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Performance Evaluation of PET Strip Fiber Reinforced Concrete

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Abstract

Polyethylene Terephthalate, commonly known as PET, is a petroleum-based plastic polymer that is widely used in the packaging of various commodities due to its durability, and poses a major threat to the environment. To tackle this scenario, the construction industry is researching all possibilities to incorporate this waste into concrete and enhance the properties of concrete. The present study evaluates the performance characteristics of M 30 grade concrete when reinforced with PET strip fibers. The addition of PET strips is done as 0.75%, 1.00%, and 1.25% of the volume of fresh concrete to be mixed. As the PET percentage increases, the slump of fresh concrete decreases. The mix containing 1.25% PET strips shows the lowest slump of 20mm with a true slump. Compressive strength at 28 days increased in the 0.75% and highest was achieved by the 1.00% PET mix, as an 11.96% increase compared to the control mix, whereas the 1.25% mix shows a 40.11% decrease. Flexural strength revealed a similar trend with a 38.2% increase in flexural strength of 1.00% mix; however, split tensile strength showed a gradual ascending increase and a maximum of 15.2% increase in split tensile strength of 1.25% mix. After assessment, a 1.00% addition of PET strips was deemed optimum. The 1.00% mix was further tested for acid attack and non-destructive tests, namely Ultrasonic-pulse-velocity test for concrete quality and Schmidt hammer for surface hardness. Specimens were cured in an acidic medium (1:100) hydrochloric acid solution for 28 days, and no significant changes were observed in compressive strength.

Keywords: Concrete, fiber-reinforced, PET, plastic, compressive strength, flexural strength, tensile strength, acid attack, UPV, Schmidt (Rebound) hammer

INTRODUCTION

Poly-Ethylene Terephthalate, commonly known as PET, is a petrochemical polymer which is produced from the lesser valuable derivatives of fossil fuels [1]. Due to its high recyclability, PET is widely used in various domestic commodity packaging. Although recyclable, the production rates of PET exceed the recycling rates of PET by a massive difference [2]. This difference gives rise to pollution, as PET is not biodegradable [1]. The discarded unrecycled PET waste continues to fill numerous landfills, causing undue loss of land [2]. The methods to produce keep on improving, while the methods to recycle are yet lacking [2].

Polyethylene terephthalate is a widely utilized plastic found in items like water bottles, food packaging, and textiles. It's lightweight, durable, and flexible, and that makes it important; however, the increasing use of PET has resulted in an issue of waste management throughout the world, as

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improper disposal of the PET goods has caused massive [3]. Environmental damage. The recycling of PET is crucial in both reducing this problem and as it has the potential of substantially minimizing the amount of plastic that is dumped into landfills and oceans. The recycling of PET involves the collection of PET goods that have been used, converting them into new substances, and thereafter utilizing these substances to produce different goods. However, despite its essentiality, PET recycling faces a variety of challenges restricting it from being effective on an international scale [4].

India recycles or reprocesses on an annual basis around 5.5 million metric tons of plastic waste PW which is around equal to 60% of the total PW put out in the nation. Out of this 70% is recycled through the registered formal units, 20% informally, and 10% at home.

The other 40% of PW is either uncollected or littered, contributing to pollution in water and land and causing drain blockages. Each year, around 2.5 million tons of PW is sent to landfills, more than 1 million tons is incinerated, and about 0.25 million tons is co-processed as an alternative energy source in blast furnaces by cement companies. Thermoset plastics, such as HDPE, PET, and PVC, which are recyclable, make up 94% of the total PW produced. The remaining 6% consists of non-recyclable plastics, including multilayered plastics and thermocol. While plastics like PP, PS, and LDPE are partially recyclable, they are rarely recycled in India due to the economic challenges associated with their recycling processes. [5,6]

As PET is a non-biodegradable, inert to chemical reactions under normal conditions, strong and durable, the use of PET as a reinforcing material for concrete to develop an economical and sustainable fibre reinforced concrete mix is an area of interest for many researchers. Fiber-reinforced concrete (FRC) incorporating polyethylene terephthalate (PET) fibres has garnered significant attention in recent years due to its potential to enhance the mechanical properties and sustainability of concrete. Numerous studies have investigated the effects of PET fibres on various concrete characteristics, including tensile strength, flexural strength, impact resistance, and durability [7–16]. Research indicates that the incorporation of PET fibres can improve the post-cracking behaviour of concrete, leading to increased toughness and reduced crack propagation. Additionally, PET fibres contribute to the overall ductility of concrete, making it more resilient to dynamic loads.

Thus, this study focuses on the application of PET fibers in concrete for tackling the stated issues.

MATERIALS

P.E.T. Strips

The P.E.T. strips utilized in the research are taken from waste recycled PET water bottles collected from local restaurants. The strips were cut using wavey-bladed scissors that provided ribbed, deformed fibers when cut. Table 1 shows the detailed characteristics of the PET strips. Figure 1 shows the length, and Figure 2 shows the width of PET strips.

Cement

The properties of OPC grade 53 were evaluated with reference to IS 2386 (Part-1) 1963 [17], and the test outcomes are presented in Table 2.

Table 1. Characteristics of PET strips.

Name	Polyethylene Terephthalate (P.E.T.) strips
Length	50 mm
Width	5 mm
Thickness	0.2 mm
Specific Gravity	1.38
Effective diameter of fiber (d_e)	1.128 mm
Aspect ratio of fiber	44.31

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Table 2. Test results for cement.

S.N.	Characteristics	Value
1	Consistency of cement	30 %
2	Initial setting time	112 min
3	Final setting time	308 min
4	Fineness of cement	99 %
5	Soundness of cement	2 mm

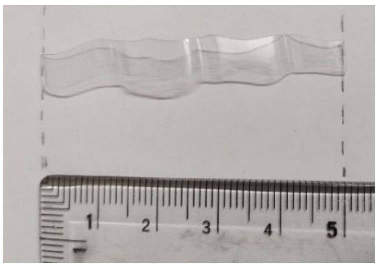

Figure 1. Length of PET fiber.

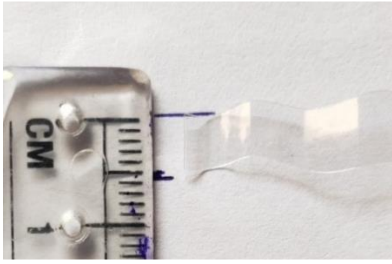

Figure 2. Width of PET Fiber.

Fine Aggregate

A mesh sieve of size 4.75 mm segregates debris from aggregates; thus, the material that passes through is termed fine aggregate. Its properties are defined by IS-2386 (Part-1) 1963.

Coarse Aggregate

The study utilized 20 mm coarse aggregate, properties of which are defined as per IS-2386 (Part-1) 1963.

METHODOLOGY

Mix Design

The concrete of grade M30 was selected for this study as M30 comes under the standard concrete category and is most widely used in general construction activities as per current trends. OPC 53 grade cement, aggregates having a mean size of aggregates of 20 mm, and fine aggregate passing a 4.75 mm sieve were used in the study. Table 3 represents the calculations of the mix design for 1 m^3 of concrete. The actual quantity of materials varies according to casting volume.

Addition of PET Strips

PET strips are added at a percentage of 0.50 %, 1.00 % and 1.25 % of the volume of fresh concrete to be mixed. PET strips are manually shredded using scissors and paper guillotines.

Casting

The calculation of the quantity of materials required for casting the test specimens was carried out based on the following parameters. All the following data is the same for all four concrete mixes, plastic being the only varying component in experimental mixes (P1, P2, P3).

1. Compressive strength test – 9 cubes – 150x150x150mm, set of 3 cubes each to be tested on 7, 14, 28 days of curing.
2. Flexural strength test - 3 beams – 100x100x500 mm, all 3 to be tested on 28 days of curing.
3. Tensile strength test- 3 cylinders – 150mm dia. x 300mm height, all 3 to be tested on 28 days of curing.

The quantity of cement, fine aggregate, and coarse aggregate required for casting each set is the same, as the increase in volume after adding pet fibers is less than 2%, and it is neglected. The following values shown in Table 4 are calculated for one set of specimens (including 9 cubes, 3 beams, and 3 cylinders as mentioned previously.

(Table 5) For the second phase of the project, i.e., for NDT and durability test, two sets of 6 cubes each shall be cast as follows:

Set 1 – Control Mix and Set 2 – Optimum Plastic Content Mix, for each set purpose is as follows:
1. 3 cubes for Normal (water) curing, which shall be used for NDT first, and then the crushing strength test.
2. 3 cubes for the Durability (acid attack) test.

Curing

Specimens were cured in immersion tanks under standard conditions and tested after specified intervals as stated in the Indian Standard codes. For the durability test, an acidic medium was prepared using Pure concentrated Hydrochloric acid [HCl] and further diluted to a ratio of 1:100 with neutral water. Hence, for every 20 liters of water, 200 ml of HCl was used to create an acidic medium. The following figures depict the curing conditions of the specimen.

TESTS CONDUCTED ON CONCRETE

Slump Cone Test

This study evaluates the influence of varying percentages of PET strips on the fresh properties of concrete, specifically its workability and flowability, before setting. For M30 grade concrete, the slump test was conducted by incorporating PET strips in incremental proportions ranging from 0% to 1.25%. The accompanying figure depicts the slump cone test setup, which involves placing concrete into a standardized cone mold in three layers, each compacted adequately.

Upon removal of the cone, the vertical displacement (slump) of the concrete is measured to assess its workability. Performance as shown in Figure 3 and measuring of slump in Figure 4

Table 3. Proportions of components in concrete mixes.

S.N.	Material	P0	P1	P2	P3
1	PET content in % by volume	0.00 %	0.75 %	1.00 %	1.25 %
2	Weight of PET strips (kg/m^3)	0.00	10.35	13.8	17.25
3	Cement (OPC 53)(kg/m^3)	438	438	438	438
4	Water (kg/m^3)	197	197	197	197
5	Fine aggregate (kg/m^3)	750	750	750	750
6	Coarse aggregate (kg/m^3)	1016	1016	1016	1016
7	w/c ratio	0.45	0.45	0.45	0.45

Table 4. Casting calculations for destructive tests.

S.N.	Mix Details for: Volume of concrete = 0.0614 m^3	Qty. of cement (kg)	Qty. of fine aggregate (kg)	Qty. of coarse aggregate (kg)	Qty. of water (kg)	Qty. of PET strips (g)
1.	Control Mix – P0	27	46	62.4	12	0.00
2.	0.75 % PET Mix – P1	27	46	62.4	12	634.23
3.	1.00 % PET Mix – P2	27	46	62.4	12	845.61
4.	1.25 % PET Mix – P3	27	46	62.4	12	1057.1

Table 5. Casting calculations for NDT and durability.

S.N.	Mix Details for: Volume of concrete = 0.02025 m^3	Qty. of cement	Qty. of fine aggregate	Qty. of coarse aggregate	Qty. of water	Qty. of PET strips
1.	Control Mix – P0	9 kg	15 kg	20.5 kg	4 kg	0.00 g
2.	1.00 % PET Mix – P2	9 kg	15 kg	20.5 kg	4 kg	280 g

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Figure 3. Filling of slump cone with fresh concrete.

Figure 4. Measuring the slump value of fresh concrete and noticing its nature.

Compressive Strength Test

Nine cube specimens, each of 150 x 150 x 150 mm dimension for all proportions, were cast and cured for 7days, 14days 28 days by the method of immersion curing. Compressive strength test was performed on the specimen as per specifications IS 516-(2021)[18] for Tests on Mechanical properties of Hardened concrete, on the compression testing machine after removing from immersion curing tanks and drying for three hours. The compressive strength was calculated as per the formula given in IS 516-2021 as;

$$F_{ck} = \frac{P}{S^2}$$

Where,
Fck = Compressive Strength, in MPa.
P = Maximum Load, in N.
S = Dimension of the specimen, in mm.
Thus, by calculating the values of compressive strength, the results were portrayed.

Flexural Strength Test

Three Beam specimens, each of 100 x 100 x 500 mm dimensions for all proportions, were cast and cured for 28 days by the method of immersion curing. Four-point loading test was performed on the specimen as per specifications in IS 9399 (1979) for the apparatus of the four-point loading test and [IS 516 (2021): Part I – Sec 1] for Tests on Mechanical properties of Hardened concrete, after removing from immersion curing tanks and drying for three hours.

The Flexural strength was calculated as per the formula given in IS 516-2021, according to failure type A as shown in Figure 5;

$$F_b = \frac{PL}{BD^2}$$

Where;
F_b = Flexural Strength, in MPa.
P = Maximum Load, in N.
B, D = Lateral dimensions (breadth and height) of the specimen, in mm.

L = Length of span on which the specimen is supported, in mm

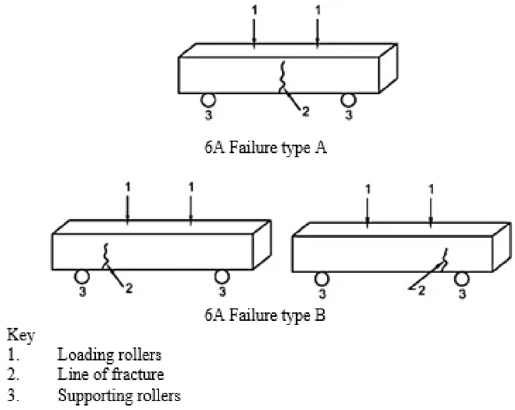

Figure 5. Failure typed as specified in IS 516-2021.

Split Tensile Strength Test

Three cylindrical specimens, each of 150 mm diameter and 300 mm height for all proportions, were cast and cured for 28 days by the method of immersion curing. Split tensile strength test was performed on the specimen as per specifications IS 516-(2021)for Tests on Mechanical properties of Hardened concrete, on the compression testing machine after removed from the immersion curing tanks and dried for three hours.

The Split tensile strength was calculated as per the formula given in IS 516-2021 as;

$$F_c = \frac{2P}{\pi LD}$$

Where;
Fc = Split tensile Strength, in MPa.
P = Maximum Load, in N.
L = Lateral Dimension of the specimen (Length), in mm.
D = Diameter of specimen, in mm.

Rebound Hammer Test

It is also known as the Schmidt Hammer Test. The test works based on the principle that harder surfaces will cause a rebound of a spring-loaded hammer. The extent of the rebound is then measured and used to infer the concrete's strength. Three cubic specimens each for the control mix and P2 mix were cast and cured in clean water immersion tanks for 28 days. Precautions were taken while casting the cubes so that the compaction is uniform and the surfaces of the cubes are perfectly plane. Five markings were made on the fairest surface to mark the positions (zones) where the rebound hammer was supposed to be applied. The rebound hammer was held steady at a precisely normal position on the markings, and the reading of the rebound number for each zone was taken, and the corresponding value of compressive strength was deduced using standard graphs. Test is performed in accordance with [IS 516 (2018): Part V – Sec 4]. The marking of zones is as shown in Figure 6, and performance is shown in Figure 7.

Ultrasonic Pulse Velocity Test

This test is a specific NDT method used to assess the quality and integrity of concrete and natural rocks. It involves measuring the velocity of an ultrasonic pulse passing through a material. Higher velocities typically indicate good quality and continuity, while lower velocities may suggest the presence of cracks, voids, or other imperfections. The UPV test was carried out on the same specimens used for the rebound hammer test. The direct method of transmission was applied to two opposite faces of the cubes having perfectly plane and finished surfaces. Grease was applied to the surface of the cubes to ensure proper transmission of the pulse through the concrete. It is performed as outlined in [IS 516

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(2018): Part V – Sec 1]. Performance is shown in Figures 8 and 9.

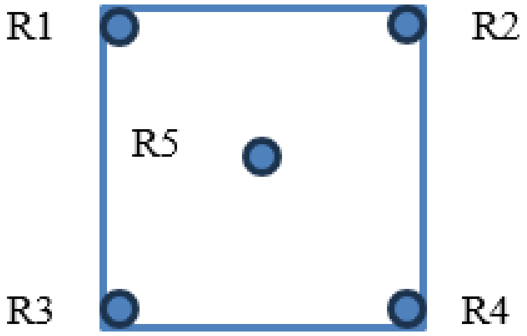

Figure 6. Marked zones on cube specimen for ebound hammer test.

Figure 7. Rebound hammer test on control mix and PET mix specimen.

Figure 8. UPV (Ultrasonic Pulse Velocity) test on control and PET mix specimen durability (acid attack) test.

Figure 9. UPV display unit.

The acid attack test of concrete is a method used to assess the durability of concrete when exposed to acidic environments. Concrete structures, especially those in contact with acids or acidic conditions—such as wastewater treatment plants, coastal areas with salty water, or industrial environments—can suffer damage over time due to the chemical reactions between the concrete and acids. In the acid attack test, a concrete sample is submerged in a solution of acid (typically hydrochloric acid or sulfuric acid) for a specific period. The standard procedures of this test are provided in [ASTM C1898, 20-2020] [19] Standard Test Methods for Determining the Chemical Resistance of Concrete Products to Acid Attack. Durability test is performed to check the resistance of concrete against harsh acidic environments, generally in industrial areas.

TEST RESULTS AND DISCUSSIONS

Slump Cone Test

With the increase in the quantity of fibers in the concrete mix, workability is seen to be reduced by a noticeable difference. During the mixing of fresh concrete, the fibers did not cause the formation of lumps in the concrete, hence creating a uniform mix. Control mix shows the workability of 95mm, which is comparable to the design stipulations. Other values are as shown in Table 6.

As the PET fibers form a mesh-like structure within the concrete matrix, they prohibit the movement of fine as well as coarse aggregate. Thus, with increase in PET content causes reduced workability.

Compressive Strength Test

Compressive strength evaluation for M30 concrete mixes was carried out in compliance with IS 516:2021 guidelines, employing 150 mm cube specimens. The tests were performed after a standard curing period of 28 days. For each mix, three specimens were tested, and the mean compressive strength was determined. This test, being essential for assessing the structural integrity of concrete, revealed noticeable differences in strength across the mixes.

These variations underscore the influence of PET strip incorporation on the compressive behavior of the concrete [20-23]. **Figure 10** shows the variation of compressive strength.

Table 6. Slump values of Concrete Mixes.

Proportion	Slump value in mm.	Nature of slump
P0 – 0.00%	95	Shear
P1 – 0.75%	65	Shear
P2 – 1.00%	45	Shear
P3 – 1.25%	20	True

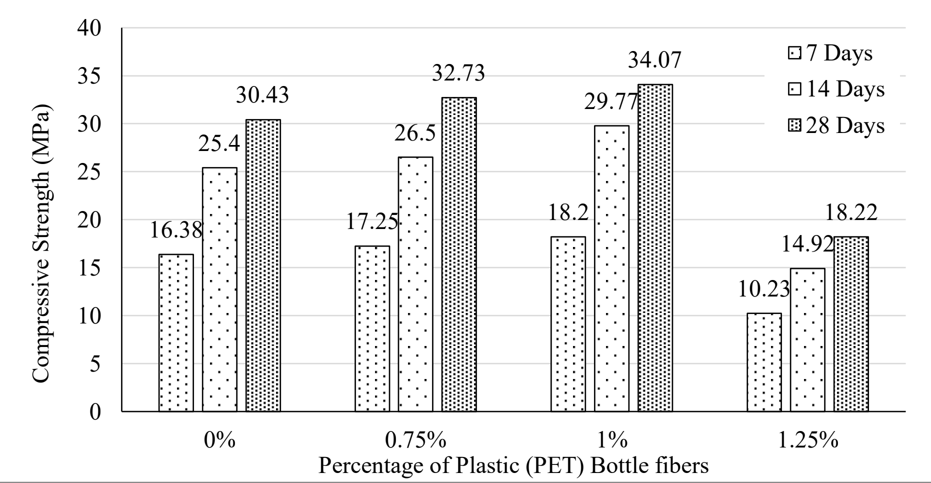

Figure 10. Percentage of PET fibers V/s compressive strength (MPa)

From the results, it is seen that the highest strength was achieved in P2 mix with an increase of 12 % compared to the control mix. Whereas, P1 mix shows an increase of 7.5 %. P3 mix showed a drastic fall in compressive strength with a decrease of 40 %. The compressive strength increases successively till 1.00% and then shows a drastic fall, which signifies that although the addition of PET Strips increases the strength but if added in excess, it can cause harm. As excess PET causes inefficient binding within the concrete matrix, its strength suffers. But when added in appropriate proportion, i.e., 1.00% its strength increased as the mesh of PET fibers holds the components of concrete together and increases the binding within the aggregates [20–23].

Flexural Strength Test

Following IS 516 (2021) standards, the Flexural strength test was performed on concrete beams (100 mm × 100 mm × 500 mm) after 28 days of curing. Two-point loading flexural testing aims to analyze flexural characteristics essential for resilience against bending and tensile forces.

All the fibre reinforced mixes show higher flexural strength than the control mix. P2 shows the highest strength with an increase of 38 %. P3 mix shows a 22.5 % increase, while P1 shows a 20.5 % increase in Flexural strength, as depicted in Figure 11.

As PET increases the bonding of the concrete matrix, flexural strength is seen to increase in all the mixes. The similar tends where obtained by past researchers [24–26]. The highest strength increase is seen in P2 mix, as increased fiber quantity added flexural strength to the concrete mix, as PET fibers reinforce concrete under flexural loading. The flexural strength of P3 mix is seen to decline similarly to the compressive strength, as excess PET caused bonding discrepancies in concrete.

Split Tensile Strength Test

The Split Tensile Strength test was conducted according to IS 516:2021 and IS 5816:199 standards, using cylindrical specimens of dimensions length:300mm and diamter:150 mm. As the results depict in **Figure 12**, the highest increase of 15 % more than that of the control mix was seen in the P3 mix, with the P2 mix having an increase of 7.5 %. P1 mix and control mix, however, showed the same tensile strength.

Similar to the flexural strength results, the tensile strength of PET fibers works in unison with the concrete to yield higher tensile strength than plain concrete [27–29]. In split tensile strength, the area under splitting action was larger compared to flexural strength, and higher PET quantity caused increased PET interference in the Split tensile strength test. Thus, with an increase in PET percentage, tensile strength is seen to be increased as additional PET fibers dispersed over a larger area are present against the splitting action [30–31].

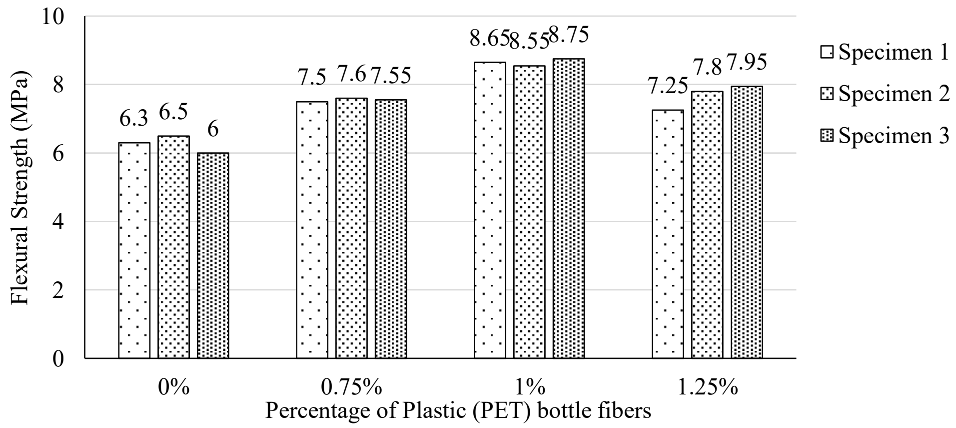

Figure 11. Percentage of PET fibers V/s Flexural strength (MPa).

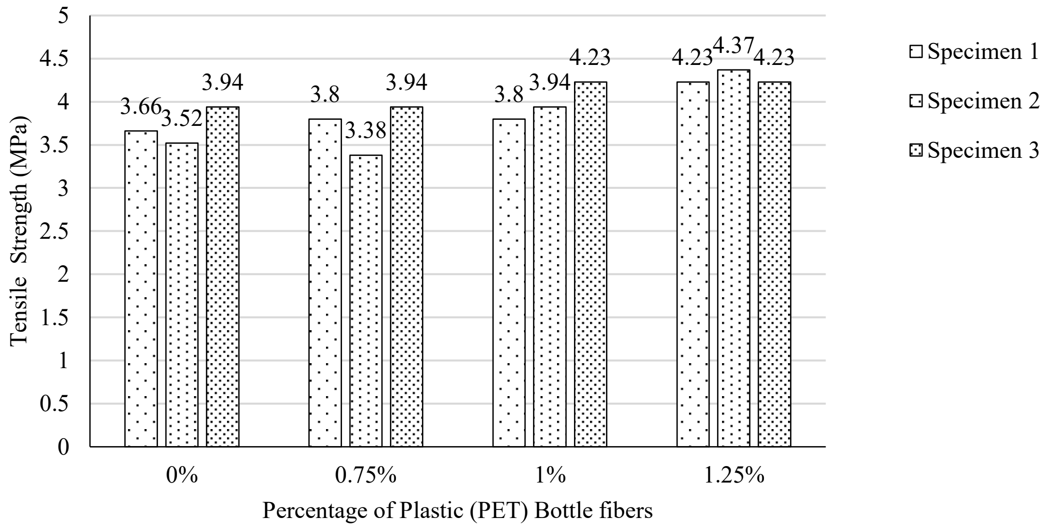

Figure 12. Percentage of PET fibers V/s Tensile strength (MPa).

NDT – Rebound Hammer Test										
Control Mix (0%)	***Direction of Hammer (Plunger)***	***R1***	***R2***	***R3***	***R4***	***R5***	***R_{avg}***	***Comp. Strength (MPa)***	***Avg. NDT Comp. Strength (MPa)***	***Avg. Destructive Comp. Strength (MPa)***
C1	Vertically Down	38	32	32	34	30	33.2	31	32.00	33.92
C2	Vertically Down	38	32	30	36	34	34	32		
C3	Vertically Down	35	36	36	30	35	34.4	33		
P2 Mix (1%)	***Direction of Hammer (Plunger)***	***R1***	***R2***	***R3***	***R4***	***R5***	***R_{avg}***	***Comp. Strength (MPa)***	***Avg. NDT Comp. Strength (MPa)***	***Avg. Destructive Comp. Strength (MPa)***
C1	Vertically Down	35	32	36	36	37	35.2	35	35.33	37.33
C2	Vertically Down	38	34	32	38	36	35.6	36		
C3	Vertically Down	38	32	34	36	36	35.2	35		

Table 7. Rebound hammer test results.

Rebound Hammer Test

From the results in Table 7, it is verified that the surface hardness of the control mix and P2 mix shows that the results of NDT are comparable to the destructive compressive strength of the concrete in both cases. Furthermore, the destructive compressive strength test was performed after the rebound hammer test, which verifies that the procedure for the rebound hammer test was accurate and the results are verified.

Ultrasonic Pulse Velocity Test

As seen in the results, the control mix and P2 mix both show that the quality of the concrete is good, and no issues regarding uniformity or continuity of solid concrete occur. The results in Table 8 verify that the UPV test results are unaffected by the presence of plastic fibres in concrete.

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Table 8. UPV test results.

NDT – Ultrasonic Pulse Velocity Test (Direct Transmission) (L = 150 mm)			
Control Mix (0%)	***Time***	***V = L/T (km/s)***	***Nature of Specimen***
C1	33	4.54	Excellent
C2	35	4.28	Good
C3	36	4.17	Good
P2 Mix (1%)	***Time***	***V = L/T (km/s)***	***Nature of Specimen***
C1	35	4.28	Good
C2	37	4.05	Good
C3	38	3.95	Good

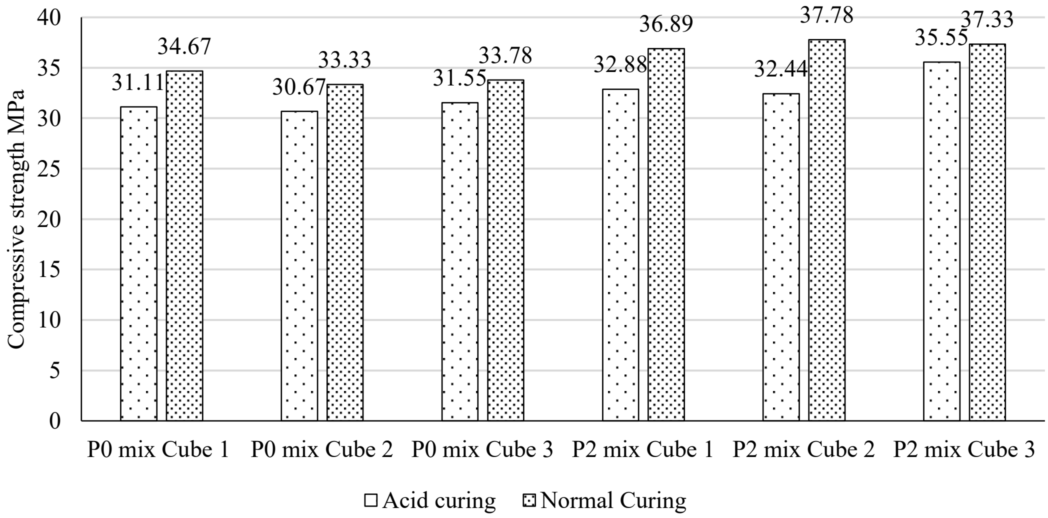

Figure 13. Graphical representation of durability test results.

Durability (Acid Attack) Test

Durability test is performed to check the resistance of concrete against harsh acidic environments, generally in industrial areas. From the results of this specific test in the study, it is seen that the compressive strength of P2 mix decreased by 10 %, while the control mix lost 8.3 % of its compressive strength. Thus, the results show that the performance of both concrete mixes in an acidic environment is comparable, without any drastic changes. Figure 13 shows the results of the durability test.

CONCLUSION

The construction industry's heavy reliance on concrete and cement-based composites has created significant environmental challenges. The current study focuses on the mechanical behavior of concrete when adding waste plastic bottle fibers. This approach aims to reduce the excessive plastic waste that ends up in landfills. This research demonstrates the mechanical impact of waste plastic fibers in concrete. Plastic fibers enhanced the compressive, flexural, and tensile strength of concrete. The most important outcomes of this research are below.

1. The mechanical properties, i.e., the Compressive strength, Flexural strength, and split tensile strength of concrete, are seen to be improved in at least one of the experimental fiber-reinforced concrete mixes by a noticeable change.
1. The optimum percentage of recycled PET plastic fibers added by volume of concrete is found to be in the mix P2, i.e., the 1.00% mix of experimental FRC, as it shows a maximum increase in compressive and flexural strength, acceptable workability, increase in split tensile strength. Also, no instances of honeycombing or segregation were observed. The specimen showed a smooth surface finish and a homogeneous internal matrix.

2. There was no notable additional expense to acquire PET strips in this study, as the waste plastic was collected from hotels and restaurants, further shredded manually, making it a recycled plastic product.
3. The addition of PET strips caused a generalized increase in the discussed strength parameters in P2 mix, at the cost of a loss in slump value, decreasing the workability.
4. The UPV test and rebound hammer test performed on P2 mix verify that after the addition of PET, the behavior of the concrete shows no noticeable change. Rather, these tests verify the performance of the P2 mix against the control mix.
5. The PET strips with the dimensions 50 × 5 × 0.2 mm, when added to M30 concrete in a 1.00 % proportion of volume of concrete, show no degradation or reduction in concrete strength and quality.

Hence, to reduce the volume of PET waste ending up in the landfills, costing large volumes of valuable land taken up by non-biodegradable waste, PET can be added to concrete in general construction, such as road pavements, etc., without compromising the strength of concrete.

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