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Compressive Strength Comparison Between Plain Concrete and Polyethylene Terephthalate (PET) Mixed Concrete

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Abstract-- **The construction industry continuously seeks innovative approaches to enhance the mechanical properties of concrete while addressing environmental concerns. This research investigates the quality, mechanical properties, compressive strength of concrete incorporating Polyethylene Terephthalate (PET), a plastic material usually Cold drinks bottle, and compares it with plain concrete. Study involves to replace natural aggregate by an artificial aggregate (PET). PET were introduced into the concrete mix at varying percentages by weight of fine aggregate, following the principle of design mix and comprehensive laboratory testing was conducted to determine the density, quality, Compressive strength and flexural strength of concrete with and without Polyethylene Terephthalate. Non-Destructive test was conducted using Rebound Hammer and Ultrasonic Pulse and Destructive test using Universal Testing Machine. The results reveal that PET mixed concrete slightly decreases the compressive strength of concrete with increasing the percentage of Polyethylene Terephthalate (PET). Density of concrete is 2400kg/m^{3}and concrete up to 6% PET follows the standard value. Based on this study optimum 3.52% of PET by weight can be used in concrete mix. This study underscores the potential of PET fibers as an effective reinforcement material for concrete, contributing to the reduction of plastic waste in the environment. The findings provide valuable insights for the construction industry, highlighting the feasibility of incorporating recycled plastics into concrete mixes to enhance structural performance while promoting sustainability.**

Keywords: Waste PET, Design Mix, Compressive Strength, Light weight Concrete

Introduction

1.1 Background

Concrete is a basic material to start every engineering project. The performance of concrete depends upon w/c ratio, quality of cement, type and size of fine and coarse aggregate. Concrete constituents will vary the mechanical properties: Compressive strength, tensile strength. Concrete has multiple design possibilities i.e; concrete can accommodate reinforcement as well. Hard plastic bottles are widely used in the recent periods which resulted in excessive increase of waste plastic. It is very essential that the waste plastic is responsible for higher proportion of pollution all over the world. The management of such waste plastic seems difficult as it is easy to collect but not separated nor recycled to new product. The best way to manage such waste is to send on landfill or energy recovery.

Different research was conducted to evaluate the mechanical properties, durability, workability, and long-term performance of PET-modified concrete. It is lightweight, strong, and resistant to corrosion and chemical degradation. Due to its strengths, longevity, and ease of processing, it can be utilized for several objectives. According to studies, plastic is almost inert, meaning that chemicals little impact it and that it is more durable. The environmental restriction of these items led to their use in concrete. The environment, the protection of natural resources, and the recycling of waste items are given a lot of emphasis. Use of PET in concrete will improve the ductility of concrete.

Concrete cubes and beams are tested by both destructive and non-destructive test. Here in my research, I conducted Ultrasonic test and smith Rebound hammer test for non-destructive test. For destructive I used Universal Testing Machine (UTM).

1.2. Rationale of the study

The incorporation of PET (Polyethylene Terephthalate) into concrete mixes presents a multifaceted approach to address several critical challenges faced by the construction industry. By integrating PET, a recycled material, into concrete formulations, the following compelling reasons underscore the significance and necessity of this study:

- Sustainability and Resource Conservation: PET incorporation offers a sustainable alternative by reducing the demand for traditional concrete constituents like aggregate and cement, both of which are finite resources. This approach aligns with global efforts towards sustainable development and environmental conservation, making it a crucial aspect to explore and understand thoroughly.
- Cost-Effectiveness and Feasibility: Assessing the cost-effectiveness of incorporating PET into concrete mixes

is essential for determining the feasibility of large-scale implementation. This aspect not only considers the environmental benefits but also evaluates the economic viability of adopting PET mixed concrete in construction projects. By analyzing the cost implications, stakeholders can make informed decisions regarding material selection and project planning, promoting sustainable practices without compromising financial objectives.

This study seeks to explore the multifaceted benefits of incorporating PET into concrete mixes, ranging from sustainability and resource conservation to optimization of mix designs, cost-effectiveness, and regulatory compliance. Through comprehensive analysis and evaluation, the research aims to contribute valuable insights that drive positive change and innovation in the construction industry towards a more sustainable and environmentally conscious future.

1.3. Objectives

The primary objective of the study is:

- to evaluate the compressive strength comparison between plain concrete and polyethylene terephthalate (pet) mixed concrete.

The secondary objectives of the study are:

- To assess the quality of design mix concrete by comparing the compressive strength with and without the addition of hard plastic (PET) using destructive testing methods.
- To evaluate the environmental benefits and reduction of plastic waste by incorporating hard plastic (PET) into concrete mixtures.
- To analyze the economic feasibility and cost-effectiveness of utilizing plastic mix concrete in construction projects.
- To explore the potential applications and practical implications of plastic mix concrete for sustainable construction practice

1.4 Scope and Limitations of the study

Scope:

The scope of this study encompasses a comprehensive comparison of the compressive strength between plain concrete and concrete mixed with Polyethylene Terephthalate (PET). Building upon the guidelines outlined in the Nepal National Building Code (NBC: 105: 2020), which mandates the use of M25 concrete for taller structures, this research focuses specifically on the utilization of M25 concrete mix. By aligning with national building standards, the study ensures relevance and applicability to the prevalent construction practices in Nepal.

By choosing M25 concrete as the subject of investigation, the research extends its scope to address a crucial aspect of building construction in Nepal. The findings of the study will provide valuable insights into the performance and suitability of M25 concrete, particularly in seismic-prone regions like Nepal, where structural integrity is of paramount importance. Moreover, the research outcomes will offer practical implications for builders, engineers, and policymakers involved in the construction industry, aiding in informed decision-making and the adoption of best practices in structural design and construction methods.

In essence, the selection of M25 concrete for the study not only aligns with national building regulations but also enhances the relevance and applicability of the research findings to real-world construction scenarios prevalent in Nepal

Limitations:

While this study provides valuable insights into the compressive strength comparison of plain concrete and PET-mixed concrete using M25 grade, it is essential to acknowledge its limitations. The research is intended for a specific grade (M25), and the results and outputs may vary for other concrete grades. Furthermore, the study is performed using 3%, 6% & 9% PET in replacement of fine aggregate, which may impact the generalizability of findings to different PET dosage levels.

Material and Methods

2.1 Mix Design

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. In other words, mix design is the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties, notably work-ability, strength and durability. Mix design refers to the process of proportioning and selecting the constituent materials (such as aggregates, cement, water, and admixtures) to create a concrete or asphalt mix with desired properties for a specific application or project. Different materials are used for the preparation concrete mixture. These materials vary in properties and their function in the mixture.

2.2. Non-destructive Test

Strength and quality of concrete can be tested without any damage. NDT helps to determine the properties of material, age of structures or components as well. Various method can be used for non-destructive test like Smith rebound hammer, Ultrasonic testing, Penetration resistance test, Carbonation depth measurement test and Half-cell potentiometer test. Among these test scheme Smith rebound hammer and Ultrasonic testing are used for my research purpose. The result of testing can show whether the components need to be repaired or if they are safe for operation. Using Ultrasonic testing we can determine cracking depth, Young's modulus of Elasticity, Compressive Strength, Pulse velocity etc. Here in my research using Ultrasonic testing we observed for Compressive Strength and Pulse Velocity of Concrete (cube and beam) to analyze the strength and quality of concrete.

TABLE 1

AVERAGE REBOUND NUMBER FOR QUALITY OF CONCRETE GRADING

Average Rebound Number	Quality of Concrete
>40	Very good hard layer
30 – 40	Good layer
20 – 30	Fair
< 20	Poor concrete
0	Delaminated

TABLE 2

VELOCITY CRITERION FOR QUALITY CONCRETE GRADING

Average value of Pulse velocity (km/s)	Concrete Quality Grading
Above 4.4	Excellent
3.75 to 4.4	Good
3.00 to 3.75	Doubtful
Below 3.00	Poor

2.3. Destructive Test

Destructive testing refers to deform or destroy the precast material in such a way that test can pass and material can no longer used for service. Also known as destructive physical analysis (DPA) which are used to analyze the behavior of concrete under compressive load. If the test result obtained from non-destructive test are not reliable than destructive test must be followed for the verification. It includes Compressive test, Tensile strength test and Bond strength test.

TABLE 3

COMPRESSIVE STRENGTH OF CONCRETE WITH RESPECT TO AGE

Days	Strength Percentage
3	40
7	65
14	90
28	99

During the initial curing period, typically the first few days after placement, concrete undergoes rapid strength development. Concrete strength at 28 days is widely used as a standard measure for quality control and design purposes in construction projects. While concrete continues to gain strength beyond 28 days, the rate of strength gain gradually diminishes over time.

PET Bottle

PET in our study denotes cold drink bottles. Cold drink bottles can be collected from the waste coming from the day-to-day use of water bottles, cold drink bottles etc. The collected plastic waste is cleaned and shredded into small pieces so as to use as concrete constituent. Only the mid-section of the bottle was used, top and bottom section of the bottles were superfluous. The average weight of one PET bottle is 60 grams, this leaves 28 grams of cleaned part of the bottle and the amount of fiber acquire is just 32gram from a bottle.

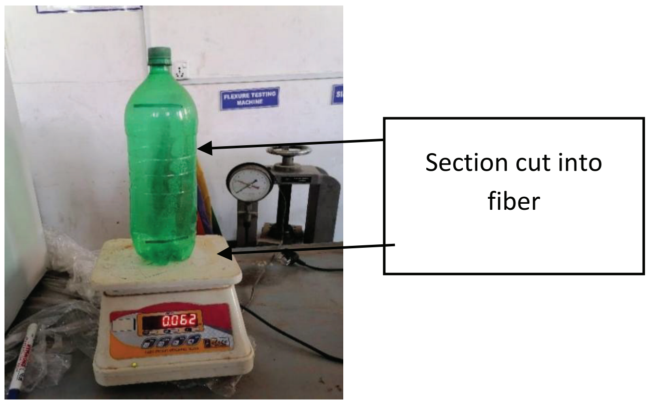

Fig. 1 A representation of parts of PET that are used into fiber

TabLE 4

LIST OF MATERIAL

S. N	Material Type	Specification
1.	Cement	OPC, 43 grade (Shivam)
2.	Fine aggregate/Sand	5 mm
3.	Coarse Aggregate	20mm down
4.	Shredded hard plastic from bottles	10mm
5	Kerosene	

RESULT AND DISCUSSION

3.1 Specific Gravity

Specific gravity is the ratio of density of substance to the density of a reference substance, generally we use water to determine the specific gravity of other substances. If the density of substance is less than 1 it will float and if the density is greater than 1 then substance will sink. It is a dimensionless quantity. Specific gravity of kerosene lies between 0.78 to 0.82. The specific gravity of Ordinary Portland cement is typically around 3.15. Fine aggregate has a specific gravity range from 2.5 to 2.8. Specific gravity of coarse aggregate varying from 2.60 to 2.95. In our research work final Result of Specific gravity after testing on lab are:

TABLE 5

PERCENTAGE VARIATION BY WEIGHT OF HARD PLASTIC TO REPLACE FINE AGGREGATE

S.NO	Weight of fine aggregate	3% by weight	6% by weight	9% by weight
1	25	0.750	1.500	2.250
2	37	1.110	2.220	3.330

3.3 Density of Sample

Density is a measure of mass per unit volume. Its units are expressed in kg per m^3. Density of concrete is around 2400kg/m^3 or 2.4 g/cm^3. This value can change based on the proportions of its components, such as cement, aggregate and water.

3.3.1 Density of Cube

Volume of Cube (V) = 15cm ´ 15cm ´ 15cm = 3375cm^3 = 0.003375 m^3

Mass of Cube (M) = 8.480 kg

Density of Cube (r) = MV= 8.4800.003375= 2512.593 kg/m^3

Fig. 2 PET Cube Sample

3.3.2 Density of Beam

Volume of Beam (V) = 50cm ´ 10cm ´ 10cm = 5000cm^3 = 0.005 m^3

Mass of Beam (M) = 12.542 kg, Density of Beam (r) = MV= 12.5420.005= 2508.4 kg/m^3

Fig. 3 Beam Sample

3.5 Destructive Test

It can be done by using Universal testing machine (UTM). These tests are often used to evaluate the mechanical properties, performance characteristics, and failure modes of materials and structures. Destructive testing provides valuable insights into the properties and performance of materials and structures, allowing engineers and researchers to make informed decisions about their suitability for specific applications. Destructive testing provides crucial data for material selection, quality control, and design optimization. Compressive strength test and flexural strength test were conducted in laboratory for concrete cubes and beams respectively for different proportion of PET at 7 days, 14 days and 28 days.

Fig. 4 Compression testing machine

3.5.1 Compressive strength test

Direct compressive strength test was conducted in laboratory using Universal Testing Machine. The compressive strength test results are typically reported in units of pressure (MPa or psi).Compressive strength testing provides valuable information about a material's behavior under compression, aiding in material selection, quality control, and structural design. Three samples each at 7 days, 14 days and 28 days were tested up to its failure to determine the ultimate strength of concrete. Following samples were taken for the conduction of test:

3.5.2. Flexural Strength Test

Modulus of rupture is computed to determine cracking and deflection in beam. The tensile strength of concrete in flexure is called modulus of rupture. Concrete has relatively low tensile strength. Also known as flexural strength, bend strength or fracture strength. Third-point loading test can be conducted in standard size plain concrete beam.

Fig. 5 Flexural testing machine

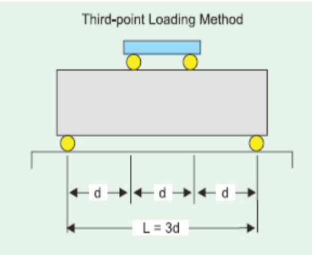

Fig 6 Third point loading

Conclucion and Recommendation

TABLE 6

% OF PET VERSUS DENSITY OF CONCRETE

% of PET	Days	Density	Remarks
0	7	2470.91	OK
	14	2495.8	OK
	28	2497.58	OK
3	7	2426.07	OK
	14	2426.27	OK
	28	2453.73	OK
6	7	2417.38	OK
	14	2431.41	OK
	28	2419.36	OK
9	7	2365.83	<2400 Not OK
	14	2313.68	<2400 Not OK
	28	2314.07	<2400 Not OK

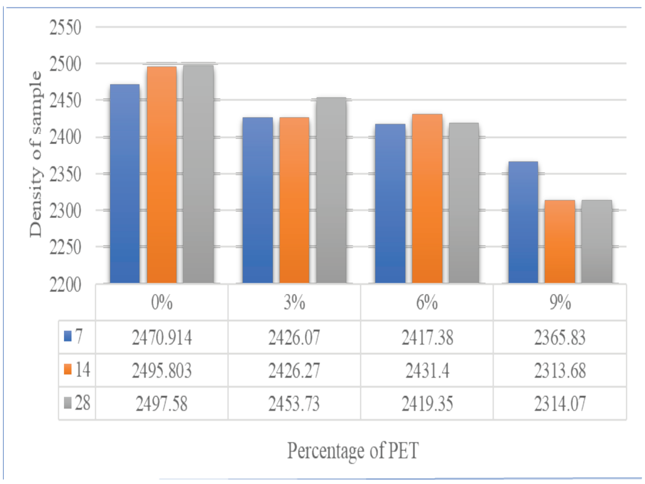

Fig. 7 Density Versus % of PET

TABLE 7

AVERAGE COMPRESSIVE STRENGTH OF CONCRETE CUBES

Grade of Concrete	Days	% weight of PET	Average Compressive Strength (N/mm²)
M25 (1:1.29:2.15)	7	0	24.88
		3	21.19
		6	16.84
		9	16.31
	14	0	26.82
		3	25.01
		6	17.62
		9	17.43
	28	0	29.68
		3	26.34
		6	19.13
		9	18.55

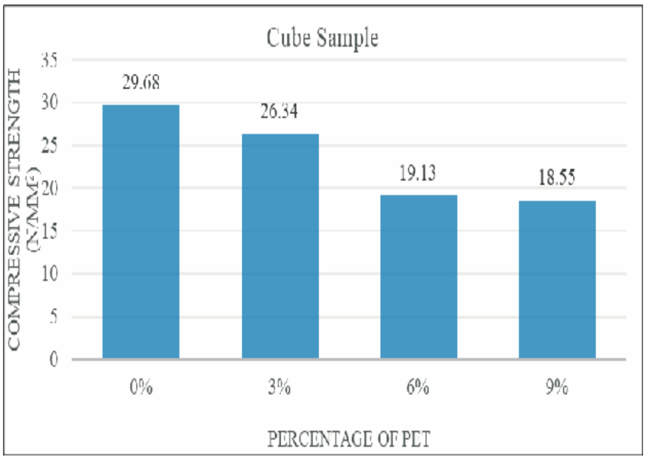

Fig. 8 Strength Versus % of PET

TABLE 8

AVERAGE FLEXURAL STRENGTH AND COMPRESSIVE STRENGTH OF BEAm

Description	Days	Average Flexural Strength or Modulus of rupture (N/mm²)	Average Characteristic Strength (f_{ck}) (N/mm²)
0% PET	7	3.27	21.85
3% PET		3.26	21.66
6% PET		2.76	15.59
9% PET		2.32	11.01
0% PET	14	3.587	26.390
3% PET		3.580	26.275
6% PET		2.50	12.88
9% PET		2.240	10.292
0% PET	28	3.777	29.163
3% PET		3.537	25.669
6% PET		2.423	12.073
9% PET		2.497	12.747

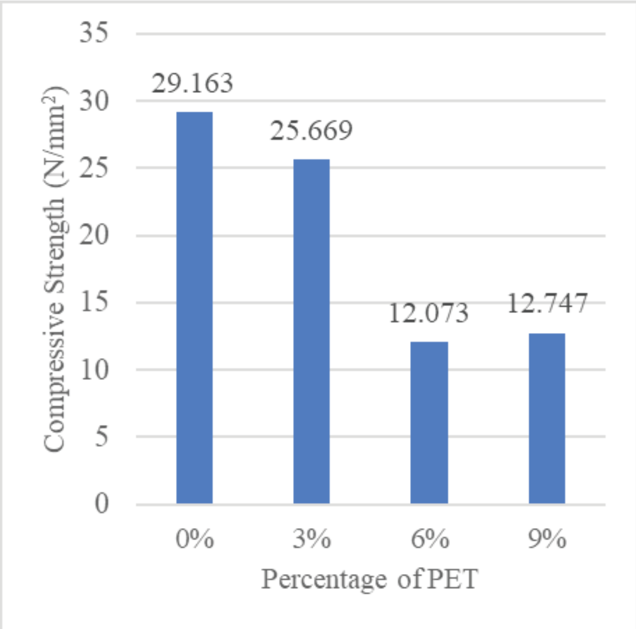

Fig. 9 Strength Versus % of PET

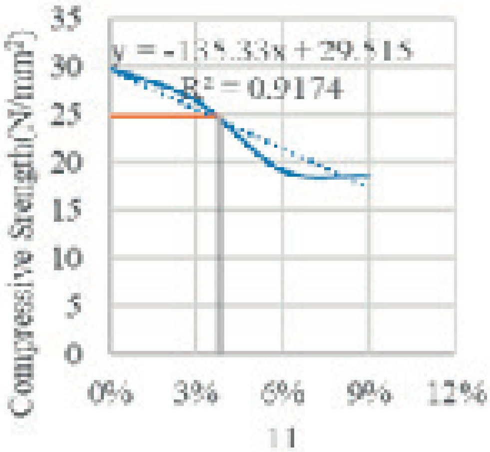

Fig. 10 Trend Analysis

Cost Estimation for 1 m³ of M25 Concrete						
S. N	**Item**	**Unit**	**Quantity**	**Rate**	**Amount**	**Remark**
1	Cement	Bag	10.16	700	7112	All rate is taken from Jilla Dar Rate Ktm
2	Sand	Kg	728.91	2.07	1508.844	
3	Coarse Aggregate	m^3	0.7589	3566.31	2706.473	
Total Amount					**11327.32**	

Cost Estimation for 1 m³ of M25 Concrete With PTE						
S. N	Item	Unit	Quantity	Rate	Amount	Remark
1	Cement	Bag	10.160	700	7112	
2	PTE	Kg	25.731	0	0	3.52% By wt of sand
3	Sand	Kg	703.179	2.07	1455.582	All rate is taken from Jilla Dar Rate Ktm
4	Coarse Aggregate	m^3	0.759	3566.31	2706.473	
Total Amount					**11274.05**	

The above Result shows that 3.52% of PTE in the concrete as a fine aggregate the cost is reduced by 0.47 % for 1 m³ of concrete of M25.

4.1 Findings and Conclusion

Study findings align with several existing studies on the utilization of Polyethylene Terephthalate (PET) in concrete mixes. The comparison of the findings with the existing literature has been listed as follows:

Compressive Strength: The research findings indicate a decrease in compressive strength of concrete with increasing PET content. Specifically, after 28 days, the compressive strength values were recorded as follows: 29.88 N/mm² for plain concrete, 26.34 N/mm² for concrete with 3% PET, 19.13 N/mm² for concrete with 6% PET, and 18.55 N/mm² for concrete with 9% PET. This trend aligns with previous studies, suggesting that while PET incorporation offers certain advantages, such as waste management, it may compromise concrete strength beyond the optimum dosage. The study demonstrates a reduction in compressive strength with increasing PET content, which is consistent with findings from various studies (Suram, Srinivas, & Varma, 2021; Daisy, Akshaya, S, & Vanitha, 2023; Temesgen, Abreham, & Desalegn, 2021; Córdoba, Barrera, Díaz, Nuñez, & Yañez, 2013).

Optimum PET Content: The study identifies an optimal PET content of 3.52% by weight of fine aggregate to achieve desired strength properties. This finding is consistent with existing research indicating an optimal range for PET dosage, (Askar, AI-Kamaki, & Hassan, 2023; Temesgen, Abreham, & Desalegn, 2021) ensuring a balance between strength enhancement and cost-effectiveness.

The study findings corroborate with existing literature, providing further insights into the optimal utilization of PET in concrete mixes while addressing environmental concerns and promoting sustainable construction practices. Through careful analysis and comparison, the study contributes to the growing body of knowledge on the utilization of recycled materials in construction and their impact on concrete properties and performance.

Discussion on findings

The observed decrease in compressive strength with increasing PET content reflects the trade-off between sustainability and structural performance in concrete mixes. While PET incorporation offers environmental advantages, such as waste reduction and resource conservation, it must be carefully balanced with the mechanical properties required for structural integrity.

Furthermore, the potential cost reduction of 0.47% for 1 m^3 of concrete highlights the economic viability of PET incorporation. This cost-saving aspect enhances the attractiveness of using recycled materials in construction projects, contributing to the adoption of sustainable practices within the industry.

From an environmental perspective, the utilization of improperly disposed PET bottles in construction not only mitigates waste accumulation but also reduces the release of harmful pollutants into the ecosystem. This aligns with global sustainability initiatives aimed at promoting circular economy principles and reducing environmental degradation.

Conclusions of the study:

In conclusion, the research findings emphasize the importance of judiciously incorporating PET into concrete mixes to achieve a balance between sustainability, cost-effectiveness, and structural performance. By identifying an optimal PET content and highlighting its economic and environmental benefits, the study provides valuable insights for stakeholders involved in concrete production and construction projects.

4.2 Recommendation

Following are the recommendations from the study:

Optimization of PET Content: Building upon the findings of the study and consistent with existing research, further investigations should focus on optimizing the PET content in concrete mixes. Experimentation across various percentages of PET can help identify the most cost-effective and environmentally sustainable dosage for different concrete grades and applications. This recommendation aligns with previous studies (Askar, AI-Kamaki, & Hassan, 2023; Temesgen, Abreham, & Desalegn, 2021) and ensures a balance between strength enhancement and cost-effectiveness.

Environmental Impact Assessment: Given the environmental benefits associated with utilizing improperly disposed PET bottles in construction, future studies should conduct comprehensive assessments of the environmental impact of PET-mixed concrete. This includes evaluating factors such as carbon footprint, energy consumption, and emissions reduction compared to conventional concrete production methods. By quantifying the environmental benefits of PET incorporation, stakeholders can make informed decisions and contribute to global sustainability efforts, as emphasized in previous research (Nadimalla, Masjuki, Saad, Ismail, & Ali, 2019; Choi, Moon, Chung, & Cho, 2005; Tatheer, Nabi, Bashir, & Hassan, 2021).

Recommendations for Further Study:

Durability Assessment: Investigate the durability of PET-mixed concrete under various environmental conditions and exposure scenarios to determine its resistance to factors such as freeze-thaw cycles, chemical corrosion, and abrasion. Long-term durability testing will provide valuable data on the material's service life and maintenance requirements, informing its practical application in construction projects.

Field Trials and Real-world Applications: Implement field trials and pilot projects to demonstrate the practical feasibility and performance of PET-mixed concrete in real-world construction applications. Collaborating with industry partners and construction firms will enable the validation of laboratory findings in actual construction projects, fostering technology transfer and adoption.

By addressing these recommendations, future research endeavors can advance the understanding and application of PET-mixed concrete, contributing to sustainable construction practices and environmental conservation efforts.

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