It is used in packaging, water bottles, household products, pipes and many industrial applications. However, its widespread use also generates a considerable amount of waste. When plastic waste is not collected and managed properly, it can accumulate in landfills, drainage systems, rivers and other natural environments. Its slow degradation makes long-term disposal a significant challenge. [4], [11], [14]

One possible solution is to reuse suitable plastic waste in construction materials. Instead of treating all discarded plastic as useless material, it can be collected, sorted, cleaned and processed into particles for use in concrete. In this approach, a selected portion of natural coarse aggregate

is replaced with plastic aggregate while the remaining concrete ingredients are kept under controlled conditions.

Plastic differs from natural stone in several important ways. It generally has a lower density and may have a smoother surface, lower stiffness and different deformation behaviour. These characteristics can affect the bonding between the plastic particles and the cement paste. Consequently, adding plastic waste does not automatically improve concrete performance

. The replacement percentage and the intended application must be considered carefully. Research has shown that plastic aggregate can reduce the density of concrete, while its effect on strength and durability depends on the plastic type and mix proportions. Abu Saleem et al. (2021), for example, investigated PET, HDPE and PP as partial replacements for coarse aggregate and reported that replacement levels up to 20% could satisfy the strength requirements considered for kerb applications in their study. Such findings suggest that plastic waste may be useful for selected applications, although they cannot be generalised to every concrete grade or structural element. [1]

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Therefore, this review examines the benefits, limitations and practical considerations associated with the use of plastic waste as a partial replacement for coarse aggregate in concrete.However, plastic differs considerably from natural stone in density, stiffness, surface characteristics, and deformation behaviour. These differences can affect the fresh and hardened properties of concrete. Consequently, the use of plastic waste must be evaluated through systematic experimental testing rather than assuming that it can directly substitute natural aggregates without modifying concrete performance. [1], [7], [11]

This review summarizes the principal findings of published studies, identifies the advantages and limitations of recycled plastic aggregates, and highlights areas requiring further investigation.

1. Types Of Plastic Waste Used In Concrete

Different types of plastic waste can be processed into particles suitable for aggregate replacement. Their suitability depends on their physical characteristics, chemical composition, processing method, and interaction with cement paste.

2. Polyethylene Terephthalate (Pet)

PET is commonly used in beverage bottles and food packaging. After collection, sorting, cleaning, and shredding, PET waste can be converted into particles of a suitable size for concrete production. PET aggregates have been investigated because they provide a potential use for discarded plastic bottles.

3. High-Density Polyethylene (HDPE)

HDPE is commonly found in containers, pipes, and household products. Its relatively low density can help reduce concrete unit weight. However, itssurface characteristics and comparatively low stiffness may affect the bond between the plastic particles and cement paste. [1], [7], [11]

4. Polypropylene (Pp)

PP is used in packaging, containers, and various industrial products. Processed PP waste has been studied as a partial replacement for coarse aggregate. Its effect on concrete depends on particle geometry, surface texture, and replacement proportion.

5. Other Plastic Types

Low-density polyethylene (LDPE), polystyrene, and other recycled plastics have also been investigated in cement-based materials. However, plastic fibres, fine plastic particles, and coarse plastic aggregates are different material forms and should not be treated as interchangeable in experimental comparisons. [1], [7], [11]

II. REVIEW METHODOLOGY

This paper adopts a literature-review approach based on published journal articles and review studies concerning the incorporation of recycled plastic waste into concrete.

The literature considered includes research on coarse aggregate replacement, concrete mechanical properties, durability, and the environmental implications of plastic recycling. Particular attention is given to studies investigating PET, HDPE, and PP aggregates.

The reviewed evidence is compared according to the following parameters:

- Type and processing of plastic waste.
- Percentage of natural coarse aggregate replaced.
- Workability and fresh concrete density.
- Compressive strength.
- Split tensile and flexural strength.
- Durability and intended application.
- Limitations and research recommendations.

Because the reviewed studies use different concrete grades, replacement methods, aggregate sizes, curing conditions, and testing procedures, their

results cannot always be compared directly. This paper therefore presents a qualitative synthesis rather than claiming to establish a universal optimum replacement percentage.

III. EFFECT OF PLASTIC WASTE ON FRESH CONCRETE PROPERTIES

1. **Workability**

Workability refers to the ease with which fresh concrete can be mixed, transported, placed, and compacted without segregation. Plastic aggregates can alter workability because of their particle shape, surface texture, grading, and interaction with the cement paste. [1], [6], [11]

Several studies have reported a reduction in slump as the proportion of plastic aggregate increases, although the direction and magnitude of the change depend on the plastic processing method and mix composition. Irregular or angular particles may increase internal friction, while smooth particles can behave differently.

Workability should therefore be measured experimentally using an appropriate test method. Water should not be added indiscriminately to compensate for a reduction in slump

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because doing so may increase the water–cement ratio and reduce strength.

2. Density of Concrete

Plastic generally has a lower density than natural stone aggregate. Replacing natural coarse aggregate with plastic particles can consequently reduce the density of concrete, depending on the replacement method and the properties of the materials. [1], [7], [11]

A reduction in density may be beneficial where lower self-weight is desirable. Nevertheless, the term *lightweight concrete* should be used only when the resulting material meets the relevant density and performance criteria.

Fresh density and hardened density should be measured separately because they represent different material conditions.

IV. EFFECT ON MECHANICAL PROPERTIES

1. Compressive Strength

Compressive strength is a primary parameter for evaluating the load-bearing capacity of concrete. It is commonly determined by testing standard concrete specimens after specified curing periods

The incorporation of plastic aggregates may reduce compressive strength because plastic is generally less stiff than natural stone and may develop a weaker interfacial bond with cement paste. Differences in particle shape and deformation under loading can also influence crack initiation and propagation. [1], [6], [8], [11]

The reduction is not necessarily proportional to the replacement percentage in every mix. Abd El Aal et al. reported a relatively small strength reduction at 2.5% replacement but a much larger reduction at 5% in their particular experimental programme [6].

Accordingly, the influence of plastic aggregates should be evaluated through compressive-strength tests at suitable ages, such as 7 and 28 days. The control concrete should be prepared using the same mix design and curing conditions to allow a meaningful comparison. [1], [6], [8], [11]

2. Split Tensile Strength

Split tensile strength indicates the resistance of concrete to indirect tensile stresses. Concrete specimens containing plastic aggregates may exhibit lower split tensile strength because of weak bonding, differences in stiffness, and stress concentration around the aggregate–paste interface. [6], [11]

However, the behaviour depends on the shape, distribution, surface characteristics, and percentage of plastic particles. Split tensile strength should therefore be measured rather than inferred solely from compressive strength. [6], [11]

3. Flexural Strength

Flexural strength represents the ability of concrete to resist bending stresses. It is particularly relevant to pavement slabs, kerbs, and other elements subjected to bending.The use of plastic aggregates may reduce flexural strength as a result of lower aggregate stiffness and weaker interfacial bonding. Nevertheless, some applications may tolerate a degree of strength reduction if the concrete satisfies the applicable performance requirements. [6], [11]

Research by Abd El Aal et al. reported a reduction in flexural strength as plastic replacement increased, supporting the need for a balanced assessment of strength and sustainability [6].

V. ENVIRONMENTAL AND ECONOMIC BENEFITS

The use of plastic waste as a partial coarse aggregate replacement may provide several potential benefits.

- **Reduction in plastic waste:** Processed waste plastic can be diverted from landfills and other disposal routes, provided it is collected and processed responsibly.
- **Conservation of natural aggregates:** Partial replacement can reduce the quantity of natural stone required for concrete production.
- **Potential reduction in self-weight:** The lower density of many plastics can reduce concrete density, which may be advantageous in selected applications.
- **Resource efficiency:** Recycling waste plastic into construction materials can contribute to circular-economy objectives by recovering material value.
- **Potential economic benefits:** Local availability of suitable waste plastic may reduce material costs in some locations. However, collection, sorting, washing, shredding, transportation, quality control, and testing also involve costs.
- The environmental advantage should not be assumed solely from the use of recycled material. A complete assessment should consider processing energy, transportation distance, durability, service life, and end-of-life management.

- **Limitations and Challenges**

  Despite its potential, plastic aggregate concrete presents several limitations:

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- **Reduction in mechanical strength:** Higher replacement percentages may reduce compressive, tensile, and flexural strength.
- **Weak interfacial bonding:** Smooth or hydrophobic plastic surfaces may limit bonding with cement paste.
- **Variability of waste material:** Plastic composition, contamination, shape, and particle size may vary between batches.
- **Workability concerns:** Some plastic aggregate mixtures may require adjustments to the mix design or admixture dosage. [1], [6], [11]
- **Fire performance:** The response of plastic-containing concrete at elevated temperatures requires careful evaluation.
- **Long-term durability:** More evidence is needed for long-term exposure to moisture, chemicals, temperature variation, and repeated loading.
- **Environmental safety:** The potential release of plastic particles during service, abrasion, demolition, and disposal requires assessment.
- **Lack of a universal replacement limit:** A replacement percentage suitable for one application may not satisfy the requirements of another.

These limitations highlight the need for material-specific testing and appropriate engineering design.

VI. CONCLUSION

This review examined the use of plastic waste as a partial replacement for natural coarse aggregate in concrete. The published literature demonstrates that recycled plastics, including PET, HDPE, and PP, have potential for use in selected concrete applications.The principal potential benefit is the reduction in demand for natural aggregates and the productive utilization of plastic waste. The lower density of plastic particles can also reduce the density of concrete, which may be beneficial for selected lightweight applications.However, plastic aggregates differ from natural stone in stiffness, density, surface characteristics, and bonding behaviour. These differences can affect workability, compressive strength, split tensile strength, flexural strength, and durability. Several studies have reported that increasing the replacement percentage reduces mechanical strength, although the magnitude of the reduction varies between materials and mix designs.The reviewed research does not establish a single optimum replacement percentage for all concrete applications. Instead, the appropriate proportion should be determined experimentally for the selected plastic type, concrete grade, replacement method, and intended use.It is therefore concluded that plastic waste can be a useful component of sustainable concrete when processed appropriately and incorporated at a validated replacement level. Further research on long-term durability, fire performance, environmental safety, and life-cycle impacts is necessary before broader structural applications can be recommended. [1], [6], [11]

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