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PET Water Bottle Recycling via Enhancing Concrete's Characteristics

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Abstract:

The escalating global crisis of plastic wastes, coupled with the industry's demand for sustainable materials highlights the need for innovative recycling solutions. This study investigates the use of recycled polyethylene terephthalate (PET) bottle fibers as a sustainable additive in concrete to mitigate the environmental impact of single-use plastics that often remains in landfills for extended periods. PET bottles were selected for their recyclability and environmental efficiency. They were collected, cleaned and then processed into fibers of size 50 mm x 2.5 mm. These fibers were then incorporated into concrete at proportions of 0%, 2%, 3%, and 4% by volume. The mechanical performance of the resulting concrete was assessed using cube, beam and cylindrical molds to measure compressive, flexural and tensile strengths after 28 days of curing in accordance to Indian Standard procedures. Five distinct mixes were tested, enabling a systematic analysis of PET fiber content's influence on concrete behavior. Experimental results showed a decline in workability as PET fiber percentage increased thus indicating a trade-off between sustainability and fresh concrete performance. Compressive strength decreased by an average of 48.01% at 4% PET fiber content, while tensile strength remained stable at 3% but diminished at 2% and 4%. these findings underscore the potential of PET fiber-reinforced concrete as a sustainable solution however its mechanical properties requires careful consideration for practical applications.

Keywords: Recycling, PET fiber, Environmental economics, Concrete, Concrete's strength.

1. Introduction

Rapid industrialization and urbanization have spurred extensive infrastructural development in order to meet growing societal demands and consequently have also intensified waste management challenges (Salman & Abbas, 2021). One promising solution is to recycle construction and plastic waste into alternative construction materials and energy sources. This research aims to investigate the incorporation of polyethylene terephthalate (PET) bottle fibers into non-structural concrete as a sustainable strategy to address two pressing challenges: the increasing demand for construction materials and the growing issue of plastic waste management.

With the increase of technology, for comfort, and ease of life, there has been increasing uses of plastic goods, replacing the traditional metal, glass, wood, and natural fiber. Among the plastic group, Polyethylene Terephthalate (PET) has rapidly replaced glass and metal uses due to its light

weight, strength, cost-effectiveness, and ease in molding into different shapes and sizes. Being cheaper in cost, it can be thrown mostly after a single use which results in the large uses of PET and has also been the burden of waste management, in the context of Nepal.

Technological advancements have widely increased the use of plastic goods. Among these plastic groups, polyethylene terephthalate (PET) has emerged as a prominent substitute for traditional packaging materials like glass and metal, primarily due to its lightweight nature, mechanical strength, cost-efficiency and versatility in molding into different forms. The affordability has also facilitated widespread single-use applications, especially in the beverage and food packaging industries (Somwanshi et al., 2022). Globally. Plastic consumption has surged from 5 million tons in the 1950s to over 100 million tons by the early 2000s (Chavan et al., 2018). In Nepal, PET bottles-widely used in food and beverage packaging due to its clarity, inertness and resistance to microbial attacks, these products have posed significant challenges for waste management systems, contributing to environmental degradation and emphasizing the urgent need for sustainable disposal and recycling strategies.

Despite these challenges, PET is recyclable and recycling represents the most environmentally efficient method of reuse. However, effective recycling requires substantial investment in infrastructure and technology. This study evaluates the feasibility of recycling PET bottles by integrating their fibers into concrete, proposing a cost-effective and eco-friendly approach to mitigate Nepal's growing PET waste burden while addressing construction material needs. By examining the mechanical and physical properties of PET fiber-reinforced concrete, the research seeks to establish its potential as a resource-efficient solution to solid waste accumulation.

2. Research Objectives

The primary objective of this research is to comprehensively investigate the impact of incorporating Polyethylene Terephthalate (PET), as an aggregate replacement on the mechanical properties of concrete. This study will focus on assessing the changes in the workability, flexural strength and compressive strength of the concrete mixes containing PET. A comparative analysis will be conducted to determine the efficiency and viability of PET-modified concrete relative to the conventional concrete mixtures.

3. Materials and Methods

Materials used in this study are detailed in Table 1. PET fibers were sourced from discarded water bottles, which were collected, cleaned, and manually cut into strips measuring 50 mm in length and 2.5 mm in width. The 43-grade Ordinary Portland Cement (OPC) was used. Fine aggregate consisted of good-quality sand with a maximum particle size of 4.75 mm, while the coarse aggregate ranged from 4.75 mm to 20 mm. Potable water was used for mixing and curing.

Table 1: Descriptions of the materials used

S.N.	Materials	Descriptions
1.	Polyethylene Terephthalate (PET) fibers	Wasted water bottles collected, washed, and cut manually into 50mm long and 2.5 mm wide in size
2.	Cement	43 grade OPC
3.	Fine Aggregate	4.75mm downsize good quality sand
4.	Coarse Aggregate	Particle fall within 20 mm and 4.75 mm i.e. retained on 4.75 mm size sieve and passing through 20 mm sieve
5.	Water	Potable water

The concrete mix was prepared manually by mixing PET fibers of size 50mm x 2.5mm with a cement, sand and aggregate mixture with a volumetric ratio of 1:1.5:3 (cement: sand: aggregate). the water cement ratio was maintained at 0.5 for all mixed. Five distinct concrete mixes were developed: a control mix with 0.00% PET fibers and four experimental mixes containing 2%, 3%, 4%, and 5% PET fibers by volume.

For each mix, two specimens of each type were prepared: cubes (150 mm x 150 mm x 150 mm) for compressive strength tests, beams (100 mm x 100 mm x 500 mm) for flexural strength tests and cylinders (150 mm diameter x 300 mm height) for splitting tensile strength tests. The specimens were casted, compacted and cured for 28 days under standard conditions.

The mechanical properties of the PET fiber-reinforced concrete were evaluated after 28 days of curing in accordance with the Indian Standard Testing procedure. Compressive strength was determined using the cube specimens as per IS516, flexural strengths using the beam specimens as per IS516 and splitting tensile strength using the cylinder specimens as per IS5816.

The proposed work schedule for the laboratory experiments is presented in Table 2, detailing the number of samples for each PET fiber percentage and specimen type.

Table 2: Proposed Work Schedule of the Lab Work

S.N.	PET	Number of Samples		
	%	Cube	Beam	Cylinder
1	0	2	2	2
2	2	2	2	2
3	3	2	2	2
4	4	2	2	2
5	5	2	2	2

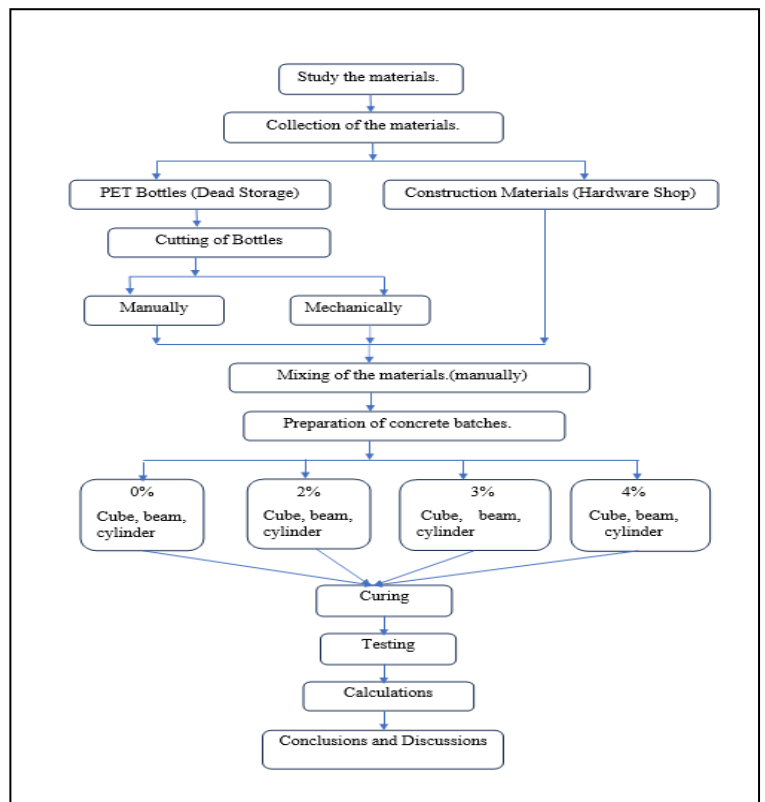


Figure 1: Research Methodology

The overall research methodology is illustrated in Figure 1, which outlines the steps from material collection to testing and analysis.

4. Result and Discussions

4.1 Workability

The Workability of concrete mixes were evaluated using the slump test. The control mix (0.00% PET fibers) achieved the highest slump value of 10 mm, while the mix with 4% PET fibers

recorded the lowest value of 5 mm. A consistent decrease in workability was observed as PET fiber content increased as shown in Figure 2. This decline could be due to fiber bridging effect, which restricts the mobility of the mix by occupying voids and enhancing internal cohesion.

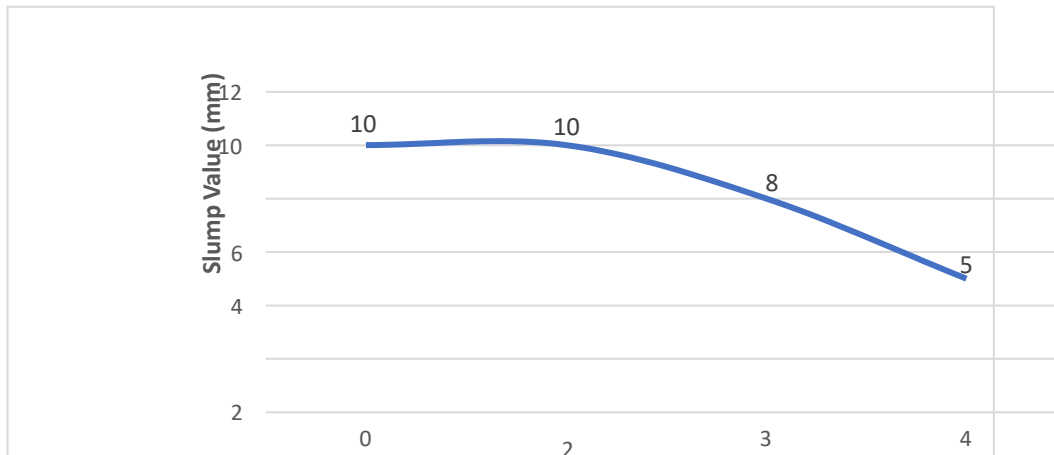


Figure 2: Slump Value vs PET Fiber Content

4.2 Mechanical Properties

4.2.1 Compressive Strength

The compressive strength of concrete decreased significantly with the incorporation of PET fibers. Compared to the plain concrete mix, reductions of 40.79% at 2% PET fibers, 40.63% at 3% and 62.63% at 4% were observed. Despite these declines, the compressive strength remained above 8.55 N/mm² across all mixes as shown in Figure 4. The substantial reduction suggests weak bonding between the small, non-corrugated PET fibers and the concrete matrix, impairing the mix's ability to withstand compressive loads.

4.2.2 Tensile Strength

The split tensile strength displayed a varied response to PET fiber content. At 2% PET fibers, tensile strength decreased by 15.21% relative to the control mix. At 3% PET fibers, it matched the tensile strength of plain concrete, but at 4% it dropped by 38.58%. This trend is shown in Figure 4 and suggests that 3% PET fibers may represent an optimal content where the fibers reinforce the concrete without excessively disrupting the matrix.

4.2.3 Flexural Strength

Flexural strength exhibited a consistent decline with increasing PET fiber content. Reductions of 32.10% at 2%, 49.67% at 3% and 67.32% at 4% were recorded compared to the control mix. These results indicate that the PET fibers used in this study do not enhance bending resistance, possibly due to increased porosity or poor fiber distribution within the concrete.

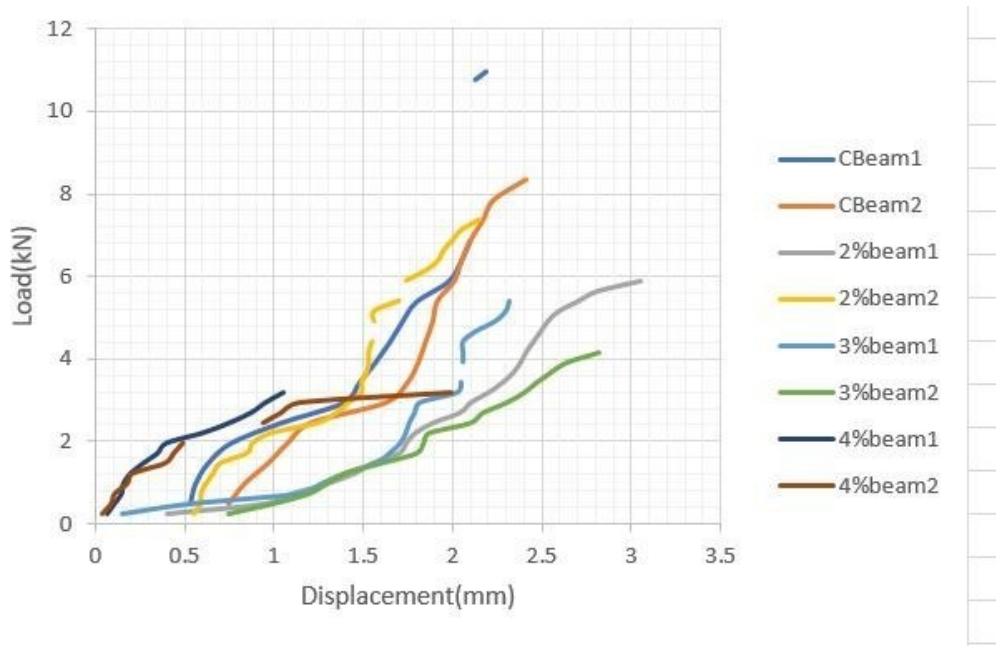


Figure 3: Load-Displacement Curve

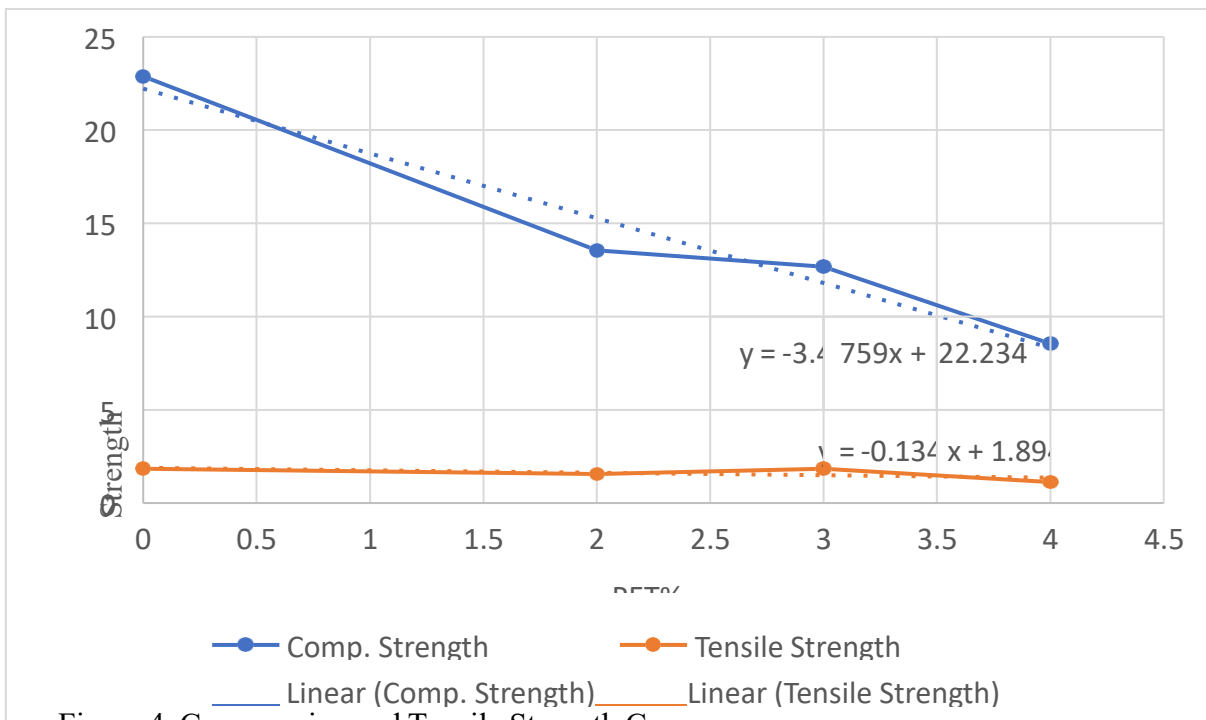


Figure 4: Compressive and Tensile Strength Curve

4.3 Discussions:

The primary aim of this study was to optimize the use of PET bottle fibers in concrete to reduce environmental pollution from discarded plastics, especially in the urban and semi-urban areas, while determining their suitability for structural and non-structural applications. The findings offer valuable insights on the performance of PET fiber-reinforced concrete.

The observed decrease in workability with higher PET fiber content is due to the fiber bridging effect, which restricts mix flow. For compressive strength, the significant reductions across all PET fiber percentages highlight the limitations of small, non-corrugated fibers that exhibit weak bonding with concrete matrix. In contrast, larger, corrugated fibers might improve bonding and strength, though they were not tested in this study. The tensile strength results indicate that stability of 3% PET fibers suggests a potential optimal fiber content where reinforcement benefits are maximized. However, the overall reductions in compressive and flexural strengths indicate that PET fiber-reinforced concrete is less suitable for structural elements under compressive or bending loads, where strengths typically exceeds 15 N/mm². Instead, the minimum compressive strength of 8.55 N/mm² at 4% PET fibers exceeds the typical requirement for non-structural applications, such as pedestrian walkways (5-7 N/mm²), making it a viable option for such uses (Khan, 2024).

These findings align with the study's sustainability goals by demonstrating that PET fibers can be repurposed in concrete, reducing waste while offering practical applications in non-structural contexts. The consistent trend of decreasing strength with increasing PET fiber content as shown in Figure 4 supports the hypothesis that excessive fiber incorporation adversely affects concrete performance, likely due to segregation, increased porosity or poor-fiber matrix interactions.

5. Hypothesis Tests

The study hypothesized that the mechanical properties of concrete would improve with the addition of PET fibers up-to a certain percentage, beyond which they would decline. The results partially validate this hypothesis: tensile strength remained stable at 3% PET fibers but decreased at 2% and 4%, while compressive and flexural strengths consistently declined with increasing fiber content. This aligns with existing literature (Kim et al., 2010; Khalid et al., 2018) on fiber-reinforced concrete, confirming the hypothesis for tensile strength but not compressive or flexural properties.

6. Conclusions

Based on the results and observations made in an experimental research study, the following conclusions are drawn.

- a) Workability: Increasing PET fiber content reduces workability due to the fiber bridging effect.
- b) Compressive Strength: An average reduction of 48.01% was observed with up to 4% PET fibers.
- c) Tensile strength: Tensile strength matches plain concrete at 3% PET fibers but decreases at 2% and 4%.

- d) Optimal Use: A 3% PET fiber content is recommended for non-structural concrete applications, balancing performance and sustainability.

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