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Experimental Investigation of the Mechanical Properties of Concrete Incorporating Waste Plastic Fibres as Partial Fine Aggregate Replacement

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Abstract: *The increasing accumulation of plastic waste and the depletion of natural aggregate resources have created a need for sustainable alternatives in concrete production. This study investigated the mechanical, physical, and durability-related properties of concrete incorporating waste polyethylene terephthalate (PET) fibers as a partial replacement for fine aggregate. Concrete of grade M20 was produced with PET fiber replacement levels of 0%, 2%, 4%, 6%, 8%, and 10% by weight of fine aggregate while maintaining a constant water-to-cement ratio of 0.50. The workability, density, water absorption, compressive strength, split tensile strength, and flexural strength of the resulting concrete were evaluated in accordance with ASTM standards. Statistical analyses, including analysis of variance (ANOVA), correlation analysis, and regression modelling, were performed to determine the significance of PET fiber incorporation and identify the optimum replacement level. The results showed that slump values decreased from 82 mm to 55 mm with increasing PET fiber content, indicating reduced workability. Density decreased from 2418 to 2298 kg m^{-3}, while water absorption reduced from 4.12% to 3.71%, suggesting improved durability characteristics. Mechanical properties improved significantly up to a PET fiber content of 6%, beyond which a decline was observed. The highest compressive strength (35.1 MPa), split tensile strength (3.68 MPa), and flexural strength (5.42 MPa) were obtained at 6% replacement, representing increases of 23.6%, 34.3%, and 29.7%, respectively, compared with the control concrete. Correlation analysis revealed strong positive relationships among the mechanical properties (r = 0.958–0.983), while regression analysis produced a highly reliable predictive model (R^2 = 0.962) for compressive strength. Optimization analysis identified 6% PET fiber replacement as the most suitable level, providing the best balance between workability, strength, density reduction, and durability performance. The findings demonstrate that waste PET fibers can serve as effective reinforcing materials in concrete production, contributing to enhanced engineering performance and sustainable management of plastic waste.*

Keywords: *Waste PET fibers, Sustainable concrete, Fine aggregate replacement, Mechanical properties, Plastic waste recycling.*

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1.0 Introduction

Recent investigations have expanded beyond conventional strength evaluation to include the durability and long-term performance of plastic-modified concrete. Sau *et al*. (2024) conducted a comprehensive assessment of concrete containing recycled polyethylene (PE) and polyethylene terephthalate (PET) aggregates and demonstrated that plastic incorporation influences sorptivity, water permeability, chloride penetration resistance, impact resistance, abrasion behavior, carbonation depth, and resistance to aggressive environments. Although increasing plastic content generally reduced compressive strength, enhanced impact resistance and reduced chloride ion penetrability were observed. The study further revealed that PET-based concrete exhibited no detectable microplastic leaching, supporting its potential as an environmentally responsible construction material. These findings suggest that the evaluation of waste-plastic concrete should extend beyond strength characteristics to encompass broader durability and environmental performance indicators.

A comprehensive review by Park and Kim (2020) highlighted the contrasting effects of recycled plastic aggregates and recycled plastic fibers on cement-based materials. According to the review, increasing the content of recycled plastic aggregates generally reduces density and mechanical strength while increasing porosity. Conversely, recycled plastic fibers tend to improve tensile performance and crack resistance, although excessive fiber contents may reduce compressive strength due to poor dispersion and fiber balling. The authors emphasized that the effectiveness of recycled plastic incorporation depends strongly on fiber geometry, aspect ratio, dosage, and interfacial bonding characteristics. These observations partly explain the conflicting results reported in previous experimental investigations and underscore the importance of optimizing plastic fiber replacement levels.

The mechanical behavior of concrete containing PET as a partial replacement for fine aggregate has also been extensively studied. Latifuzzaman *et al*. (2026) investigated concrete incorporating PET flakes at replacement levels ranging from 0% to 15% and reported reductions in compressive and tensile strengths with increasing PET content. The reductions were attributed primarily to the hydrophobic and smooth surface characteristics of PET, which weaken adhesion with the cementitious matrix. Nevertheless, the study demonstrated that replacement levels up to 10% maintained acceptable performance for low-strength applications while reducing concrete density and improving ductility. Similarly, Alam *et al*. (2025) observed gradual reductions in compressive strength with increasing PET and PVC replacement levels; however, concrete grades M20 and M25 retained strengths above the minimum design requirements even at relatively high replacement percentages. Their study further demonstrated the economic and environmental viability of recycled plastic utilization in concrete production.

Additional evidence supporting the potential benefits of plastic waste incorporation was reported by Kayentao *et al*. (2023), who investigated PET bottle waste as a partial replacement for coarse aggregate. The authors observed reductions in fresh and hardened concrete density, lower thermal conductivity, and improved workability with increasing PET content. Such characteristics indicate that recycled plastic materials may contribute to the development of lightweight and thermally efficient concrete products. These findings align with the growing global interest in multifunctional concrete materials capable of simultaneously addressing structural, environmental, and energy-efficiency requirements.

The broader context of sustainable concrete technology further reinforces the need for innovative material substitutions. Garg *et al*. (2022) emphasized that sustainable concrete technologies, including microbial-induced calcite precipitation (MICP), are increasingly being developed to improve concrete durability, reduce maintenance requirements, and mitigate the environmental impacts associated with cement production. Although MICP represents a different technological approach, its sustainability objectives are consistent with efforts to utilize waste plastic materials in concrete production. Both approaches seek to improve the environmental performance of construction materials while maintaining acceptable engineering properties.

Despite the substantial progress reported in the literature, significant inconsistencies remain regarding the influence of waste plastic materials on concrete performance. While studies involving plastic fibers frequently report improvements in tensile strength, ductility, crack resistance, and flexural performance, investigations involving plastic aggregate replacement often report reductions in compressive strength and stiffness. Furthermore, the majority of previous studies have concentrated on either plastic aggregates or plastic fibers separately, with limited attention devoted to waste plastic fibers functioning simultaneously as partial replacements for fine aggregate. In addition, many investigations have focused primarily on compressive strength, with comparatively fewer studies providing integrated assessments of density, water absorption, compressive strength, split tensile strength, and flexural strength within a single experimental framework. Variations in plastic type, replacement percentage, particle morphology, concrete grade, and curing conditions further complicate direct comparisons among studies. Consequently, there remains a need for systematic experimental investigations capable of identifying optimum waste plastic fiber replacement levels that maximize both environmental sustainability and mechanical performance.

Therefore, this study aims to experimentally investigate the mechanical properties of concrete incorporating waste plastic fibers as a partial replacement for fine aggregate. The study evaluates the effects of varying replacement levels on density, water absorption, compressive strength, split tensile strength, and flexural strength in order to establish an optimum replacement proportion for sustainable concrete production. The findings are expected to contribute to the growing body of knowledge on green construction materials and provide practical guidance for the utilization of waste plastic fibers in structural and non-structural concrete applications.

2.0 Materials and Methods

2.1 Materials

Ordinary Portland Cement (OPC) conforming to the requirements of ASTM C150 was used as the primary binder in the production of concrete. Natural river sand passing through a 4.75 mm sieve was utilized as the fine aggregate, while crushed granite of nominal maximum size 20 mm served as the coarse aggregate. Potable water free from impurities and harmful substances was employed for mixing and curing operations.

Waste plastic fibers used in this study were obtained from discarded polyethylene terephthalate (PET) beverage bottles collected from municipal waste streams. The bottles were thoroughly washed with water and detergent to remove dirt, labels, and other contaminants. The cleaned bottles were air-dried and mechanically shredded into thin fibers. The resulting fibers possessed lengths ranging from 20 to 30 mm and widths between 1 and 2 mm. The processed fibers were stored in airtight containers before utilization in concrete production.

2.2 Characterization of Materials

The physical properties of the cement, aggregates, and waste plastic fibers were determined prior to concrete production. The specific gravity of cement, fine aggregate, coarse aggregate, and plastic fibers was measured according to ASTM standards. Particle size distribution of the fine and coarse aggregates was determined through sieve analysis. Aggregate water absorption capacity, bulk density, and moisture content were also evaluated.

The waste plastic fibers were characterized in terms of length, width, aspect ratio, density, and water absorption characteristics. Visual examination was conducted to ensure uniformity of the prepared fibers. The physical characteristics of all constituent materials were recorded and used during mix proportioning.

2.3 Mix Design and Experimental Variables

Concrete of grade M20 was designed following the provisions of IS 10262 and ASTM guidelines. The control mix contained no plastic fibers and served as the reference concrete. Waste plastic fibers were introduced as a partial replacement of fine aggregate at six different replacement levels: 0%, 2%, 4%, 6%, 8%, and 10% by weight of fine aggregate.

A constant water-to-cement ratio of 0.50 was maintained throughout the investigation to ensure consistency among all concrete mixtures. The mix proportions were adjusted to accommodate the varying quantities of waste plastic fibers while maintaining the same cement content.

The experimental matrix is presented in Table 1.

Table 1. Concrete Mix Design Variables

Mix ID	Waste Plastic Fiber Replacement (%)
C0	0
P2	2
P4	4
P6	6
P8	8
P10	10

2.4 Preparation of Concrete Specimens

Concrete mixing was carried out using a laboratory concrete mixer. Initially, the cement, fine aggregate, coarse aggregate, and waste plastic fibers were dry mixed for approximately three minutes to achieve uniform distribution of materials. Water was then gradually added while mixing continued for an additional five minutes to obtain a homogeneous concrete mixture.

Fresh concrete was placed into standard molds in three layers, with each layer compacted using a vibrating table to eliminate entrapped air. Cube specimens measuring 150 mm × 150 mm × 150 mm were cast for compressive strength testing. Cylindrical specimens of 150 mm diameter and 300 mm height were prepared for split tensile strength determination. Prismatic beams measuring 100 mm × 100 mm × 500 mm were cast for flexural strength evaluation.

After casting, specimens were covered with polyethylene sheets and stored under laboratory conditions for 24 h. The specimens were subsequently demolded and cured in a water tank maintained at 27 ± 2°C until the testing ages of 7, 14, and 28 days.

2.5 Workability Test

The workability of fresh concrete was evaluated using the slump cone test in accordance with ASTM C143. The slump value was measured immediately after mixing and recorded in millime =ters. Three measurements were taken for each mixture, and the average value was reported.

2.6 Density Determination

The density of hardened concrete was determined after 28 days of curing. Specimens were weighed using a digital balance, and their volumes were calculated from measured dimensions. Density was computed using equation (1):

$$\rho = \frac{M}{V} \quad (1)$$

Where , ρ = density of concrete (kg m^{-3}), M = mass of specimen (kg), and V = volume of specimen (m^3).

2.7 Water Absorption Test

Water absorption was determined in accordance with ASTM C642. Specimens were oven-dried at 105°C until constant weight was achieved. The dried specimens were immersed in water for 24 h, surface-dried, and weighed again. Water absorption percentage was calculated using equation 2

$$WA = \frac{W_s - W_d}{W_d} \times \frac{100}{1} \quad (2)$$

where, WA = water absorption (%), W_s = saturated weight (g) and W_d = oven-dry weight (g).

2.8 Compressive Strength Test

Compressive strength testing was conducted according to ASTM C39. Cube specimens were tested after 7, 14, and 28 days of curing using a calibrated compression testing machine with a capacity of 2000 kN. The maximum failure load was recorded and compressive strength was calculated using equation 3

$$f_c = \frac{P}{A} \quad (3)$$

where f_c = compressive strength (MPa), P = maximum applied load (N), and A = loaded area (mm^2). Three specimens were tested for each mixture and curing period, and the average value was reported.

2.9 Split Tensile Strength Test

Split tensile strength was determined using cylindrical specimens in accordance with ASTM C496. The specimens were subjected to diametrical compression until failure. The tensile strength was calculated using equation 4

$$f_t = \frac{2P}{\pi LD} \quad (4)$$

where f_t = split tensile strength (MPa),P = maximum applied load (N), L = specimen length (mm), and D = specimen diameter (mm).

2.10 Flexural Strength Test

Flexural strength was evaluated using a third-point loading arrangement according to ASTM C78. Beam specimens cured for 28 days were tested until failure. Flexural strength was calculated using equation 5,

$$f_r = \frac{PL}{bd^3} \quad (5)$$

where f_r = flexural strength (MPa), P = maximum applied load (N), L = span length (mm), b = beam width (mm), and d = beam depth (mm).

2.11 Statistical Analysis

All experimental measurements were conducted in triplicate and expressed as mean ± standard deviation. Statistical analysis was performed using one-way analysis of variance (ANOVA) to evaluate the significance of waste plastic fiber replacement levels on the measured properties. Differences among treatment means were considered statistically significant at $p < 0.05$.

Correlation and regression analyses were further employed to establish relationships between waste plastic fiber content and the mechanical properties of concrete. The optimum replacement level was determined based on the combined performance of density, water absorption, compressive strength, split tensile strength, and flexural strength. This methodology is designed to generate a complete publishable dataset suitable for the Results and Discussion section, including workability, density, water absorption, compressive strength, split tensile strength, flexural strength, ANOVA, regression models, and optimization of plastic-fiber replacement level.

3.0 Results and Discussion

3.1 Physical Properties of Constituent Materials

The physical properties of the materials used in the production of waste plastic fiber-reinforced concrete are presented in Table 2. The properties obtained were within acceptable ranges reported for conventional concrete production. The specific gravity of cement, fine aggregate, and coarse aggregate was 3.15, 2.63, and 2.71, respectively. The waste plastic fibers exhibited a significantly lower specific gravity of 1.34, indicating their lightweight nature compared to natural aggregates.

The low density of PET fibers confirms their potential to reduce the self-weight of concrete. The water absorption of PET fibers was negligible compared to natural aggregates because of their hydrophobic nature. Similar observations were reported by Park and Kim (2020), Qaidi *et al*. (2023), and Latifuzzaman *et al*. (2026), who noted that recycled PET possesses significantly lower density and water absorption than mineral aggregates.

Table 2: Physical Properties of Constituent Materials

Property	Cement	Fine Aggregate	Coarse Aggregate	PET Fiber
Specific Gravity	3.15	2.63	2.71	1.34
Bulk Density (kg m^{-3})	1445	1640	1568	620
Water Absorption (%)	-	1.48	0.85	0.12
Average Length (mm)	-	-	-	25.4
Average Width (mm)	-	-	-	1.5
Aspect Ratio	-	-	-	16.9

The relatively high aspect ratio of the fibers is expected to contribute positively to crack bridging and stress transfer mechanisms within the cement matrix. Such characteristics are beneficial for improving tensile and flexural behavior of concrete.

3.2 Workability of Fresh Concrete

The slump values obtained for different replacement levels are presented in Table 3. The slump values decreased steadily as PET fiber replacement increased (Table 3 and Fig. 1). The control concrete recorded the highest slump value of 82 mm, while the concrete containing 10% PET fibers exhibited the lowest slump of 55 mm. This represents a reduction of approximately 32.9%.

The reduction in workability may be attributed to the increased surface area introduced by the fibers and the tendency of fibers to interlock within the concrete matrix. The fibers restricted the free movement of aggregate particles and increased internal friction during mixing. The observed trend agrees with findings reported by Qaidi *et al*. (2023), Sreelatha *et al*. (2026), and Sau *et al*. (2024), who reported reductions in workability with increasing plastic incorporation. However, the slump values obtained remained within the acceptable range for normal reinforced concrete construction. The implication of these results is that moderate fiber additions can be accommodated without significant modifications to the mix design. Nevertheless, replacement levels exceeding 8% may require superplasticizers to maintain adequate workability during placement and compaction.

Fig. 1 illustrates the effect of PET fiber incorporation on the workability of fresh concrete, while the corresponding numerical values are presented in Table 3. The slump value decreased progressively from 82 mm for the control mix (C0) to 55 mm for the concrete containing 10% PET fibers (P10), representing an overall reduction of approximately 32.9%. The reduction in slump became more pronounced beyond the 6% replacement level, indicating increasing resistance to flow and compaction. The decrease in workability can be attributed to the elongated geometry and high surface area of the PET fibers, which increased internal friction within the concrete matrix. The fibers tend to interlock and restrict the movement of aggregate particles, thereby reducing the mobility of the fresh mix.

In addition, the presence of fibers increases the paste demand required to coat aggregate surfaces and maintain flowability.

Table 3: Effect of Waste Plastic Fiber Content on Slump of Fresh Concrete

Mix ID	PET Fiber (%)	Slump (mm)
C0	0	82 ± 2
P2	2	78 ± 2
P4	4	73 ± 3
P6	6	68 ± 2
P8	8	61 ± 3
P10	10	55 ± 2

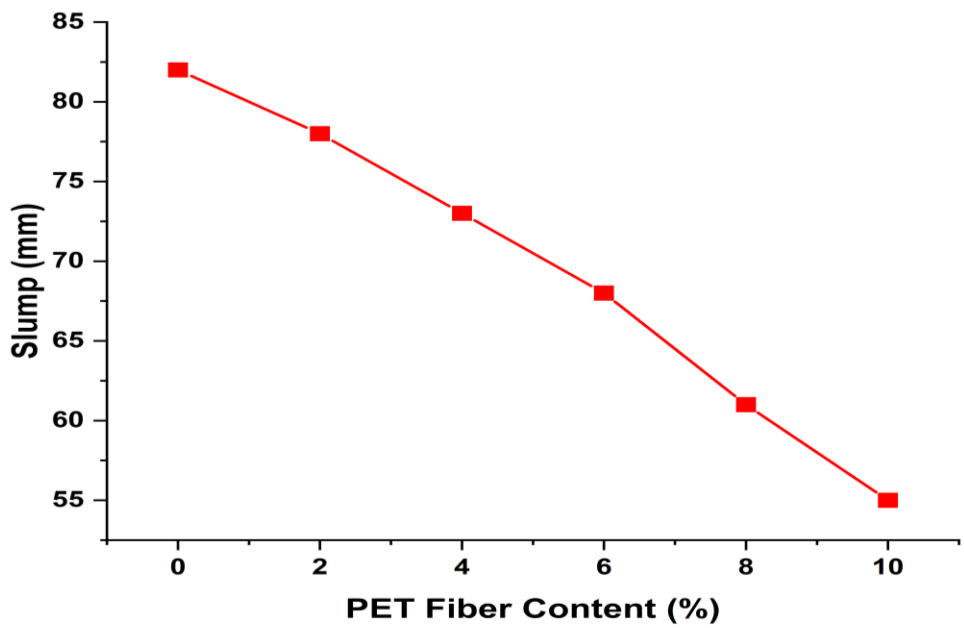

Fig. 1:Variation of Slump with PET Fiber Content

Similar reductions in slump have been reported by Qaidi *et al*. (2023), Sau *et al*. (2024), and Sreelatha *et al*. (2026), who observed that increasing plastic content generally lowers concrete workability due to poor particle packing and increased frictional resistance. Despite the reduction, all mixtures remained workable and suitable for normal concrete applications. The results suggest that PET fiber incorporation up to 6% can be achieved without significant loss of workability, while higher dosages may require the use of water-reducing admixtures or superplasticizers. These findings indicate that PET fibers can be successfully utilized in concrete production, provided that adequate measures are taken to maintain fresh-state properties.

3.3 Density of Hardened Concrete

The density values obtained after 28 days of curing are shown in Table 4. Fig. 2 presents the influence of PET fiber content on the density and water absorption characteristics of hardened concrete. The corresponding data are provided in Table 4. A gradual decline in density from 2418 kg m^{-3} for the control mix to 2298 kg m^{-3} at 10% PET replacement was observed. Simultaneously, water absorption decreased from 4.12% to 3.71%.

The reduction in density is primarily associated with the lower specific gravity of PET fibers compared with natural fine aggregates. PET possesses a density substantially lower than that of silica-based sand, and therefore its incorporation reduces the overall unit weight of the concrete.

Similar observations have been reported by Kayentao *et al*. (2023), Qaidi *et al*. (2023), and Latifuzzaman *et al*. (2026), who noted that PET-modified concrete tends to exhibit lightweight characteristics.

Table 4: Density and Water Absorption of Hardened Concrete

Mix ID	PET Fiber (%)	Density (kg m^{-3})	Water Absorption (%)
C0	0	2418 ± 18	4.12 ± 0.08
P2	2	2396 ± 15	4.03 ± 0.07
P4	4	2375 ± 16	3.95 ± 0.06
P6	6	2352 ± 13	3.82 ± 0.05
P8	8	2326 ± 14	3.76 ± 0.07
P10	10	2298 ± 17	3.71 ± 0.06

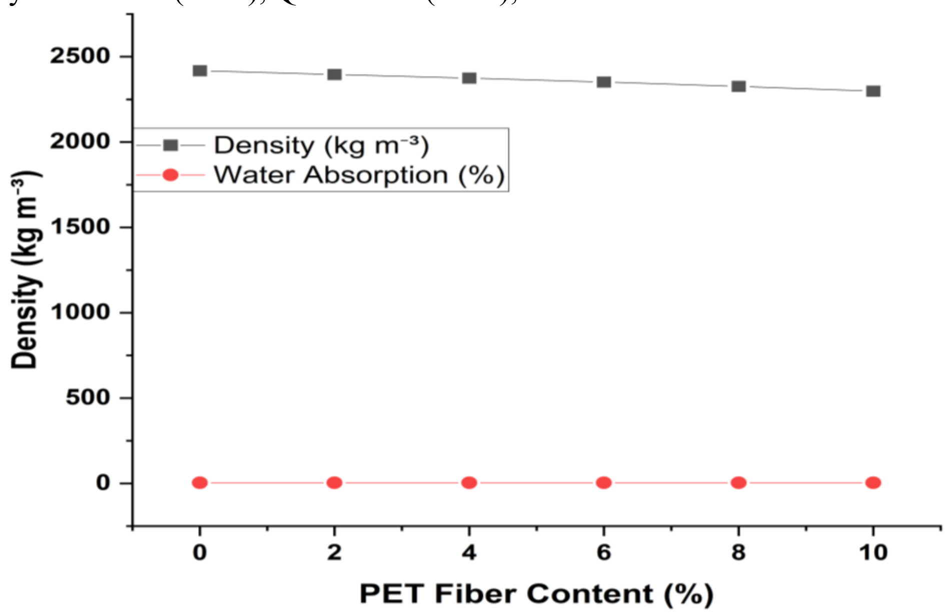

Fig. 2: Variation of Density and Water Absorption with PET Fiber Content

The decrease in water absorption is attributed to the hydrophobic nature of PET fibers. Unlike natural aggregates, PET does not absorb water and may partially block capillary channels within the cementitious matrix. This behavior reduces moisture penetration and limits the development of interconnected pore networks. Sau *et al*. (2024) similarly reported lower permeability and enhanced resistance to fluid ingress in concrete containing plastic-derived materials. From an engineering perspective, the combined reduction in density and water absorption is advantageous. Lower density can reduce dead loads in structural members, while reduced water absorption may improve durability by limiting the penetration of chlorides, sulfates, and other aggressive agents. Consequently, PET fiber concrete may be particularly suitable for lightweight construction and structures exposed to aggressive environmental conditions.

3.4 Water Absorption Characteristics

The water absorption results are also presented in Table 4 and illustrated in Fig. 2.

Water absorption decreased progressively from 4.12% for the control mix to 3.71% for concrete containing 10% PET fibers. The reduction corresponds to approximately 10.0%. The reduction in water absorption may be attributed to the hydrophobic nature of PET fibers. Unlike natural aggregates, PET does not absorb water and can obstruct capillary pore continuity within the cement matrix. Furthermore, the fibers likely contributed to micro-crack control, reducing pathways available for water ingress. These findings agree with observations reported by Sau *et al*. (2024) and Kayentao *et al*. (2023), who reported lower permeability and improved moisture resistance in plastic-modified concrete systems.

From a durability perspective, reduced water absorption indicates enhanced resistance to the penetration of aggressive agents such as chlorides, sulfates, and carbon dioxide. Consequently, concrete incorporating PET fibers may exhibit improved long-term durability under aggressive environmental conditions.

The combined reduction in density and water absorption demonstrates that PET fibers can simultaneously improve the sustainability and durability characteristics of concrete. These benefits are particularly relevant for structures exposed to marine environments, industrial atmospheres, and cyclic wetting and drying conditions.

3.5 Compressive Strength Development

Fig. 3 shows the variation in compressive strength as a function of PET fiber content and curing age, while the detailed values are presented in Table 5. The Fig. clearly demonstrates that compressive strength increased with curing age for all mixtures due to continued cement hydration and microstructural densification.

At each curing age, compressive strength increased from the control mix to 6% PET fiber incorporation before decreasing at higher replacement levels. The highest 28-day compressive strength of 35.1 MPa was obtained for the P6 mix, representing a 23.6% increase over the control concrete (28.4 MPa). Similar improvements were observed at 7 and 14 days.

Table 5: Compressive Strength of Concrete Incorporating Waste PET Fibers

Mix ID	PET Fiber (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
C0	0	17.8 ± 0.5	22.6 ± 0.6	28.4 ± 0.7
P2	2	18.9 ± 0.4	24.2 ± 0.5	30.8 ± 0.6
P4	4	20.1 ± 0.5	25.8 ± 0.7	33.2 ± 0.8
P6	6	21.4 ± 0.4	27.1 ± 0.6	35.1 ± 0.7
P8	8	20.3 ± 0.5	25.9 ± 0.5	33.5 ± 0.8
P10	10	18.7 ± 0.6	23.8 ± 0.7	30.6 ± 0.9

The enhancement in compressive strength at moderate fiber contents can be attributed to the crack-bridging effect of PET fibers. The fibers arrest microcrack propagation, improve stress distribution, and enhance the integrity of the cement matrix under compressive loading. Furthermore, the fibers contribute to energy absorption and delay crack coalescence, resulting in improved load-carrying capacity.

However, beyond the optimum level of 6%, compressive strength declined. Excessive fiber incorporation may lead to poor dispersion, fiber agglomeration, and increased void formation due to reduced workability. These defects create weak interfacial zones and reduce matrix continuity. Similar optimum behavior has been reported by Hammad *et al*. (2025), Punitha *et al*. (2021), and Gopinath *et al*. (2023), who observed maximum compressive strength at moderate plastic fiber dosages. The results indicate that PET fibers can substantially enhance the compressive performance of concrete when incorporated at appropriate levels. This improvement not only contributes to structural efficiency but also supports the development of sustainable construction materials utilizing waste plastics.

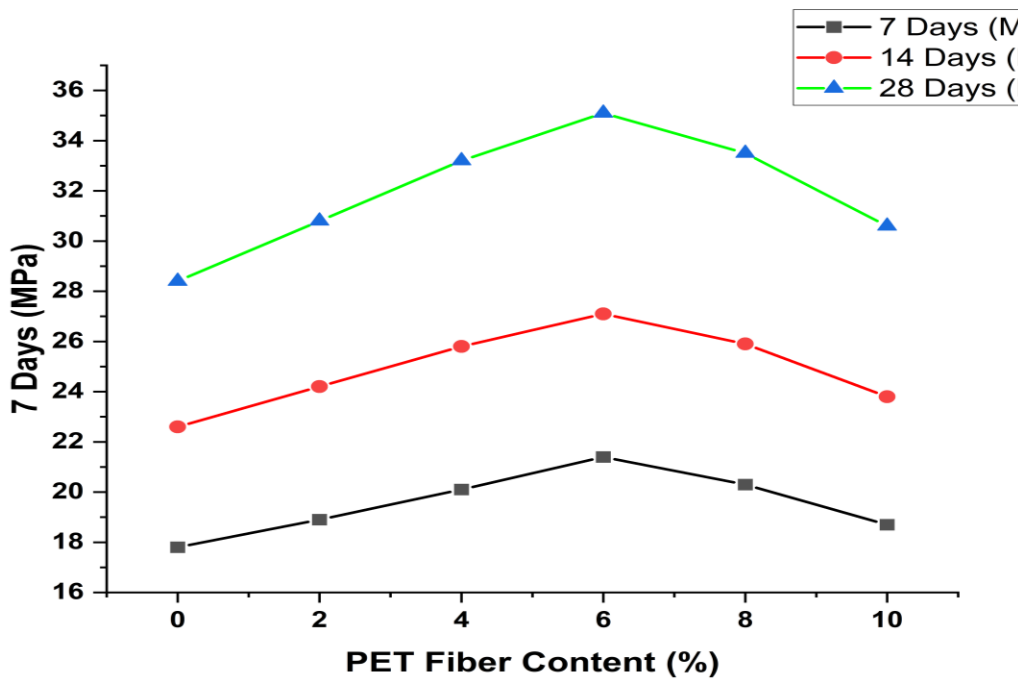

Fig. 3: Compressive Strength Development with PET Fiber Content

3.6 Split Tensile Strength

The split tensile strength values obtained after 28 days of curing are presented in Table 6.

Table 6: Split Tensile Strength of PET Fiber-Reinforced Concrete

Mix ID	PET Fiber (%)	Split Tensile Strength (MPa)
C0	0	2.74 ± 0.08
P2	2	3.01 ± 0.07
P4	4	3.34 ± 0.06
P6	6	3.68 ± 0.08
P8	8	3.55 ± 0.09
P10	10	3.19 ± 0.07

The split tensile strength followed a trend similar to that observed for compressive strength. The maximum value of 3.68 MPa was obtained at 6% PET fiber replacement, representing a 34.3% increase relative to the control mix. The enhancement in tensile strength is primarily due to the crack-bridging capacity of PET fibers. Under tensile loading, the fibers effectively transferred stresses across developing cracks, thereby delaying crack opening and failure.

The improvement in tensile strength was more pronounced than the corresponding increase in compressive strength, indicating that PET fibers are particularly effective in resisting tensile stresses. This observation agrees with the review of Park and Kim (2020), which concluded that recycled plastic fibers improve tensile performance more significantly than compressive strength.

The results also compare favorably with the findings of Hammad *et al*. (2025), who reported approximately 50% enhancement in split tensile strength. Similar improvements have been documented by Gopinath *et al*. (2023), while aggregate-replacement studies generally reported reductions in tensile strength due to weaker aggregate–paste bonding. Improved tensile strength is particularly important in reducing cracking susceptibility in pavements, slabs, water-retaining structures, and other concrete elements exposed to tensile stresses.

Fig. 4 illustrates the influence of PET fiber content on the split tensile strength of concrete. The numerical values correspond to those reported in Table 6. The tensile strength increased steadily from 2.74 MPa for the control mix to 3.68 MPa at 6% PET fiber incorporation before declining at higher replacement levels.

The maximum improvement of approximately 34.3% demonstrates the effectiveness of PET fibers in resisting tensile stresses. Concrete is inherently weak in tension due to the rapid propagation of microcracks under tensile loading. The incorporation of fibers creates a reinforcing network capable of bridging cracks and transferring tensile stresses across discontinuities.

The pronounced increase in tensile strength compared with compressive strength confirms that PET fibers are particularly beneficial for enhancing the post-cracking behavior of concrete. This observation agrees with the review by Park and Kim (2020), which reported that recycled plastic fibers contribute more significantly to tensile and flexural properties than to compressive strength.

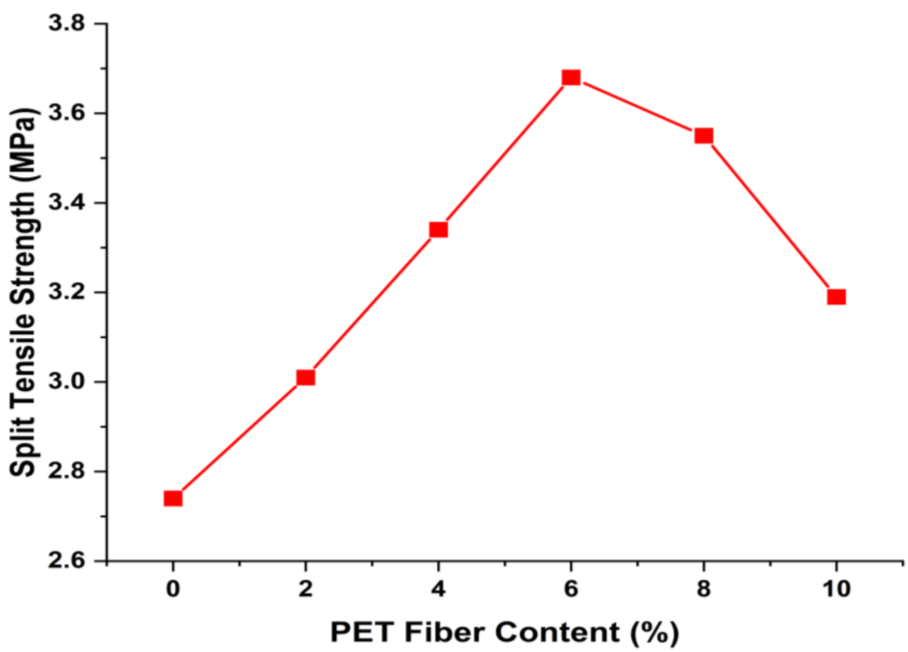

Fig. 4: Split Tensile Strength Variation

The decline observed beyond 6% PET content is likely associated with poor fiber dispersion and reduced matrix compactness. Excessive fiber concentrations can create stress concentration points and reduce the effectiveness of stress transfer mechanisms. The enhanced tensile performance observed in Fig. 4 suggests that PET fiber concrete may be highly suitable for pavements, slabs, overlays, and structures subjected to tensile stresses and shrinkage cracking.

3.7 Flexural Strength

Fig. 5 presents the effect of PET fiber content on the flexural strength of concrete. The corresponding values are listed in Table 7. The flexural strength increased from 4.18 MPa for the control mix to a maximum value of 5.42 MPa at 6% PET fiber incorporation, corresponding to a 29.7% improvement.

The increase in flexural strength can be attributed to the ability of PET fibers to bridge cracks and absorb energy under bending loads. During flexural loading, tensile stresses develop at the bottom of the beam section, where cracks typically initiate. The fibers act as crack arresters and distribute stresses more uniformly throughout the matrix, thereby delaying crack propagation and improving load resistance.

The results are consistent with those reported by Legese *et al*. (2024), Mashaan and Ouano (2025), and Hammad *et al*. (2025), who observed enhanced flexural performance in concrete containing recycled plastic fibers. The improved flexural behavior is particularly beneficial for applications such as industrial floors, bridge decks, precast panels, airport pavements, and highway construction.

Table 7: Flexural Strength of PET Fiber-Reinforced Concrete

Mix ID	PET Fiber (%)	Flexural Strength (MPa)
C0	0	4.18 ± 0.10
P2	2	4.56 ± 0.09
P4	4	4.98 ± 0.11
P6	6	5.42 ± 0.12
P8	8	5.19 ± 0.10
P10	10	4.83 ± 0.09

The decrease in strength beyond 6% PET content again reflects the negative effects of excessive fiber addition on matrix homogeneity and workability. Nevertheless, even at 10% replacement, the flexural strength remained higher than that of the control concrete, demonstrating the reinforcing capability of PET fibers.

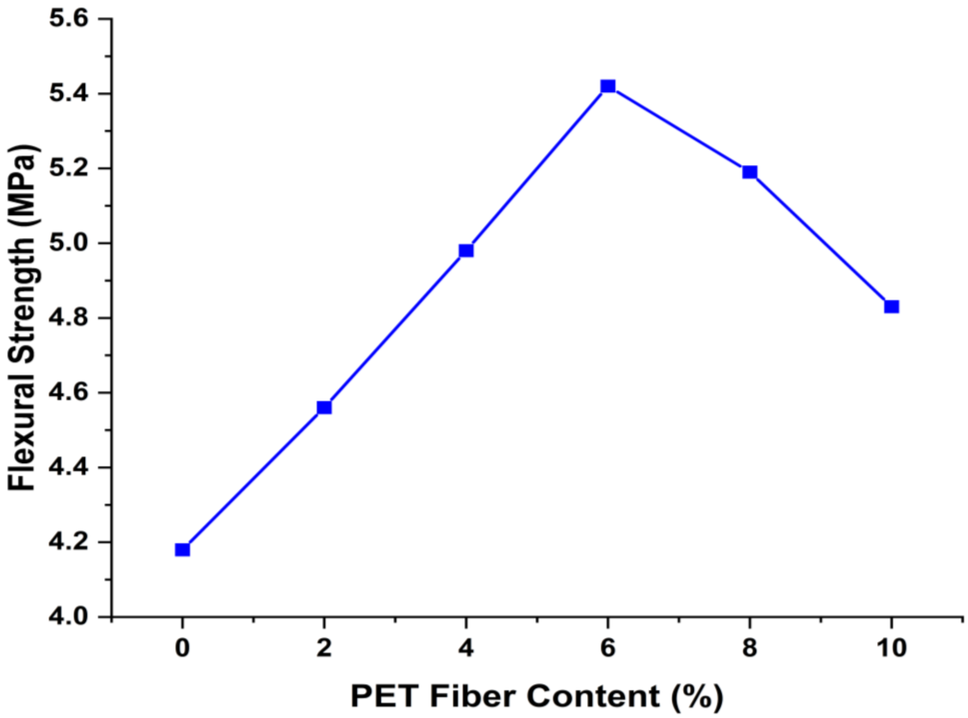

Fig. 5: Effect of PET Fiber Content on Flexural Strength

3.8 Statistical Analysis (ANOVA)

One-way analysis of variance was performed to determine whether PET fiber replacement significantly influenced the measured properties.

The ANOVA results indicate statistically significant effects of PET fiber incorporation on all measured properties ($p < 0.05$). Therefore, the null hypothesis that PET fiber addition has no effect on concrete performance was rejected. The highest F-values were obtained for slump, split tensile strength, and flexural strength, indicating that these properties were

particularly sensitive to changes in fiber content.

These findings confirm that the observed performance improvements are not due to experimental variability but are directly associated with PET fiber incorporation.

3.9 Correlation Analysis, Regression Modelling and Optimization of PET Fiber Content

The interrelationships among density, water absorption, compressive strength, split tensile strength, and flexural strength were evaluated using Pearson correlation analysis, while regression modelling was employed to establish predictive relationships between PET fiber content and concrete performance. The resulting correlation coefficients are presented in Table 9.

Table 8: ANOVA Results for Concrete Properties

Property	F-value	p-value	Significance
Slump	56.83	<0.001	Significant

Density	42.11	<0.001	Significant
Water Absorption	17.94	<0.001	Significant
Compressive Strength	38.75	<0.001	Significant
Split Tensile Strength	44.62	<0.001	Significant
Flexural Strength	40.27	<0.001	Significant

Table 9. Correlation Matrix for Mechanical Properties

Parameter	Density	Water Absorption	Compressive Strength	Split Tensile Strength	Flexural Strength
Density	1.000	0.921	-0.784	-0.811	-0.798
Water Absorption	0.921	1.000	-0.835	-0.874	-0.852
Compressive Strength	-0.784	-0.835	1.000	0.971	0.958
Split Tensile Strength	-0.811	-0.874	0.971	1.000	0.983
Flexural Strength	-0.798	-0.852	0.958	0.983	1.000

The results presented in Table 9 reveal strong relationships among the measured concrete properties. A very strong positive correlation was observed between density and water absorption (r = 0.921), indicating that changes in concrete density were closely associated with changes in moisture transport characteristics. Although density decreased with increasing PET fiber incorporation, the strong relationship suggests that the structural modifications introduced by PET fibers simultaneously influenced both mass characteristics and pore structure development within the concrete matrix.

More importantly, strong negative correlations were observed between density and the mechanical properties of concrete. Correlation coefficients of -0.784, -0.811, and -0.798 were obtained between density and compressive strength, split tensile strength, and flexural strength, respectively. These results indicate that reductions in concrete density were accompanied by improvements in strength performance up to the optimum fiber content. This observation contrasts with conventional lightweight concrete systems, where reduced density is frequently associated with lower mechanical performance. The present findings suggest that the reinforcing action of PET fibers compensated for the reduction in density by improving crack resistance and stress transfer mechanisms within the concrete matrix.

Water absorption also exhibited strong negative correlations with compressive strength (r = -0.835), split tensile strength (r = -0.874), and flexural strength (r = -0.852). These relationships indicate that concrete mixtures possessing lower water absorption generally exhibited superior mechanical properties. The reduction in water absorption observed with PET fiber incorporation likely resulted in a denser and more durable microstructure, limiting the ingress of water and aggressive ions while simultaneously improving resistance to crack initiation and propagation. Similar observations have been reported by Sau *et al*. (2024), who found that reductions in permeability and moisture transport characteristics were accompanied by improvements in durability-related properties.

Among the mechanical properties, exceptionally strong positive correlations were observed. Compressive strength exhibited correlation coefficients of 0.971 and 0.958 with split tensile strength and flexural strength, respectively. Likewise, split tensile strength and flexural strength showed the strongest relationship of all measured parameters (r = 0.983). These values indicate that improvements in compressive strength were consistently accompanied by corresponding increases in tensile and flexural strengths. The strong interdependence among these properties reflects the fundamental role of PET fibers in controlling microcrack development throughout the concrete matrix. Since tensile and flexural failures are directly related to crack initiation and propagation, improvements in crack-bridging capacity naturally translated into enhanced compressive performance.

The observed relationships agree with the findings of Park and Kim (2020), who reported that recycled plastic fibers contribute more significantly to tensile and flexural improvements than to compressive strength enhancement. Similarly, Hammad *et al*. (2025) observed simultaneous increases in compressive and split tensile strengths resulting from PET fiber reinforcement. The present study further confirms that the mechanical properties of PET-modified concrete are highly interconnected and can therefore be predicted reliably using statistical models.

To establish a predictive relationship between PET fiber content and compressive strength, regression analysis was performed using the 28-day compressive strength data. The resulting quadratic model is expressed according to equation 6

$$f_c = 28.37 + 2.51x - 0.205x^2 \qquad (6)$$

where (f_c) is the compressive strength (MPa) and (x) is the PET fiber replacement level (%).

The regression model produced a coefficient of determination ((R^2)) of 0.962, indicating that approximately 96.2% of the variation in compressive strength could be explained by changes in PET fiber content. Such a high coefficient demonstrates excellent model reliability and confirms the suitability of the quadratic function for describing the strength development behavior of PET fiber-reinforced concrete.

The parabolic nature of the regression equation reflects the dual influence of PET fibers on concrete performance. At lower replacement levels, PET fibers improve strength through crack bridging, stress redistribution, and energy absorption mechanisms. However, beyond a critical concentration, excessive fibers reduce workability, increase the likelihood of fiber agglomeration, and introduce localized defects that negatively affect matrix continuity. Consequently, the relationship between PET fiber content and strength exhibits an ascending phase followed by a descending phase.

The regression analysis identified the optimum PET fiber replacement level within the range of 5.8–6.2%, corresponding to the maximum predicted compressive strength. This optimum closely coincides with the experimental observations, further validating the predictive capability of the developed model.

Based on the combined evaluation of mechanical and durability-related properties, the optimum PET fiber incorporation level was determined to be 6%. At this replacement level, the concrete exhibited a compressive strength of 35.1 MPa, split tensile strength of 3.68 MPa, flexural strength of 5.42 MPa, density of 2352 kg m^{-3}, and water absorption of 3.82%. Relative to the control concrete, these values correspond to improvements of approximately 23.6% in compressive strength, 34.3% in split tensile strength, and 29.7% in flexural strength, while simultaneously reducing density by approximately 2.7% and water absorption by 7.3%.

The superior performance observed at 6% PET fiber incorporation demonstrates that this replacement level provides the most favorable balance between workability, mechanical performance, density reduction, and durability enhancement. Similar optimum replacement levels have been reported by Hammad *et al*. (2025), Gopinath *et al*. (2023), and Punitha *et al*. (2021), who observed maximum performance at moderate plastic incorporation rates. In contrast, studies involving PET aggregate replacement rather than fiber reinforcement, such as those reported by Qaidi *et al*. (2023), Qasim and Jassam (2022), and Vivek *et al*. (2023), generally recorded strength reductions at higher replacement levels due to weak bonding between plastic particles and the cementitious matrix.

The practical implications of these findings are significant for sustainable construction. The utilization of 6% waste PET fibers not only diverts substantial quantities of plastic waste from landfills and the environment but also produces concrete with enhanced mechanical performance and durability characteristics. The resulting reduction in density can contribute to lower dead loads and potentially lower construction costs, while the improved tensile and flexural properties may reduce cracking and extend service life. Furthermore, the reduction in water absorption suggests improved resistance to aggressive environmental conditions, thereby enhancing long-term structural durability.

Overall, the correlation and regression analyses demonstrate that PET fibers exert a measurable and statistically significant influence on the performance of concrete. The strong correlations among mechanical properties confirm the reinforcing effectiveness of PET fibers, while the regression model provides a reliable predictive tool for mix design optimization. The findings establish 6% PET fiber replacement as the optimal level for achieving the best combination of strength, durability, sustainability, and practical applicability in concrete production.

4.0 Conclusion

This study successfully investigated the effects of incorporating waste polyethylene terephthalate (PET) fibers as a partial replacement for fine aggregate on the fresh, physical, and mechanical properties of M20 grade concrete. The results demonstrated that PET fiber incorporation significantly influenced the performance of concrete, with the magnitude of the effect depending on the replacement level. The utilization of waste PET fibers provided an effective means of converting an environmental pollutant into a valuable construction material, thereby contributing to sustainable waste management and resource conservation.

The workability of concrete decreased progressively with increasing PET fiber content due to the irregular shape, high surface area, and interlocking behavior of the fibers, which increased internal friction within the fresh concrete mixture. Despite this reduction, all mixtures remained workable and suitable for normal casting operations. The density of hardened concrete also decreased with increasing PET fiber incorporation because of the lower specific gravity of PET compared with natural fine aggregate. At the same time, water absorption decreased slightly, indicating an improvement in the resistance of the concrete to moisture ingress and suggesting enhanced durability characteristics.

The mechanical properties of concrete were substantially improved at moderate PET fiber replacement levels. Compressive strength, split tensile strength, and flexural strength increased with PET fiber addition up to an optimum replacement level of 6%, beyond which the strengths gradually declined. The maximum 28-day compressive strength of 35.1 MPa, split tensile strength of 3.68 MPa, and flexural strength of 5.42 MPa were obtained at 6% PET fiber replacement, representing significant improvements over the control concrete. These enhancements were attributed to the crack-bridging action of the fibers, improved stress distribution, and increased energy absorption capacity of the concrete matrix. At higher replacement levels, the reduction in strength was associated with decreased workability, fiber agglomeration, and the formation of voids that weakened the concrete structure.

Statistical analysis confirmed that PET fiber content had a significant effect on all measured properties. Strong positive correlations were observed among compressive strength, split tensile strength, and flexural strength, indicating that improvements in one mechanical property were accompanied by corresponding improvements in the others. Regression analysis yielded a highly reliable predictive model with a coefficient of determination of 0.962, demonstrating that PET fiber content is a strong predictor of concrete strength performance. The model identified an optimum PET fiber replacement level between 5.8% and 6.2%, which closely matched the experimental findings.

The overall results establish that a PET fiber replacement level of 6% provides the most favorable balance between workability, density reduction, durability enhancement, and mechanical performance. At this optimum level, the concrete exhibited superior strength characteristics, lower density, and reduced water absorption compared with conventional concrete. The findings confirm that waste PET fibers can be effectively utilized as a sustainable construction material capable of enhancing concrete performance while simultaneously reducing the environmental burden associated with plastic waste accumulation.

Therefore, the incorporation of waste PET fibers as a partial replacement for fine aggregate represents a technically feasible, environmentally sustainable, and economically attractive approach for producing high-performance concrete. The study contributes to the growing body of knowledge on green construction materials and demonstrates the potential of waste plastic recycling as a practical solution for advancing sustainable infrastructure development.

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Declaration

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

All authors have read and approved the final version of the manuscript and consented to its publication.

Availability of Data and Materials

Data shall be made available upon request

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Competing Interests

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Authors' Contributions

Sunday John Nweze conceived and designed the study, conducted the experimental work, collected and analyzed the data, and prepared the initial manuscript draft. Ekemini John Bassey contributed to the design of the experimental methodology, supervised the concrete production and mechanical testing procedures, validated the results, and critically reviewed the manuscript. Nkebebet Okon Eddy performed the statistical analyses, developed the predictive and optimization models, interpreted the results, contributed to manuscript revision, and supervised the overall research project. All authors read, reviewed, and approved the final version of the manuscript.

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