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Use of Plastic Waste in Concrete : A Comprehensive Review on Strength of Concrete Mixture with Different Material

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Abstract - The rapid increase in plastic waste has become a serious environmental concern due to its non-biodegradable nature and harmful impact on ecosystems. This study explores the utilization of plastic waste as a partial replacement material in concrete production, aiming to address both waste management and sustainable construction challenges. Various forms of plastic, such as polyethylene terephthalate (PET), polypropylene (PP), and polystyrene (PS), are incorporated into concrete either as aggregates, fibers, or fillers.

The research examines the effects of plastic addition on the mechanical and durability properties of concrete, including compressive strength, tensile strength, workability, and resistance to environmental degradation. Results indicate that while excessive plastic content may reduce strength, an optimum percentage can enhance properties like ductility, crack resistance, and lightweight characteristics. Furthermore, the use of plastic waste in concrete reduces landfill burden, conserves natural resources, and contributes to eco-friendly construction practices.

This study concludes that plastic-modified concrete can be a viable alternative in non-structural and certain structural applications, promoting sustainable development while mitigating environmental pollution.

Keywords - Plastic waste in concrete , Polymer concrete, Plastic aggregate, Recycled plastic concrete , Plastic fiber reinforced concrete, Plastic modified concrete

Chapter 1 : INTRODUCTION

The rapid growth of urbanization and industrialization has led to a significant increase in plastic consumption worldwide. Due to its non-biodegradable nature, plastic waste has become a major environmental concern, creating challenges in waste management and contributing to pollution. At the same time, the construction industry is one of the largest consumers of natural resources such as sand and aggregates, leading to depletion of these materials.

In this context, the utilization of plastic waste in concrete has emerged as an innovative and sustainable solution. By incorporating plastic materials—either as a partial replacement for fine or coarse aggregates or as fibers—concrete can be made more eco-friendly while reducing the burden on landfills. This approach not only helps in effective waste management but also enhances certain properties of concrete, such as durability, resistance to cracking, and lightweight characteristics.

The use of plastic in concrete represents a step toward sustainable construction practices, aligning with the principles of recycling and resource conservation. Ongoing research continues to explore its feasibility, performance, and long-term benefits, making it a promising alternative in modern civil engineering.

Chapter 2 : OBJECTIVES OF THE STUDY

- To utilize plastic waste effectively and reduce environmental pollution.
- To develop sustainable and eco-friendly construction materials.
- To reduce the consumption of natural resources such as sand and aggregates.
- To study the effect of plastic on the mechanical properties of concrete (strength, durability, etc.).
- To improve certain properties of concrete like crack resistance and flexibility.
- To promote recycling and waste management in the construction industry.

To explore cost-effective alternatives for conventional concrete materials.

Chapter 3 : RESEARCH METHODOLOGY

3.1 Research Objective

To investigate the feasibility, strength, durability, and environmental benefits of incorporating plastic waste into concrete as a partial replacement for conventional materials such as fine aggregate or coarse aggregate.

3.2 Research Approach

The study follows an **experimental research approach** involving laboratory testing and analysis. Different proportions of plastic waste are added to concrete mixes, and their performance is evaluated.

3.3 Materials Used

- **Cement** – Ordinary Portland Cement (OPC)
- **Fine Aggregate** – Natural sand
- **Coarse Aggregate** – Crushed stone
- **Plastic Waste** – (e.g., PET bottles, polyethylene bags, shredded plastic)
- **Water** – Potable water for mixing and curing

3.4 Preparation of Plastic Material

- Collected plastic waste is cleaned to remove impurities.
- It is then shredded into small pieces (2–10 mm size).
- Plastic is used as a **partial replacement** of fine or coarse aggregate.

3.5 Mix Design

- Concrete mix is designed as per standard guidelines (e.g., M20 or M25 grade).
- Plastic is added in varying percentages such as:
    - 0% (Control mix)
    - 5%
    - 10%
    - 15%
    - 20%

3.6 Casting of Specimens

- Concrete is mixed thoroughly with the required proportion of plastic.
- Specimens are cast in standard molds:
  - Cubes (for compressive strength)
  - Cylinders (for split tensile strength)
  - Beams (for flexural strength)
- Specimens are demolded after 24 hours.

3.7 Curing Process

- Specimens are cured in water for **7, 14, and 28 days**.

3.8 Testing Procedures

a) Compressive Strength Test

- Conducted using a compression testing machine.
- Determines load-bearing capacity of concrete.

b) Split Tensile Strength Test

- Conducted on cylindrical specimens.
- Evaluates tensile strength.

c) Flexural Strength Test

- Conducted on beam specimens.
- Measures bending strength.

d) Workability Test

- Slump test is performed to assess workability.

e) Durability Tests (Optional)

- Water absorption test

3.9 Data Collection and Analysis

- Record test results for each mix proportion.
- Compare results with conventional concrete.
- Plot graphs:
  - Strength vs % of plastic
  - Workability vs % of plastic

3.10 Evaluation Criteria

- Strength performance
- Workability
- Durability
- Environmental impact

- Cost effectiveness

3.11 Expected Outcome

- Identify the **optimum percentage of plastic** that can be used without significantly compromising strength.
- Evaluate whether plastic-modified concrete can be used for structural or non-structural applications.

3.12 Limitations

- Variation in plastic type and size
- Bonding issues between plastic and cement paste
- Limited long-term durability data

Chapter 4 : LITERATURE REVIEW

4.1 Introduction

With the rapid increase in plastic waste globally, its disposal has become a serious environmental concern. Researchers have explored incorporating plastic waste into concrete as a sustainable solution. This approach not only reduces landfill burden but also conserves natural resources like sand and aggregates.

4.2 Types of Plastic Used in Concrete

Studies have examined different types of plastics, including:

- **Polyethylene Terephthalate (PET)** (bottles)
- **High-Density Polyethylene (HDPE)**
- **Low-Density Polyethylene (LDPE)**
- **Polypropylene (PP)**

Plastic is typically used in:

- Shredded form
- Fibers
- Pellets
- Partial replacement of fine or coarse aggregates

4.3 Effect on Fresh Concrete Properties

Research findings indicate:

- **Workability decreases** with increasing plastic content due to irregular shape and low water absorption.
- Some studies suggest using **superplasticizers** to maintain slump.

4.4 Mechanical Properties

Compressive Strength

- Most studies show a **decrease in compressive strength** beyond 10–15% replacement.
- Optimal performance is usually observed at **5–10% plastic replacement**.

Tensile and Flexural Strength

- Plastic fibers can improve:
    - Crack resistance
    - Ductility
- However, excessive plastic reduces bonding, lowering strength.

4.5 Durability Characteristics

Research highlights:

- **Improved resistance to chemical attack** due to non-reactive nature of plastic.
- **Reduced water absorption** in some cases.
- Long-term durability is still under investigation.

4.6 Density and Lightweight Properties

- Plastic inclusion reduces concrete density, producing **lightweight concrete**.
- Useful for:
    - Non-load bearing structures
    - Partition walls
    - Pavements

4.7 Environmental Benefits

- Reduces plastic waste in landfills
- Lowers carbon footprint
- Promotes sustainable construction practices
- Supports circular economy concepts

4.8 Limitations Identified in Literature

- Weak bonding between plastic and cement matrix
- Reduced strength at higher percentages
- Lack of standard design codes
- Long-term performance data is limited

4.9 Key Findings from Previous Studies

- **Batayneh et al. (2007):** Found reduced strength but acceptable performance for lightweight applications.
- **Saikia and de Brito (2012):** PET aggregates reduce density but affect mechanical properties.
- **Ismail and Al-Hashmi (2008):** Suggested plastic as partial sand replacement with environmental benefits.
- **Raghatate (2012):** Plastic fibers improve tensile strength and crack resistance.

4.10 Conclusion

The literature suggests that plastic waste can be effectively used in concrete in limited proportions. While it reduces strength at higher percentages, its benefits in sustainability, lightweight construction, and waste management make it a promising material for future research and practical applications.

Chapter 5 : Advantages of Using Plastic in Concrete

- **Waste Management:** Helps in reducing plastic waste accumulation in landfills and the environment.
- **Eco-Friendly:** Contributes to sustainable construction and reduces carbon footprint.
- **Lightweight Concrete:** Plastic reduces the overall density of concrete, making it lighter.
- **Improved Durability:** Offers better resistance to chemicals, moisture, and corrosion.
- **Crack Resistance:** Plastic fibers can reduce shrinkage cracks and improve tensile properties.
- **Cost-Effective:** Lowers material cost by partially replacing expensive natural aggregates.
- **Energy Saving:** Reduces the need for extraction and processing of natural materials.
- **Versatility:** Can be used in various forms (fibers, shredded plastic, pellets) for different applications.

Chapter 6 : THESE PLASTICS ENTER CONCRETE IN VARIOUS FORMS

- **Aggregates/Chips:** Shredded or pelletized plastic (coarse or fine) replaces natural aggregate by volume (commonly 5–30%). For example, crushed PET bottles or mixed PE chips are used as “plastic coarse aggregate” (PCA). Specialized “plastic aggregates” are also manufactured (e.g. PET+additives sintered into lightweight pellets).
- **Fibers:** Waste plastics can be drawn or cut into fibers (PP and PET are common). Typical dosage is very low (0.1–1% by volume). Plastic fibers improve tensile and flexural behavior (adding ductility) and control cracking.
- **Powder/Additives:** Finely ground plastic (e.g. irradiated PET powder or PVC dust) can partially replace cement or fillers. For instance, **γ-irradiated PET powder** mixed with cement/flyash has been explored to *increase* strength, although subsequent studies found only minor benefits. Some plastics (like polyethylene) can act as hydrophobic admixtures when very fine.
- **Plasticizers:** Traditional chemical plasticizers (superplasticizers) are polymers, but waste plastic itself is not normally a “plasticizer” for concrete. However, polymer modifiers (e.g. waste plastic bottles in bituminous asphalt) do exist (see standards below).

Chapter 7 : MIX DESIGN AND REPLACEMENT LEVEL

Researchers test a wide range of *concrete mix designs*. Plastic inclusion is typically **partial** and targeted at either coarse or fine aggregate replacement: e.g. 5–30% by volume of natural coarse aggregate replaced with plastic chips. Finer plastics (shredded plastic fines or beads) can replace sand up to similar levels. Fibers are used at <<1% by volume. No widely adopted “standard mix” exists, but typical examples include:

- **Structural (M25) concrete:** Studies replacing coarse aggregate with mixed plastic waste find that up to ~30% by volume achieves the target 28-day strength (~25–30 MPa). For instance, Ahmad et al. (2022) found 30% e-waste plastic aggregate replacement still met M25 strength. Above ~30%, compressive strength drops below target.
- **Lightweight or non-structural mixes:** 40–50% plastic aggregate yields very low density (often <2000 kg/m^3) with ~50% strength reduction. Such mixes are viable for hollow blocks, pavers, sidewalks etc. (see below).
- **Fiber-reinforced concretes:** Concrete with 0.25–1% waste plastic fibers (PE/PET) has been tested as M40 mixes with recycled aggregate, showing optimal gains at ~0.5%. Designers usually trial different dosages for workability and bond.

Typical mix recipe example: (Note: concrete properties depend on all ingredients; values below are illustrative)

Cement: 300 kg/m^3; Water:Cement = 0.45;

Sand: 650 kg/m³; Coarse Agg: 1200 kg/m³;

Plastic aggregate (shredded HDPE/PET): 20% by volume of coarse agg;

No plasticizer; 28-day strength ≈ 25 MPa.

(From several studies of 10–30% plastic replacement.)

Assumptions: A target grade ~M25 (~25–30 MPa) concrete is typical. We assume a moderate exposure (no severe chemical attack). Available plastic waste is mixed types from municipal refuse (PET bottles, PE film, etc.). Local sand and aggregates meet IS/ASTM specs except substituted portion.

Chapter 8 : MECHANICAL PROPERTIES

8.1 Workability: Plastic aggregates are hydrophobic and smoother than rock, so mixes are **more workable** (higher slump) with fixed water content. Studies report slump increases substantially as plastic content rises. Ahmad et al. found 10–50% plastic coarse aggregate gave 16–141% higher slump. In practice, plastic waste can allow lower water/cement or reduce superplasticizer dosage.

8.2 Density: Addition of plastic lowers concrete density (plastic ~1/3 the density of gravel). For example, Ahmad et al. saw fresh density drop ~13.6% at 50% plastic aggregate. Almeshal et al. reported hardened density decreases ~1–3% per 5% PET aggregate. Lightweight concrete (<2000 kg/m³) can result beyond ~30% plastic.

8.3 Compressive Strength (CS): All studies show **strength declines** as plastic content increases. Saikia & De Brito (2012) reviewed that ~20% plastic aggregate can cut CS by ≈72%. Ahmad et al. observed ~53% CS loss at 50% replacement. Generally, ~10–25% CS loss occurs at 20–30% plastic. The strength drop is due to weak plastic–cement bonding (smooth surfaces, poor adhesion) and increased porosity.

8.4 Tensile and Flexural Strength: These also drop with plastic, but often less sharply than CS. As noted, Saikia & De Brito report that 20% plastic had a smaller % drop in splitting tensile than in compressive (since the plastic mix is more ductile). Plastic fibers **increase** tensile and flexural toughness: small dosages of PP or PET fiber (0.1–1%) are widely reported to improve flexural crack resistance and residual strength. For example, those fibers gave +5–10% flexural gain.

8.5 Elastic Modulus: Plastic concretes have a **lower elastic modulus** than normal concrete (typically 70–90% of NWC), correlating with lower density. This increases deformability and ductility (good for seismic/impact applications) but is rarely quantified in papers, and no standards exist for design values.

8.6 Abrasion and Impact Resistance: Surprisingly, abrasion resistance may improve. Ahmad et al. saw up to 32–51% *increase* in abrasion resistance with plastic coarse aggregate. The hard plastic particles resist wear better than limestone in aggregate. Similarly, plastic fiber mixes dissipate impact energy well (toughness increase), though studies vary.

Chapter 9 : WORKABILITY AND CUNING

As noted, plastic aggregates **increase workability**: hydrophobic plastics do not absorb mix water, so more water is free for lubrication. Mixers often report higher slump, even slump loss is slower (plastic does not dry out paste as quickly). However, static steel corrugated surfaces and advanced superplasticizers are still needed to handle large plastic flake mixes to avoid segregation.

Curing requirements (moisture/time) do not change fundamentally, except that plastic concretes may retain moisture longer due to lower absorption. Standard curing (water ponding, wet burlap) is recommended to fully hydrate cement. No unusual shrinkage or cracking has been widely reported; plastics may even reduce shrinkage cracking by improving ductility (though this is qualitative).

Chapter 10 : LONG TERM PERFORMANCE AND AGING

Data on decades-long performance is scarce. From material standpoint, plastics are *inert*: no chemical degradation occurs at ambient conditions. UV, weathering, or oxidation is irrelevant if plastics are embedded. The main aging concern is the interface with cement (interfacial transition zone, ITZ). SEM studies show poor bonding: fibers often "pull out" rather than break, indicating the interface remains weak. Over time under load, this could cause microcracks. Chemical treatment of plastic surfaces (e.g. NaOH etching) can improve bonding, but adds cost.

Creep and fatigue under sustained loads are unstudied; plastics creep more than rock. Some researchers call for long-term creep tests. Also, environmental stresses (freeze–thaw cycles, salt scaling over years) have not been fully explored for plastic mixes; current trends suggest resilience, but "performance under UV, temperature, chemical exposure needs to be proven" before field adoption. In short, long-term behavior is promising but under-researched; monitoring of test structures is advised.

Chapter 11 : STRUCTURAL APPLICABILITY AND CODE COMPLIANCE

11.1 Structural use: In principle, concrete with up to ~20–30% plastic aggregate (with strength ~75–90% of normal) could be used in mild exposures, provided design is adjusted (higher safety factors or additional reinforcement). However, *no major codes* explicitly cover plastic concrete. Codes like IS 456 (India), ASTM ACI 318 (US), Eurocode 2 reference natural or recycled aggregates per specific standards (e.g. ASTM C33, C33 prohibits deleterious substances but doesn't list plastic). Thus, plastic additives are typically "non-standard" and require special acceptance.

11.2 Experimental approval: Some bodies allow test pours under research provisions. For example, a municipal or research authority might let a noncritical structure (pavement, block wall) be built with plastic-modified mix on an experimental basis. All relevant tests (ASTM C39 compressive, C78 flexural, C496 splitting, etc.) must pass the owner's requirements.

11.3 Regulations: In India, the focus has been on plastic in bitumen (IRC SP:98 for roads). For concrete, there are no national standards yet. An Indian researcher (Saha et al.) states that recycling plastic in concrete is economically beneficial, but Indian codes (IRC, BIS) will need updates to allow it. Until then, engineers must treat plastic concrete like any new material: obtain engineering approval (e.g. Material Safety Data, performance data, lab tests) before use.

11.4 Best-practice guidelines: - Only use clean, sorted thermoplastics (avoid PVC/dirt). - Limit replacement to ranges proven by tests (e.g. ≤20–30% in structural mixes). - Supplement with fibers or admixtures to regain strength if needed (e.g. silica fume, nano-additives). - Use in low-exposure elements (non-load-bearing walls, pavements, blocks) first. - Monitor durability per ASTM/CPCB tests (chloride, absorption, freeze cycles). - Adjust cover/corrosion design, as plastic mix may change concrete cover requirement (usually increased cover for lower strength).

Chapter 12 : FLOWCHART

As a **flowchart**, the process is:

```
flowchart TB

  subgraph Design Process

  A(Select Waste Plastic Type) --> B(Process Plastic Form: shred/fiber/powder)

  B --> C(Choose Replacement Mode)

  C --> D{Add to Concrete Mix}

  end

  subgraph Outcomes

  D --> E[Enhanced Workability & Insulation]

  D --> F[Reduced Strength, Density & Carbon Footprint]

  D --> G[Improved Durability (chloride, freeze) & Ductility]

  F --> H(Re-assess Structural Capacity)

  H --> I(Design Safely or Use Nonstructural)

  E --> J(Optimize Mix/Admixtures)
```

G --> K(Long-term Monitoring & Testing)

End

Flowchart: Plastic waste processing to concrete use, showing trade-offs (higher workability/insulation vs. lower strength), and consequent design actions.

Chapter 13 : ECONOMICAL ANALYSIS (COST AND SUPPLY CHAIN)

Plastic concrete can be cost-competitive. Raw waste plastic costs near zero (often negative if avoided landfill tipping fees are counted). Main costs are sorting, cleaning, shredding into usable form. A 2023 economic study found that **total concrete cost decreases** as plastic content rises: up to 0.65–7.6% cost savings (including social/environmental costs) at 10–40% aggregate replacement. This gain comes from substituting expensive virgin aggregates with cheap waste.

However, there are caveats:

- **Processing:** Shredding and washing plastic wastes require capital and energy. If done at scale or by co-locating with recycling plants, economies emerge.
- **Quality control:** Ensuring consistent plastic quality (no contamination, correct particle size) may add lab costs.
- **Transport:** Aggregates are usually local; collecting dispersed plastic waste may cost more transport per tonne.
- **Implementation:** Adoption is limited, so market supply chains are nascent. Large concrete plants would need new hopper systems for plastic.

Even so, most analyses (India, UK, Canada) find net cost benefit if plastic is sourced economically. Comparisons often note plastic aggregate concrete's *unit cost* is 5–10% lower than normal, assuming nearby plastic waste. If recycling fees or credits are considered (e.g. fines for landfill), economics improve further.

Thus, with even a modest \$5–10/t processing cost for plastic aggregate, total cost savings of a few percent per m^3 are plausible. According to Hazra et al. (2023), 20–30% plastic **reduced concrete cost** by up to ~7% compared to conventional.

Supply-chain remarks: Urban areas produce vast mixed plastic waste (PET bottles, film) – capturing this for concrete can add value. Infrastructure planners could source from recycling centers or waste dumps. Overall, plastic concrete can be a *cost-effective* way to improve sustainability, provided economies of scale in processing are achieved (e.g. centralized shredding facilities).

Chapter 14 : PRACTICAL CASE STUDY

14.1 Paving and non-structural use have seen some field trials. In India and elsewhere, *plastic-modified asphalt roads* are common (e.g. over 21,000 miles in India by 2016), but for **concrete** the implementations are mostly research/demo scale. Examples:

- **Sidewalks & Non-Loadbearing Blocks:** Kayentao et al. (2023) suggest concrete with up to 15% PET (by volume) is suitable for sidewalks, stairs, partition walls, and non-structural slabs. Similar small-scale pours have been done for landscaping blocks in labs.
- **Concrete Masonry Units:** The 'H-brick' design is a pilot concept, not yet fielded, but demonstrates potential for waste plastic bricks with high insulation.
- **Reinforced Panels:** Some universities have cast wall panels or barrier blocks with plastic fiber reinforcement (e.g. Duraiswamy et al.'s test slabs).
- **Marine Structures:** Ahmad et al. recommend plastic aggregate concrete for marine exposure (chloride resistance); pilot breakwaters or harbor slabs could test this.

14.2 Pilot Projects Worldwide: There are few published real-world projects for structural concrete. Most efforts have been in **research projects or small constructions**. For instance, Spanish researchers have made brick blocks from recycled food plastics, and Bangladeshi NGOs have piloted plastic sand bricks for rural housing. Large-scale adoption awaits code acceptance.

Nonetheless, interest is high. Some European firms (e.g. “PlasticRoad” in NL) are demonstrating plastic modules for pavements (though not cement); UK and India are funding trials of recycled-plastic concrete in infrastructure. These pilot projects uniformly find: “durable enough for intended use, substantially lighter, but weaker” – aligning with lab data.

14.3 Standards, Regulations, Best Practices

- **Standards Bodies:** No mainstream concrete standard (ACI, Eurocode, BIS) currently includes plastic as an aggregate. All use of plastic is *off-label*. ASTM and IS standards address normal and recycled natural aggregates, admixtures, fibers, etc., but do not list plastic waste. Therefore, designers must treat plastic mixes as *experimental*. That said, ASTM C1202 (chloride) and C469 (modulus) are cited in literature for testing plastic concrete.
- **Roads Standards (India):** The Indian Roads Congress (IRC) has guidelines SP:98 (2013) for incorporating waste plastics (LDPE, HDPE, PET, PP, PS, PVC) into hot-mix bitumen. It prescribes 5–10% plastic by weight of bitumen, improving road performance. This demonstrates regulatory support for plastics in pavement materials. No equivalent code exists yet for Portland cement concrete, but it signals acceptance of plastic reuse in infrastructure.
- **Building Codes:** The National Building Code of India (NBC) and equivalents emphasize durability and load checks. Any plastic use must meet those criteria. Engineers may reference *performance standards*: e.g., meet IS 456 requirements for strength, IS 7861 for concrete masonry, etc., even if plastic content is nonstandard. Some local building codes allow alternative materials with certification.
- **Environmental Regulations:** Plastic waste management is governed by rules (e.g., India’s PWM Rules 2016). These encourage recycling but do not mandate use in construction. No regulations explicitly address plastic in concrete, but EHS standards apply (workers handle dust/plastic safely, etc.).

14.4 Best-practice Guidelines: Based on industry reports and research:

- Use plastic waste as permitted substitute for up to specified % by volume (common trial range 5–20%).
- Always test a pilot batch (slump, strength, durability tests) before project use.
- Ensure proper mix design: sometimes add supplementary cementitious materials (fly ash, silica fume) to offset strength loss.
- Treat plastic concrete as a *special concrete*: consider adjustments for cover, reinforcement spacing, fire rating, etc.
- Monitor end-of-life: plan for recycling or safe disposal of plastic-concrete debris.

Chapter 15 : PRACTICAL CASE STUDY

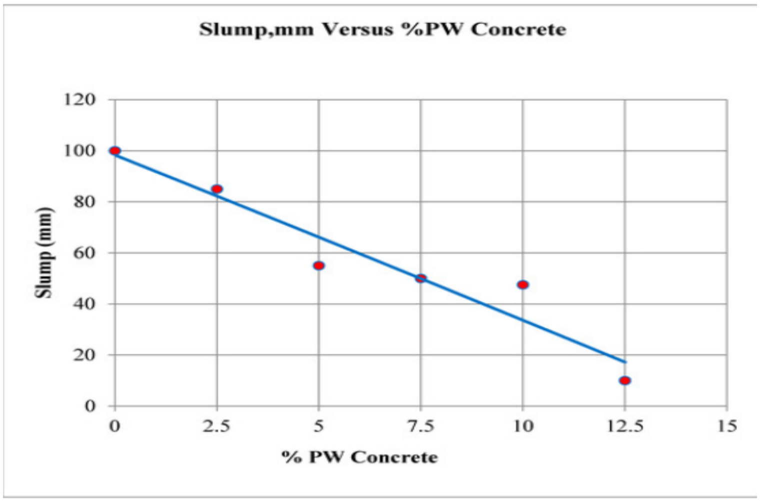

Figure 1 : Slump vs. percentage of PW in concrete.

Source: Data synthesized by the authors based on an analytical review of the existing literature [1]-[12]

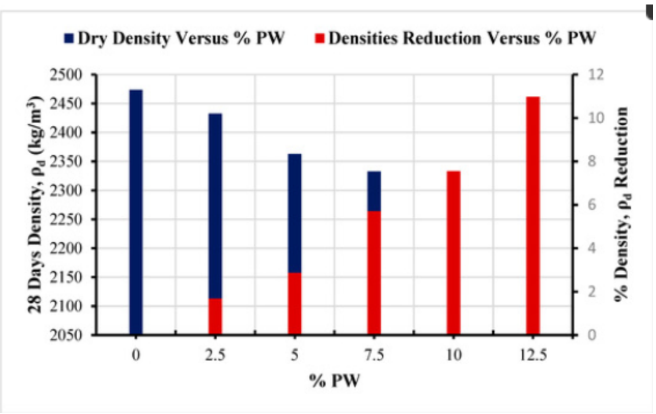

Figure 2 : Reduction in concrete dry density (ρ_d) vs. percentage of PW.

Source: Data synthesized by the authors based on an analytical review of the existing literature [1]-[12]

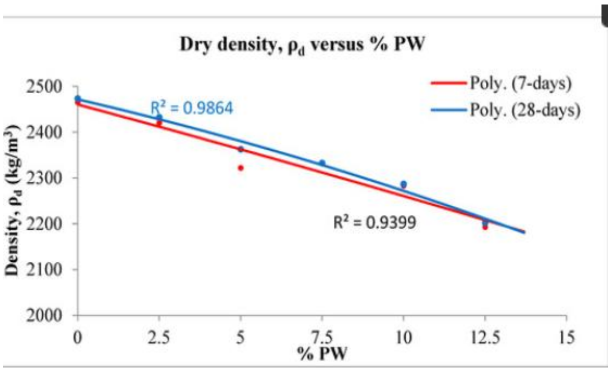

Figure 3 : Dry density (ρ_d) vs. percentage of PW.

Source: Data synthesized by the authors based on an analytical review of the existing literature [1]-[12]

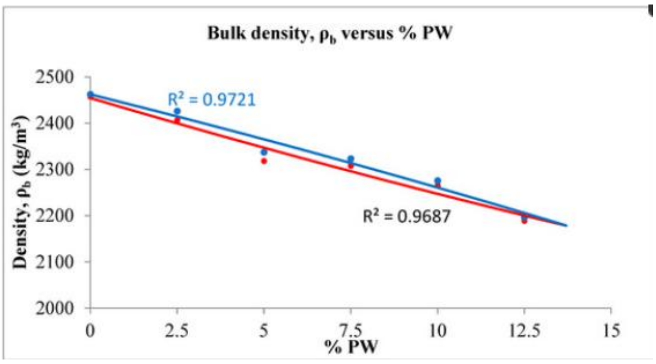

Figure 4 : Bulk density (ρ_b) vs. percentage of PW.

Source: Data synthesized by the authors based on an analytical review of the existing literature [1]-[12]

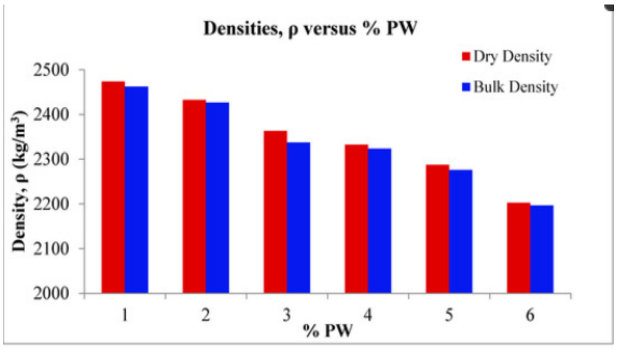

Figure 5 : Density (ρ) vs. percentage of PW.

Source: Data synthesized by the authors based on an analytical review of the existing literature [1]-[12]

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