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Effect of PET Fiber Geometry and Copper Slag on the Mechanical Properties and Durability of Concrete

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Abstract:

With increasing concerns regarding plastic waste and its environmental impact, the construction industry has started exploring sustainable alternatives to traditional materials. This research investigates the use of recycled polyethylene terephthalate (PET) fibers and copper slag as partial replacements for conventional concrete ingredients. PET fibers, obtained from waste drinking water bottles, were used in three different geometries: straight, flattened, and 'O' shapes, each at a 0.5% weight of cement. Copper slag, a by-product of copper extraction, was incorporated as a fine aggregate replacement at 0%, 20%, 40%, and 60% levels. The study focuses on the impact of these additions on the fresh and hardened properties of concrete. Experimental results indicate that the combination of 'O' shaped PET fibers and 60% copper slag significantly enhances the compressive strength, split tensile strength, and flexural strength by 25.85%, 26.39%, and 28.09%, respectively.The study concludes that PET fibers and copper slag can significantly enhance the mechanical and durability properties of concrete, making it a more sustainable alternative for construction applications

Keywords:

Concrete, Copper slag, PET fiber, Fiber geometry, Workability, Compressive strength, Split tensile strength, Flexural strength, Water absorption, Sulphury acid attack

1. Introduction

1.1 General Overview:

The construction industry is a significant contributor to global environmental degradation due to the extensive use of natural resources like sand and limestone. At the same time, the accumulation of plastic waste, particularly polyethylene terephthalate (PET) from bottles, has become an urgent issue globally.

PET, a durable and non-biodegradable plastic, contributes to environmental pollution when improperly disposed of. To address both concerns, there is a growing trend toward recycling PET waste for use in various industrial applications, including concrete production.

Simultaneously, the mining and extraction of natural resources for construction purposes, such as fine aggregates for concrete, has led to depletion of these resources. Copper slag, a by-product from copper smelting, has been proposed as a potential alternative to fine aggregates in concrete. Its use not only helps reduce environmental pollution but also offers technical advantages due to its unique physical and chemical properties.

This study aims to explore the synergistic effects of combining PET fibers with varying geometries and copper slag in concrete to enhance its mechanical properties and durability.

1.2 Types of Plastics:

Plastics, in various forms, are used extensively in multiple industries. Some common types include:

1. **Polyethylene Terephthalate (PET):** This plastic is used primarily in water bottles and food containers. PET is a thermoplastic polymer, widely recycled and repurposed for various uses.

Figure 1.1 PET bottles

2. **High-Density Polyethylene (HDPE):** Known for its strength and resistance to impact and chemicals, HDPE is used in products like milk bottles and detergent containers.

Figure 1.2 HDPE plastic

3. **Polyvinyl Chloride (PVC):** Used in pipes, flooring, and electrical cables, PVC is known for its versatility.

Figure 1.3 PVC plastic

4. **Low-Density Polyethylene (LDPE):** Often used in plastic bags, shrink wraps, and toys.

Figure 1.4 LDPE plastic

5. **Polypropylene (PP):** Commonly found in products such as yogurt containers, bottle caps, and automotive parts.

Figure 1.5 Polypropylene

6. **Polystyrene (PS):** Found in disposable cutlery, foam cups, and packaging material.
7. **Polycarbonate (PC):** Used in optical media, water bottles, and baby bottles, but its use has decreased due to concerns about BPA leaching.

PET, in particular, has high mechanical strength and excellent resistance to chemicals, making it suitable for reinforcement in concrete.

2. Literature Review

2.1 PET Fiber in Concrete:

The incorporation of PET fibers in concrete is relatively new and has gained attention due to its potential in improving concrete's mechanical and durability properties. Various studies have highlighted the advantages of using PET fibers, including improved crack resistance and enhanced tensile strength. For example:

- **Lisa Mary Thomas et al. (2020)** studied the hardened properties of concrete with recycled PET fibers and found that the inclusion of PET fibers at 0.4% by weight of cement increased compressive strength by 5.36% and flexural strength by 35.6%.
- **R. Dineshkumar & G. Balaji (2020)** conducted an experiment with PET fibers in concrete and concluded that PET fibers improved the ductility of concrete and enhanced its crack resistance, which was critical for ensuring structural integrity in buildings.

2.2 Copper Slag in Concrete:

Copper slag is a non-metallic by-product of the copper extraction process. It has been studied as a potential replacement for fine aggregates in concrete. It not only addresses disposal issues but also enhances the mechanical properties of concrete due to its high density and durability.

- **Gourav Sahu et al. (2020)** studied copper slag as a partial replacement for fine aggregates in concrete and found that replacing fine aggregates with 40% copper slag led to a 3.54% increase in compressive strength.
- **Mr. Suhas S. Malkhare et al. (2018)** observed that incorporating copper slag up to 40% improved the workability and compressive strength of concrete by 45.92%, highlighting its effectiveness in increasing concrete strength.

3. Objective and Scope of Work

3.1 Objectives:

The primary objectives of this research are:

1. To study the effects of PET fiber geometry on the mechanical properties of concrete.
2. To investigate the influence of copper slag as a partial replacement for fine aggregates in concrete.

3. To determine the optimal percentage of copper slag and PET fiber geometry that maximizes the mechanical and durability properties of concrete.

3.2 Scope of Work:

The scope of the research includes:

- Preparing and testing concrete mixes with various levels of copper slag (0%, 20%, 40%, and 60%) and PET fibers (0.5% by weight of cement) in three different shapes: straight, flattened, and 'O'.
- Conducting tests to determine the fresh properties (slump test) and hardened properties (compressive strength, split tensile strength, flexural strength, water absorption, and sulphuric acid attack resistance).
- Comparing the results with standard concrete mixes to assess the improvements in the mechanical and durability properties.

4. Materials and Experimental Study

4.1 Materials:

- **Cement:** Ordinary Portland Cement (OPC), 53 Grade, UltraTech Cement (IS: 12269).
- **Fine Aggregates:** Sand from Bhadaj area, Ahmedabad, confirmed by sieve analysis and specific gravity tests.
- **Coarse Aggregates:** Crushed stone aggregates of 20mm and 10mm size.
- **Copper Slag:** Sourced from a local copper smelting plant, used as a partial replacement for fine aggregates.
- **PET Fibers:** Waste PET bottles were manually cut into three different shapes—straight, flattened, and 'O' shapes—each added at 0.5% by weight of cement.

Figure 1.6 Straight shape fiber

Figure 1.7 “O” shape fiber

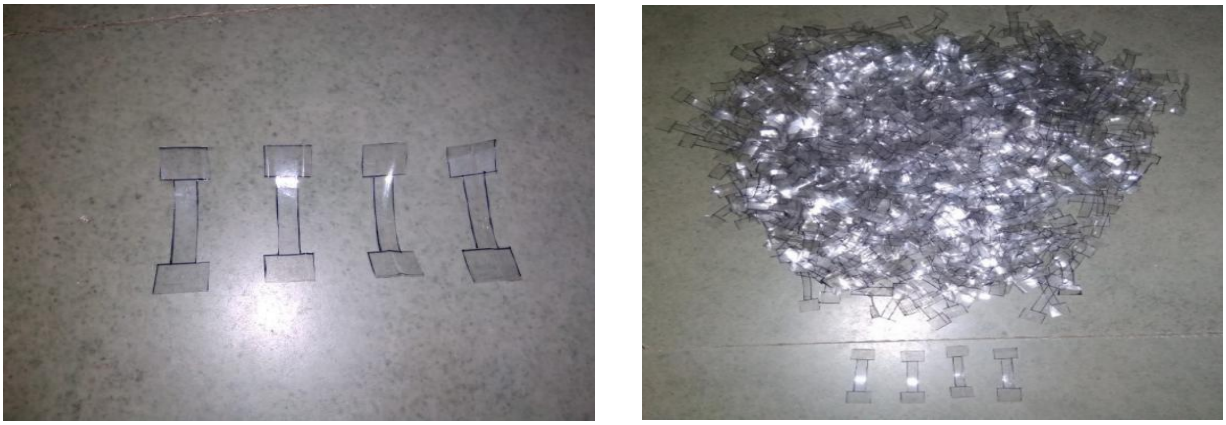

Figure 1.8 “O” shape fiber

4.2 Experimental Procedure:

- **Mix Design:** M25 grade concrete was used as a standard mix. The mix was designed using the IS 10262 guidelines.
- **Testing of Fresh Properties:** The workability of the mix was evaluated using the slump test.
- **Testing of Hardened Properties:** The compressive strength, split tensile strength, and flexural strength were measured at 7, 14, and 28 days of curing.
- **Durability Testing:** Water absorption and sulphuric acid attack tests were conducted to evaluate the concrete's resistance to chemical degradation.

5. Results and Discussion

5.1 Fresh Properties:

The slump values for concrete mixes with PET fibers and copper slag were measured to assess workability. The inclusion of PET fibers and copper slag reduced the slump slightly, with the ‘O’ shaped fibers showing the best workability. This suggests that the unique geometry of the 'O' shaped PET fibers enhanced the cohesion and viscosity of the concrete mix.

5.2 Hardened Properties:

- **Compressive Strength:** The combination of 60% copper slag and 'O' shaped PET fibers resulted in the highest increase in compressive strength (25.85%) compared to standard M25 concrete.
- **Split Tensile Strength:** A 26.39% increase in split tensile strength was observed with the same mix combination.
- **Flexural Strength:** The flexural strength showed a 28.09% increase, demonstrating that the combination of PET fibers and copper slag significantly improved the bending strength of the concrete.

5.3 Durability:

- **Water Absorption:** The water absorption rate for concrete with ‘O’ shaped PET fibers was significantly lower, highlighting the potential for improved durability in terms of resistance to water penetration.
- **Sulphuric Acid Attack:** The concrete with 'O' shaped fibers and copper slag exhibited better resistance to sulphuric acid attack, which is an indicator of improved durability.

6. Conclusion

The study conclusively demonstrates that the inclusion of PET fibers and copper slag in concrete enhances both the mechanical properties and durability. The 'O' shaped PET fibers, combined with 60% copper slag, provided the optimal mix for improving the compressive strength, tensile strength, and flexural strength of the concrete. Furthermore, the reduced water absorption and improved acid resistance indicate that this mix is more durable and sustainable than conventional concrete. Therefore, the combination of PET fibers and copper slag can be effectively used in concrete, contributing to sustainability and waste management in the construction industry.

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