Journal of Gateway to sustainable Research
February 2026, Vol. 1, Issue No. 1, pp: 1-4

An Experimental Studies On Partial Replacement Of Fine Aggregate With Recycled Plastic Waste In Concrete

S. Sruthi

Department of Civil Engineering,

*Corresponding Author E-mail: xyz@abc.com

Abstract: The Plastic is a part of our lives due to daily usage. So, the consumption of plastic is increasing every year. The decomposition of plastic takes more than thousand years because of its non-biodegradable in nature. The plastic harms the society and surrounding environment in all aspects. The exponential growth in construction industry, the demand for natural aggregates increased but leads to depletion of natural resources. To overcome this issue various types of plastic waste, including high density polyethylene (HDPE) are used as a partial replacement of fine aggregates in concrete. M40 grade of concrete through a series of laboratory experiments, various properties of plastic waste in concrete were done. The potential of plastic waste incorporated enhanced the performance and sustainability of concrete. This project contributed the advancement of eco-friendly construction practices and thus promoting circular economy principles in the construction industry.

Keywords: Plastic waste, Concrete, Fine Aggregates, Compressive Strength.

1. Introduction: Rapid industrialization and urbanization have led to a significant rise in solid waste generation, particularly plastic waste, which poses serious environmental and public health concerns. Owing to its durability and versatility, plastic consumption continues to increase globally, with millions of tonnes produced annually and a substantial share generated in countries such as India. However, plastics degrade very slowly, persisting in the environment for decades and contributing to land, water, and marine pollution. Improper disposal can block drainage systems, contaminate groundwater, harm wildlife, and release toxic emissions when incinerated. Although recycling practices exist, they offer only a partial solution to the growing waste burden. In the context of civil engineering, sustainable management strategies include utilizing plastic waste as a partial replacement for fine aggregate in concrete, thereby reducing environmental impact while promoting resource efficiency.

Recent studies have explored the feasibility of incorporating plastic and other waste materials into concrete as partial replacements for natural aggregates. Vivek et al. [1] reported that LDPE substitution in M20 concrete reduced compressive strength significantly, limiting its use to non-structural applications. Similarly, Saha et al. [2] and Almohana et al. [3] examined polyethylene- and PET-based aggregates, noting economic benefits and improved thermal and acoustic performance at higher replacement levels, though primarily suited for lightweight or non-structural elements. Dalal et al. [4] demonstrated that pharmaceutical blister waste could replace fine aggregate within codal limits despite strength reductions. Jahami et al. [5] emphasized that combined waste incorporation should generally not exceed 25% to maintain mechanical performance. Rajawat et al. [6] and Namburi et al. [7] observed optimum strength enhancement at low replacement levels (around 3–10%), beyond which properties declined. Ullah et al. [8] highlighted improved confinement behavior with E-waste aggregate, while Nwaubani et al. [9] and Dawood et al. [10] reported variable effects on strength and durability depending on dosage. Collectively, the literature indicates that controlled partial replacement of aggregates with plastic waste can contribute to sustainable construction, though performance is highly dependent on type, proportion, and treatment of the waste material.

2. Materials:

•Cement: PPC cement is made by thoroughly combining pozzolanic ingredients with clinker and gypsum. Pozzolanic materials are finely divided siliceous or aluminous materials that, when combined with calcium hydroxide in the presence of water, generate cementitious compounds. Fly ash, calcined clay, and volcanic ash are among the most commonly utilised pozzolanic ingredients in PPC. PPC cement has various advantages, including greater workability, less heat hydration, increased durability, and a lower environmental effect.

Fig 1. Portland Pozzolana Cement

• Fine Aggregate: Fine aggregate, sometimes referred to as sand, is a granular material that is usually made up of particles with a diameter of less than 4.75 millimeters. It is one of the basic ingredients of concrete, along with water, cement, and coarse aggregate. Concrete's workability, durability, and strength are all greatly influenced by fine aggregate.

Fig. 2 Fine Aggregate

• Coarse Aggregate: Coarse aggregates are rock-based construction materials that cannot pass through a 4.75mm IS sieve. Natural gravel or crushed stone is used in concrete to offer strength and durability. Materials used include natural gravel, crushed stone, and reclaimed concrete debris.

Fig 3 Coarse Aggregate

• Water: It plays an important role in the chemical reaction with cement. Water Contributes in the strength development of concrete and that is why quantity and quality if water required is looked into very carefully. The water should be free from undesirable organic and inorganic substance. In every construction work water is vital role for the mixing and curing of concrete as per IS: 456-2000. The water was clean and free from visible impurities. For this work potable water is used.

• Plastic Waste: High Density Polyethylene is a polyethylene thermoplastic made from petroleum. HDPE is commonly recycled and made into composite wood or plastic lumber. HDPE is a Type 2 plastic commonly used in making containers for milk, motor oil, shampoos and conditioners, soap bottles, detergents, and bleaches. HDPE is known for its large strength-to-density HDPE plastic waste in the form of grains are used.

Fig. 4 Plastic Waste

3. Methodology & Mix Design: The experimental program included material testing, mix design preparation, casting, curing, and mechanical testing.

Mix Design: M40 grade concrete was designed as per IS 10262:2019 guidelines. Target mean strength:

$$f_{target} = f_{ck} + 1.65S \tag{1}$$

For M40 grade with standard deviation of 5 MPa, the target strength was calculated as 48.25 MPa.

Adopted water-cement ratio: 0.36

Cement content: 533 kg/m^3

Water content: 192 kg/m^3

The final mix proportion was: 1 : 0.65 : 1.27 (Cement : Fine Aggregate : Coarse Aggregate) with W/C ratio = 0.36

Plastic waste replaced fine aggregate at 0%, 10%, 20%, 30%, and 40%.

4. Experimental Investigation

4.1 Tests on Cement: The following tests were conducted on cement to evaluate its fundamental properties and ensure its suitability for concrete production: the fineness test to determine particle size distribution, the standard consistency test to assess the water required for preparing cement paste of normal consistency, the initial and final setting time tests to measure the rate of setting and hardening, and the specific gravity test to determine the relative density of cement.All results were within IS code limits.

4.2 Tests on Aggregates: Sieve analysis, water absorption, and specific gravity tests confirmed suitability for concrete production.

4.3 Fresh Concrete Test: Slump Test, Workability decreased gradually with increase in plastic content due to lower density and poor bonding characteristics of plastic particles.

4.4 Hardened Concrete Tests: Cube specimens of size 150 mm × 150 mm × 150 mm were tested for compressive strength at curing ages of 3, 7, 14, and 28 days. The results showed that the control mix achieved the target strength. The mix with 10% replacement exhibited only a marginal reduction in strength, while 20% replacement maintained reasonable and acceptable strength levels. However, mixes with 30% and 40% replacement demonstrated a noticeable reduction in compressive strength compared to the control mix.

Split Tensile Strength Test: Cylindrical specimens (150 mm diameter × 300 mm height) were tested. Similar trends were observed, with optimum performance around 10–20% replacement.

5. Results and Discussion: This section presents and interprets the experimental findings obtained from tests conducted on cement, aggregates, fresh concrete, and hardened concrete incorporating recycled plastic waste as partial replacement of fine aggregate.

5.1 Properties of Cement: The fineness of cement was found to be 6% residue on 90 µm sieve, which satisfies IS 4031 requirements (<10%). This indicates adequate particle size distribution for proper hydration and strength development. The standard consistency was obtained at 33.5%, which lies within permissible limits. The initial setting time was recorded as 35 minutes, and the final setting time was 570 minutes. Both values satisfy codal requirements, confirming that the cement used was suitable for structural concrete. The specific gravity of cement was 2.83, consistent with typical PPC values (2.8–3.15). These results ensured reliability of mix design calculations.

5.2 Properties of Aggregates and Plastic Waste: Fine aggregate and coarse aggregate satisfied grading and physical property requirements as per IS 383. The specific gravity values were: Fine aggregate = 2.62 Coarse aggregate = 2.74 .

Plastic waste (HDPE grains) had a significantly lower specific gravity of 0.88, which directly influenced concrete density and workability. Due to its lightweight and hydrophobic surface, plastic particles tend to reduce internal friction and bonding efficiency when used in higher percentages.

5.3 Fresh Concrete – Workability: Slump Test Results

The slump value decreased gradually as the percentage of plastic waste increased.

Table 1: Slump Values and Workability Characteristics of Concrete with Varying Plastic Replacement Levels

Mix	Plastic Replacement (%)	Slump (mm)	Observation
M1	0%	25	True slump
M2	10%	23	Slight reduction
M3	20%	21	Moderate reduction
M4	30%	18	Low workability
M5	40%	15	Harsh mix

The observed reduction in slump with increasing plastic content can be attributed to several material characteristics of the plastic particles. Due to their low specific gravity, plastic grains tend to reduce the overall cohesion of the concrete mix. Additionally, the smooth and non-absorbent surface of plastic limits effective bonding with the cement paste, thereby decreasing internal friction and consistency. At higher replacement levels, the presence of plastic also contributes to increased internal voids within the mix, further reducing workability. Despite this gradual decline, concrete mixtures containing up to 20% plastic replacement remained adequately workable without the use of chemical admixtures. However, when the replacement level exceeded 30%, compaction became comparatively difficult, indicating a noticeable loss in workability.

5.4 Hardened Concrete Properties: Compressive strength Compressive strength was tested at 3, 7, 14, and 28 days. The 28-day results are summarized below:

Table 2: 28-Day Compressive Strength of Concrete with Different Percentages of Plastic Waste Replacement

Mix	Plastic Replacement (%)	28-Day Compressive Strength (MPa)
M1	0%	48.5
M2	10%	46.8
M3	20%	44.2
M4	30%	39.5
M5	40%	34.8

The results indicate that a 10% replacement of natural sand with plastic resulted in only a marginal reduction in compressive strength (approximately 3–4%). At 20% replacement, a moderate decrease of about 8–10% was observed; however, the strength remained structurally acceptable and exceeded the target characteristic strength of M40 concrete. In contrast, 30% and 40% replacement levels led to significant strength loss. The reduction in strength at higher replacement percentages can be attributed to the weak interfacial transition zone (ITZ) between plastic particles and cement paste, the lower stiffness of plastic compared to natural sand, and the increased void content within the matrix. Overall, replacement levels up to 20% can be considered structurally feasible.

5.5 Split Tensile Strength: The 28-day split tensile strength results are presented below:

Table 3: Twenty-Eight Day Compressive Strength of Concrete Incorporating Various Percentages of Plastic Waste as Fine Aggregate Replacement

Mix	Plastic Replacement (%)	Split Tensile Strength (MPa)
M1	0%	4.2
M2	10%	4.1
M3	20%	3.9
M4	30%	3.5
M5	40%	3.1

The tensile strength exhibited a trend similar to that of compressive strength. At 10% replacement, the reduction was minimal, indicating that a limited plastic content may provide slight crack-bridging effects owing to the flexibility of the plastic particles. However, beyond 20% replacement, the tensile strength decreased significantly due to reduced aggregate interlock, the lower stiffness of plastic compared to natural aggregates, and the weak bonding surface between plastic particles and the cement matrix.

5.6. Density and Failure Pattern:

Density: Due to the low specific gravity of plastic waste, concrete density decreased with increasing replacement percentage. This indicates potential for producing lightweight concrete elements.

Failure Pattern: Control mix exhibited typical brittle failure. Plastic-modified specimens showed slightly more gradual cracking, indicating marginal improvement in ductility at lower replacement levels.

6. Conclusions: Based on the experimental investigation, the following conclusions are drawn:

- Recycled plastic waste can be successfully used as partial replacement of fine aggregate in concrete.
- Workability decreases with increasing plastic percentage.
- Optimum replacement level lies between 10% and 20% for M40 grade concrete.
- Higher replacement levels (above 30%) significantly reduce compressive strength.
- Plastic-modified concrete is suitable for non-structural elements such as pavements, partition walls, and lightweight blocks.
- Utilization of plastic waste contributes to sustainable construction and resource conservation.

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