

Experimental Study on Mechanical, Durability and Crack Resistance Properties of High-Strength Concrete Made with Surface-Treated Waste PET Fibers

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Abstract

The accumulation of polyethylene terephthalate (PET) bottle waste continues to grow because of the non-biodegradable nature of the polymer and the limited capacity of conventional disposal routes to process it. This study evaluates the mechanical performance of M50 grade high-strength concrete in which 10% of ordinary Portland cement (OPC 53 grade) was replaced with silica fume and natural fine aggregate was partially replaced with waste PET fibers, both in untreated and cement-silica fume slurry surface-treated form. Five mixes were cast: a control mix without fibers, three mixes containing untreated PET fibers at 0.50%, 0.75% and 1.00% by weight of fine aggregate, and one mix containing 0.75% surface-treated PET fibers. Compressive strength, split tensile strength and flexural strength were determined at 7, 14 and 28 days, and fresh concrete workability was measured using the slump cone test. Among the untreated mixes, the 0.75% dosage gave the best 28-day results (58.31 MPa compressive, 4.41 MPa split tensile and 6.88 MPa flexural strength), closely matching the control mix (58.29 MPa, 4.31 MPa and 6.79 MPa respectively), while the 1.00% dosage caused a decline in all three properties owing to reduced workability and fiber agglomeration. The 0.75% surface-treated PET fiber mix produced the highest strengths overall — 59.37 MPa compressive, 4.57 MPa split tensile and 6.96 MPa flexural strength — confirming that surface treatment strengthens the fiber-cement interfacial bond and improves stress transfer across the matrix. The findings identify 0.75% surface-treated waste PET fiber, combined with 10% silica fume, as the optimum combination for the materials investigated and support the use of recycled PET fibers as a viable, environmentally responsible reinforcement for structural-grade concrete.

Keywords

High-Strength Concrete; M50 Grade Concrete; Waste PET Fibers; Silica Fume; Surface Treatment; Crack Resistance; Sustainable Construction Materials

1. Introduction

Concrete remains the most widely consumed construction material in the world because of its compressive strength, versatility and relatively low cost. The continued growth of infrastructure and urbanisation has, however, placed increasing pressure on the natural resources consumed in concrete production, particularly river sand and virgin aggregates. At the same time, the accumulation of post-consumer plastic waste, especially polyethylene terephthalate (PET) bottles used for beverages and packaging, has become a serious environmental concern. PET is highly resistant to biodegradation and can persist in the environment for several hundred years, so diverting it from landfills into value-added applications is an important sustainability objective.

One route that has attracted sustained research interest is the use of recycled PET as discrete fiber reinforcement in concrete. PET fibers are lightweight, possess a high tensile strength-to-weight ratio and are chemically inert, which makes them suitable for bridging microcracks and improving the post-cracking behaviour of cementitious composites. However, PET in its virgin recycled form has a smooth, hydrophobic surface that limits its adhesion to the surrounding cement paste, so the improvement in mechanical properties reported in the literature has often been inconsistent and dosage-dependent. Surface modification of the fibers,

through techniques such as alkali treatment, plasma treatment or coating with a cementitious slurry, has been proposed as a means of improving the interfacial transition zone (ITZ) and, consequently, the stress transfer between fiber and matrix.

In parallel, supplementary cementitious materials such as silica fume are used extensively in high-strength concrete because of their pozzolanic reactivity and pore-refining effect, which densify the microstructure and improve both strength and durability. Combining silica fume with PET fiber reinforcement offers a route to compensate for the loss of workability and bonding typically associated with fiber addition, while simultaneously improving the interfacial characteristics that govern fiber efficiency.

The present study investigates M50 grade concrete produced with a fixed 10% replacement of OPC 53 grade cement by silica fume and a partial replacement of natural fine aggregate with waste PET fibers at dosages of 0%, 0.50%, 0.75% and 1.00%, together with an additional mix in which 0.75% PET fibers were surface-treated with a cement-silica fume slurry prior to incorporation. The compressive, split tensile and flexural strength of all five mixes were evaluated at 7, 14 and 28 days to identify the fiber dosage and treatment condition that yields the best overall mechanical performance, and the results are interpreted in the context of previously published experimental work on PET fiber-reinforced concrete.

2. Literature Review

A substantial body of research has examined the influence of recycled PET fibers on the fresh and hardened properties of concrete. Mouna et al. reported that PET fiber inclusion reduces the workability of fresh concrete because of the increased surface area demanding additional cement paste, but that compressive and split tensile strength show only marginal variation at optimum dosage, with a 1% fiber content and 25 mm fiber length providing the best balance of ductility and strength. Hatungimana et al. observed a slight reduction in compressive strength with recycled PET (rPET) fiber addition, attributed to reduced workability and air entrainment, but noted significant gains in flexural strength, crack resistance, abrasion resistance and drying shrinkage due to the crack-bridging action of the fibers, and found that higher-aspect-ratio fibers perform better than shorter ones.

Abdulateef et al. incorporated corrugated PET strips at 1–3% by weight in M40 concrete and found that a 2% dosage produced the best 28-day performance, with compressive strength improving by approximately 8.7%, split tensile strength by nearly 19% and flexural strength by about 18.6% relative to the control mix, despite reductions in workability and density. Meza et al. used a statistical-experimental approach and reported that PET fiber dosage has a greater influence on performance than fiber aspect ratio, with fiber inclusion improving toughness and post-cracking behaviour even where ultimate tensile and flexural strengths showed limited change.

The role of silica fume in fiber-reinforced systems has also been examined extensively. Toutanji et al. found that while polypropylene fibers alone increase chloride permeability by creating additional fiber-matrix interfaces, the inclusion of silica fume significantly reduces permeability by refining the pore structure and improves fiber dispersion, resulting in denser microstructure and better impact resistance. Singh and Arora investigated silica fume replacement levels from 0–15% combined with PET fiber dosages up to 1.5% and reported that compressive strength increased progressively with silica fume content up to 12.5–15%, while PET fiber addition improved tensile and flexural performance up to about 1.25% fiber content, beyond which strength declined due to fiber clustering and reduced workability. Alani et al. studied silica fume contents from 5–35% in PET fiber-reinforced ultra-high-performance concrete and confirmed that silica fume densifies the microstructure and interfacial transition zone around the fibers, substantially reducing water absorption, sorptivity and chloride penetration.

Several studies specifically address the effect of surface treatment on PET fiber performance. Yu et al. coated recycled PET fibers with a dopamine layer and observed that the treatment increased surface roughness and

chemical activity, resulting in a stronger interfacial transition zone, improved stress transfer, and better interlayer bonding in 3D-printed concrete relative to untreated fibers. Allsmaeel et al. reviewed surface modification and compatibility-enhancement techniques for PET reinforcement and concluded that treated PET consistently outperforms untreated PET in tensile strength, toughness and crack-arresting capability because of improved bonding at the fiber-matrix interface. Girija et al. demonstrated that alkaline treatment increases the surface roughness and polarity of PET, improving its wettability and adhesion characteristics when used in composite and cementitious systems, which supports the use of similar surface activation strategies for construction applications.

Studies examining crack behaviour and fracture mechanics further support the crack-bridging role of PET fibers. A study reported in Matéria (Rio J.) on recycled aggregate concrete beams containing 1% PET fiber found that fracture energy increased by 36.7% and the critical stress intensity factor by 15.2% relative to the control mix, together with a 43.6% increase in critical crack-tip-opening displacement, confirming that PET fibers delay crack propagation and improve energy dissipation even where peak load is marginally reduced. Foti reported good adhesion between PET fibers and the cement matrix in reinforced beam specimens, with improved deformation capacity and reduced brittle failure characteristics. Umasabor and Daniel, working with pulverised PET as a fine aggregate replacement rather than discrete fibers, found that flexural strength decreased with PET content beyond 5% due to the smooth surface texture and poor adhesion of PET particles, which reinforces the observation that surface characteristics, rather than PET content alone, govern mechanical performance.

Broader reviews of recycled polymer fiber-reinforced concrete, including work by Olusunmade et al. and Akbulut et al., consistently identify weak fiber-matrix bonding arising from the hydrophobic and smooth surface of untreated PET as the principal limitation on performance, and recommend surface treatment combined with pozzolanic supplementary cementitious materials such as silica fume as an effective strategy to overcome this limitation while simultaneously improving durability and reducing permeability.

3. Research Gap

The reviewed literature demonstrates that untreated PET fibers generally improve ductility and crack-related behaviour but produce inconsistent effects on compressive strength, and that their performance is highly sensitive to fiber dosage, aspect ratio and surface characteristics. While the individual benefits of silica fume and PET fiber reinforcement are well established, direct comparative studies evaluating untreated versus cement-slurry surface-treated PET fibers under identical mix proportions, particularly within silica fume-modified M50 high-strength concrete, remain limited. Furthermore, the optimum dosage of surface-treated waste PET fiber for this specific material combination has not been clearly established in the published literature. This study addresses these gaps by evaluating untreated PET fibers at three dosages alongside a surface-treated fiber mix, under identical silica fume replacement and mix proportioning, to identify the combination that provides the best mechanical performance.

4. Objectives

The objectives of the present investigation are as follows:

1. To evaluate the effect of untreated waste PET fibers, at dosages of 0.50%, 0.75% and 1.00% by weight of fine aggregate, on the compressive, split tensile and flexural strength of M50 high-strength concrete incorporating 10% silica fume.
2. To evaluate the effect of surface treatment of PET fibers, using a cement-silica fume slurry, on the mechanical performance of concrete at the identified optimum untreated dosage.
3. To identify the optimum PET fiber dosage and treatment condition that yields the maximum combined compressive, split tensile and flexural strength.

4. To assess, indirectly through the tensile and flexural strength gains, the crack resistance imparted by surface-treated PET fiber reinforcement.
5. To promote sustainable construction practice by demonstrating a viable structural application for recycled waste PET.

5. Materials

5.1 Cement: Ordinary Portland Cement (OPC) of 53 grade, conforming to IS 269, was used as the primary binder in all mixes. The physical and chemical properties of the cement, determined through standard consistency, fineness, setting time and soundness tests, are summarised in Table 1.

Table 1. Physical Properties of OPC 53 Grade Cement

Property	Test Result	Requirement (IS 269:2015)
Fineness (m ² /kg)	301	225 (Min)
Standard Consistency (%)	28.0	—
Initial Setting Time (min)	140	30 (Min)
Final Setting Time (min)	180	600 (Max)
Le-Chatelier Expansion (mm)	1.5	10.0 (Max)
Autoclave Expansion (%)	0.051	0.8 (Max)

5.2 Fine Aggregate: Natural river sand conforming to Zone II grading of IS 383 was used as the fine aggregate. The specific gravity, fineness modulus and water absorption were determined and are presented in Table 2.

Table 2. Properties of Natural Fine Aggregate

Property	Result
Fineness Modulus	2.83
Water Absorption (%)	3.33
Specific Gravity	2.70
Grading Zone	Zone II

5.3 Coarse Aggregate: Crushed angular coarse aggregate of 20 mm maximum nominal size, conforming to IS 383, was used. Its properties are given in Table 3.

Table 3. Properties of Coarse Aggregate

Property	Result
Fineness Modulus	6.72
Water Absorption (%)	1.02
Specific Gravity	2.90

5.4 Silica Fume: Densified silica fume (microsilica) conforming to IS 15388:2003 was used as a 10% partial replacement for cement by weight in all fiber-reinforced mixes. The material consists predominantly of amorphous silicon dioxide and contributes to matrix densification through both pozzolanic reaction and particle-packing (micro-filler) effects. Its properties are summarised in Table 4.

Table 4. Properties of Silica Fume

Characteristic	Requirement (IS 15388:2003)	Test Result
SiO ₂ content (%)	85 (Min)	87.4
Moisture content (%)	3.0 (Max)	0.89

Loss on ignition (%)	6.0 (Max)	2.12
Specific surface area (m ² /g)	15.0 (Min)	20.5
Retained on 45 µm sieve (%)	10 (Max)	4.5
Specific gravity	2.10–2.30	2.23

5.5 Waste PET Fibers: Recycled PET fibers were obtained by collecting, cleaning and cutting discarded post-consumer beverage bottles to a uniform length. The dimensional and physical properties of the fibers are given in Table 5. For the surface-treated mix, fibers of identical geometry were coated with a cement-silica fume slurry before incorporation into the concrete; the coating increased surface roughness and was intended to improve the mechanical interlock and chemical adhesion between the fiber surface and the surrounding paste.

Table 5. Properties of Waste PET Fibers

Property	Result
Fiber length (mm)	30
Fiber width (mm)	2.5
Fiber thickness (mm)	0.30
Aspect ratio	60
Specific gravity	1.38
Water absorption (%)	≈0.02 (nil)

5.6 Superplasticizer: A Polycarboxylate Ether (PCE)-based superplasticizer conforming to IS 9103:1999 (Reaffirmed 2022) was used at approximately 1.0% by weight of cementitious material to offset the reduction in workability caused by silica fume and fiber addition, ensure uniform fiber dispersion and permit a reduced water-cement ratio without loss of flowability.

6. Experimental Methodology

All constituent materials were proportioned by weight using an electronic balance with an accuracy of $\pm 0.1\%$. Cement and silica fume were dry-mixed to ensure homogeneity of the binder, and PET fibers were pre-blended with the natural sand for each specific dosage prior to mixing. Coarse aggregate was used in saturated surface dry condition to avoid absorption of the design mixing water. Mixing was carried out in three stages: a dry mix of aggregates and binder for two minutes, addition of approximately 70% of the design water with continued mixing for two minutes, and finally the addition of the remaining water pre-mixed with the superplasticizer, with mixing continued until a uniform colour and consistency was achieved.

Workability of each fresh mix was assessed immediately after mixing using the slump cone test in accordance with IS 1199. Cube specimens ($150 \times 150 \times 150$ mm) were cast in three layers of approximately 50 mm each, with each layer tamped 35 times using a standard tamping rod, for compressive strength testing. Beam specimens ($150 \times 150 \times 700$ mm) were cast in two layers of approximately 75 mm, with more than 100 tamping strokes per layer to prevent segregation, for flexural strength testing. Cylindrical specimens (150×300 mm) were cast in three layers of approximately 100 mm, tamped 30 times per layer, for split tensile strength testing. All specimens were finished with a trowel or wooden float, stored at room temperature ($27 \pm 2^\circ\text{C}$) for 24 hours, demoulded, and then water-cured until the respective testing ages of 7, 14 and 28 days.

Compressive strength was determined as per IS 516, with cubes loaded in a Compression Testing Machine (CTM) at a rate of 140 N/mm^2 per minute, applied to the faces perpendicular to the direction of casting. Split tensile strength was determined on cylindrical specimens loaded diametrically in the CTM using a support jig, with the fracture surface examined to assess whether failure occurred through the aggregate or along the cement-PET interface. Flexural strength (modulus of rupture) was determined on beam specimens using a Universal Testing Machine (UTM) under two-point (third-point) loading over a clear span of 400 mm, with

strength calculated only where fracture occurred within the middle third of the span. Water used for mixing and curing was potable and free of organic impurities, curing tank temperature was maintained at $27 \pm 2^\circ\text{C}$ throughout, and the CTM and UTM were calibrated prior to the commencement of testing.

7. Mix Design

The concrete mixes were proportioned in accordance with IS 10262:2019 for M50 grade concrete, targeting a mean strength of $f_t = f_{ck} + 1.65s = 50 + 1.65(5) = 58.25 \text{ N/mm}^2$, based on an assumed standard deviation of 5 N/mm^2 from Table 1 of IS 10262:2019. A water-cement ratio of 0.35 was adopted, together with a design water content of 158 kg/m^3 after a 20% reduction from the base value of 197 litres through the use of the PCE-based superplasticizer. The cementitious content was fixed at 450 kg/m^3 , comprising 405 kg/m^3 of OPC 53 and 45 kg/m^3 of silica fume (10% replacement) in all fiber-reinforced mixes. Natural sand was replaced by PET fibers, on a weight basis, at 0%, 0.50%, 0.75% and 1.00% of the fine aggregate content, with an additional mix at 0.75% surface-treated PET fiber. The resulting mix proportions for 1 m^3 of concrete are summarised in Table 6.

Table 6. Mix Proportions for 1 m^3 of Concrete

Mix ID	Cement (kg)	Silica Fume (kg)	Water (kg)	Fine Aggregate (kg)	PET Fiber (kg)	Coarse Aggregate (kg)	Admixture (kg)	v
TM1 (Control)	450	—	158	626	—	1184	4.5	0
TM2 (0.50% PET)	405	45	158	620	6.9	1184	4.5	0
TM3 (0.75% PET)	405	45	158	614	10.4	1161	4.5	0
TM4 (1.00% PET)	405	45	158	607	13.8	1122	4.5	0
TM5 (0.75% Treated PET)	405	45	158	614	10.4	1161	4.5	0

The fresh-state workability of each mix, assessed through the slump cone test, is presented in Table 7. A general reduction in slump and compaction factor was observed with increasing PET fiber content, consistent with the higher surface area and fiber interlocking associated with greater fiber dosage.

Table 7. Slump Value and Compaction Factor

Mix	Slump Value (mm)	Compaction Factor
TM1	120	0.95
TM2	100	0.92
TM3	105	0.91
TM4	110	0.94
TM5	80	0.90

8. Results and Discussion

8.1 Compressive Strength

Table 8. Compressive Strength Results (M50 Grade)

Mix ID	SF (%)	PET (%)	7-Day (MPa)	14-Day (MPa)	28-Day (MPa)
TM1 (Control)	0	0	38.31	46.38	58.29
TM2	10	0.50	36.45	44.73	56.84
TM3	10	0.75	38.20	45.11	58.31

TM4	10	1.00	37.63	44.19	54.63
TM5 (Treated)	10	0.75	37.69	48.31	59.37

The control mix (TM1) achieved a 28-day compressive strength of 58.29 MPa, exceeding the M50 target mean strength of 58.25 MPa. The addition of 0.50% untreated PET fiber (TM2) marginally reduced the 28-day strength to 56.84 MPa, a decrease attributable to the lower stiffness of PET relative to natural sand and to a modest reduction in workability that limits compaction efficiency. Increasing the PET content to 0.75% (TM3) recovered the strength to 58.31 MPa, effectively matching the control mix, which suggests that at this dosage the crack-bridging contribution of the fibers offsets the loss of aggregate interlock caused by fiber substitution. A further increase to 1.00% (TM4) produced a marked decline to 54.63 MPa, a reduction of approximately 6.3% relative to the control mix, consistent with fiber agglomeration, non-uniform dispersion and the lower compaction factor recorded for this mix (0.94 relative to 0.95 for the control). This trend mirrors the dosage-sensitivity reported by Singh and Arora and by Mouna et al., where PET fiber content beyond an optimum threshold reduces compressive strength due to increased void content and weakened fiber-matrix bonding.

The surface-treated 0.75% PET fiber mix (TM5) produced the highest 28-day compressive strength among all mixes, at 59.37 MPa, an improvement of 1.9% over the control mix and 1.8% over the equivalent untreated mix (TM3). This improvement is consistent with the mechanism reported by Yu et al. and by Allsmael et al., in which surface treatment increases fiber roughness and promotes stronger mechanical and chemical interaction with the surrounding cement paste, thereby reducing the extent of interfacial voids that otherwise act as stress concentrators under compressive loading. It is also notable that TM5 showed a comparatively larger strength gain between 14 and 28 days (48.31 to 59.37 MPa) than the other mixes, which may reflect continued pozzolanic reaction of the silica fume at the improved interfacial transition zone created by the treated fibers.

8.2 Split Tensile Strength

Table 9. Split Tensile Strength Results (M50 Grade)

Mix ID	SF (%)	PET (%)	7-Day (MPa)	14-Day (MPa)	28-Day (MPa)
TM1 (Control)	0	0	3.18	3.46	4.31
TM2	10	0.50	3.05	3.39	4.22
TM3	10	0.75	3.12	3.41	4.41
TM4	10	1.00	3.01	3.33	4.19
TM5 (Treated)	10	0.75	3.20	3.52	4.57

The split tensile strength results follow a pattern similar to the compressive strength data. The control mix reached 4.31 MPa at 28 days, while TM2 (0.50% PET) showed a slight reduction to 4.22 MPa. TM3 (0.75% PET) improved on the control mix, reaching 4.41 MPa, a gain of approximately 2.3%, indicating that at this dosage the fibers are effective in bridging tensile microcracks and delaying their propagation across the specimen. TM4 (1.00% PET) again showed the lowest tensile strength among the fiber-reinforced mixes at 4.19 MPa, reinforcing the conclusion that excessive fiber content compromises dispersion and bonding to a degree that outweighs the crack-bridging benefit.

The surface-treated mix (TM5) recorded the highest split tensile strength of 4.57 MPa, a 6.0% improvement over the control mix and 3.6% over the equivalent untreated mix. Since split tensile strength is directly governed by the ability of the matrix and fiber network to resist crack initiation and propagation under diametral tension, this improvement provides strong indirect evidence that surface treatment enhances the crack-bridging efficiency of the PET fibers, consistent with the improved interfacial transition zone reported by Alani et al. and the stronger stress transfer mechanism described by Yu et al. for dopamine-treated PET fibers.

8.3 Flexural Strength

Table 10. Flexural Strength Results (M50 Grade)

Mix ID	SF (%)	PET (%)	7-Day (MPa)	14-Day (MPa)	28-Day (MPa)
TM1 (Control)	0	0	4.36	5.78	6.79
TM2	10	0.50	4.29	5.65	6.67
TM3	10	0.75	4.33	5.71	6.88
TM4	10	1.00	4.24	5.59	6.51
TM5 (Treated)	10	0.75	4.41	5.76	6.96

Flexural strength followed the same overall trend as the compressive and split tensile results. The control mix achieved 6.79 MPa at 28 days; TM2 decreased slightly to 6.67 MPa; TM3 improved to 6.88 MPa (a 1.3% gain over the control mix); and TM4 declined to 6.51 MPa, the lowest value among the fiber-reinforced mixes. Flexural performance is particularly sensitive to fiber dispersion because the tensile zone of a beam under bending relies on a small volume of material near the extreme fiber to resist crack initiation; localised fiber clustering at 1.00% dosage is therefore likely to have a disproportionate effect on the modulus of rupture.

TM5 again produced the best result, with a 28-day flexural strength of 6.96 MPa, representing a 2.5% improvement over the control mix and 1.2% over the untreated 0.75% mix. Because flexural strength is governed largely by crack initiation and propagation resistance at the tension face, the consistent improvement recorded for the treated fiber mix across all three mechanical properties, and particularly in split tensile and flexural strength, indicates that the fibers are engaging more effectively with the surrounding matrix and are bridging microcracks more efficiently than untreated fibers of identical geometry.

8.4 Role of Silica Fume and Surface Treatment

The consistent recovery of strength observed in the fiber-reinforced mixes, relative to what would otherwise be expected from PET inclusion alone, can be attributed largely to the presence of silica fume. Its high specific surface area (20.5 m²/g) and fine particle size allow it to fill voids around the PET fibers and around the coarse and fine aggregate particles, densifying the microstructure through both a physical micro-filler effect and a pozzolanic reaction with calcium hydroxide liberated during cement hydration. This is consistent with the mechanism described by Toutanji et al. and Alani et al., in which silica fume improves fiber dispersion and reduces the porosity generated at the fiber-matrix interface by unmodified polymer fibers.

Surface treatment of the PET fibers with a cement-silica fume slurry provided a further, distinct benefit beyond that of silica fume alone. Visual inspection of the fibers before and after treatment (Section 5.5 of the underlying experimental programme) confirmed that treatment converted the smooth, hydrophobic PET surface into a rougher, cementitious-coated surface. This coating increases the mechanical interlock between fiber and matrix and provides additional nucleation sites for hydration products, which is consistent with the improved bond strength and stress transfer reported for chemically or physically roughened PET fibers by Yu et al., Allsmael et al. and Girija et al. The consistent margin of improvement of TM5 over TM3, observed across all three mechanical properties despite both mixes containing an identical 0.75% fiber dosage and identical silica fume content, isolates the effect of surface treatment from that of fiber dosage or binder composition, and confirms that the interfacial bond, rather than the fiber content itself, was the limiting factor in the untreated mixes.

8.5 Crack Resistance

Direct fracture-mechanics testing or crack-width measurement was not performed in this study; crack resistance is therefore assessed indirectly through the split tensile and flexural strength results, which are governed principally by the initiation and propagation of microcracks under tensile and bending stress. The consistent improvement in both properties for the 0.75% surface-treated mix, relative to the control and to the

equivalent untreated mix, indicates that the treated fibers are more effective at arresting crack growth before failure. This inference is consistent with fracture studies on PET-reinforced concrete, such as the improvement in fracture energy and critical crack-tip-opening displacement reported for 1% PET fiber reinforcement in recycled aggregate concrete, and with the crack-bridging mechanism reported by Foti and by Hatungimana et al. for recycled PET fiber-reinforced concrete generally. A quantitative assessment of crack width, fracture energy or toughness for the present mixes would nonetheless be required to confirm the magnitude of this effect, and is identified as a priority for future work.

8.6 Comparison with Published Literature and Optimum Dosage

The strength trends obtained in this study are broadly consistent with the wider literature on PET fiber-reinforced concrete: a mild reduction in compressive strength at low fiber dosage, improved performance at a moderate optimum dosage, and a decline beyond that optimum due to workability loss and fiber agglomeration, as reported by Mouna et al., Singh and Arora, and Meza et al. among others. The magnitude of the improvement recorded here at 0.75% dosage is more modest than the double-digit percentage gains reported by some studies using higher fiber contents (for example, Abdulateef et al. at 2% PET, or Karthikeyan and Ramgughan at 0.5% PET in M30 concrete), which reflects both the lower fiber dosage used in the present M50 mixes and the more demanding baseline strength of the control mix itself. Nonetheless, the study confirms the central finding of the surface-treatment literature: that treating the fiber surface, rather than simply increasing fiber content, is the more effective route to improving mechanical performance without the workability penalty associated with higher untreated fiber dosages.

On the basis of the 28-day results, 0.75% surface-treated PET fiber, combined with 10% silica fume replacement, is identified as the optimum combination investigated in this study. This dosage provided the highest compressive, split tensile and flexural strength among all five mixes while maintaining workability (80 mm slump) within an acceptable range for the pumped placement method assumed in the mix design. The 1.00% untreated dosage, by contrast, is not recommended for this material combination, since the reduction in workability and mechanical performance observed at that dosage outweighs any additional crack-bridging benefit.

9. Practical Applications

Surface-treated waste PET fiber-reinforced concrete, of the type investigated in this study, is suited to structural applications in which enhanced crack resistance and moderate tensile improvement are beneficial, including precast structural elements, industrial floor slabs, pavement quality concrete and members subject to shrinkage or thermal cracking. Because the fibers are derived entirely from recycled post-consumer PET bottles, their use in structural concrete offers a practical route for diverting plastic waste from landfill while simultaneously reducing the demand for virgin fine aggregate, supporting circular-economy objectives in the construction sector. The demonstrated compatibility of surface-treated PET fibers with silica fume-modified M50 concrete further indicates that the approach can be integrated into existing high-strength concrete mix designs without requiring specialised production equipment beyond conventional batching, mixing and superplasticizer dosing systems.

10. Conclusions

1. The concrete mix containing 10% silica fume and 0.75% surface-treated PET fiber (TM5) exhibited the best overall mechanical performance among all mixes tested, achieving 28-day compressive, split tensile and flexural strengths of 59.37 MPa, 4.57 MPa and 6.96 MPa respectively.
2. Among the untreated PET fiber mixes, 0.75% dosage (TM3) produced the best performance, with 28-day strengths of 58.31 MPa (compressive), 4.41 MPa (split tensile) and 6.88 MPa (flexural), essentially matching or marginally exceeding the control mix.

3. Increasing the untreated PET fiber content to 1.00% (TM4) reduced all three strength properties relative to the 0.75% dosage, with 28-day compressive strength falling to 54.63 MPa, attributable to reduced workability, fiber agglomeration and non-uniform dispersion.
4. Surface treatment of PET fibers with a cement-silica fume slurry consistently improved mechanical performance relative to untreated fibers at the identical 0.75% dosage, confirming that fiber-matrix interfacial bonding, rather than fiber content alone, governs the effectiveness of PET reinforcement.
5. The improvement in split tensile and flexural strength for the surface-treated mix indicates enhanced crack-bridging behaviour, although this was assessed indirectly in the absence of direct fracture or crack-width testing.
6. The results support 0.75% surface-treated waste PET fiber, combined with 10% silica fume, as the optimum and recommended combination for producing sustainable, high-strength M50 concrete with recycled plastic reinforcement.

11. Future Scope

The findings of this study can be extended through the following lines of investigation. Durability testing of the optimum mix (10% silica fume + 0.75% surface-treated PET), including water absorption, Rapid Chloride Permeability Test (RCPT), sulphate resistance, acid resistance and carbonation depth, would establish its long-term performance under aggressive exposure conditions. Microstructural characterisation using Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD) and Energy Dispersive Spectroscopy (EDS) would provide direct evidence of the fiber-matrix interfacial transition zone and hydration product formation, complementing the mechanical results presented here. Direct fracture-mechanics testing, including notched beam tests to determine fracture energy, critical stress intensity factor and crack-mouth-opening displacement, would allow crack resistance to be quantified rather than inferred indirectly from tensile and flexural strength. Further work could also examine alternative surface treatment techniques, fiber lengths and aspect ratios, structural-scale testing of reinforced members incorporating surface-treated PET fibers under flexural, shear and cyclic loading, and combinations of surface-treated PET fibers with other supplementary cementitious materials such as fly ash, GGBS or metakaolin, together with long-term field performance monitoring.

References

- [1] Y. Mouna, B. Irfan, M. S. Rahman, and M. Batikha, "A statistical-experimental study to investigate the optimal parameters of fibers made from waste PET bottles for strengthening concrete."
- [2] D. Hatungimana, B. Malibita, J. Minani, A. Mardani, and H. El-Hassan, "Performance enhancement of concrete using recycled PET fibers from post-consumer bottles."
- [3] L. A. Abdulateef, S. H. Hassan, and A. M. Ahmed, "Exploring the mechanical behavior of concrete enhanced with fibers derived from recycled plastic bottles," 2024.
- [4] A. Meza, P. Pujadas, L. M. Meza, F. Pardo-Bosch, and R. D. López-Carreño, "Mechanical optimization of concrete with recycled PET fibers based on a statistical-experimental study," *Materials*, 2021.
- [5] I. Vollmer, M. J. F. Jenks, M. C. P. Roelands, R. J. White, T. van Harmelen, P. de Wild, G. P. van der Laan, F. Meirer, J. T. F. Keurentjes, and B. M. Weckhuysen, "Beyond mechanical recycling: giving new life to plastic waste."
- [6] L. Lebreton and A. Andrady, "Future scenarios of global plastic waste generation and disposal," 2019.
- [7] D. A. Silva, A. M. Betioli, P. J. P. Gleize, H. R. Roman, L. A. Gómez, and J. L. D. Ribeiro, "Degradation of recycled PET fibers in Portland cement-based materials."
- [8] H. Toutanji, S. McNeil, and Z. Bayasi, "Chloride permeability and impact resistance of polypropylene-fiber-reinforced silica fume concrete," 1998.
- [9] O. F. Olusunmade, S. J. Antony, E. Danso-Boateng, V. Sarhosis, and O. C. Ogunnigbo, "Development and optimisation of sustainable recycled PET-sand composites for construction applications."
- [10] A. Singh and N. Arora, "Impact of silica fume and PET fiber over the strength aspects of the concrete."

- [11] S. Karthikeyan and B. Ramgughan, "Experimental investigation of effect of waste PET fibers on the impact behaviour of PET fiber reinforced concrete."
- [12] A. H. Alani, M. A. Megat Johari, A. T. Noaman, N. Muhamad Bunnori, and T. A. Majid, "The role of silica fume in enhancing the strength and transport properties of PET fiber–ultra high-performance concrete."
- [13] S. H. Hassan, L. Sh. Rasheed, and A. J. Alsaad, "An examination of the mechanical performance of eco-friendly concrete incorporating recycled PET and tire steel fibers," 2026.
- [14] S. Ahmad, C.-W. Lu, and M. Sheob, "Utilizing recycled PET fiber-reinforced concrete for sustainable and seismic-resilient infrastructure: a case study of Taiwan's advancing green construction practices," 2026.
- [15] "Influence of 1% recycled PET fiber on the fracture behavior of recycled aggregate concrete beams," *Matéria* (Rio J.), vol. 31, 2026.
- [16] K. Anjaneyulu and S. K. Sekar, "Strength and microstructural improvement of silica fume-modified coconut shell aggregate concrete using machine learning analysis," 2026.
- [17] D. A. Belachew and W. A. Elsaigh, "Developing an integrated circular economy framework for nanomaterial-enhanced recycled PET (nrPET): advancing sustainable and resilient road construction practices," 2025.
- [18] S. F. Moitinho da Silva, W. S. de Jesus, T. M. S. de Almeida, R. Q. de Oliveira Novais, L. A. Sacramento, J. T. de Assis, M. J. dos Anjos, and J. R. de Castro Pessoa, "Impact of fiber type on chloride ingress in concrete: a macro XRF imaging analysis," 2025.
- [19] H. Bagheri, S. M. Mirhosseini, A. Hassani Joshaghani, E. Zeighami, and A. Karimi, "Investigating the role of chemically modified PET in enhancing the properties of green concrete with nano silica under freeze-thaw conditions," 2026.
- [20] S. Lotfollahi, R. Omranzadeh, P. Bakhtiari, and H. Khavari, "Dual mitigation of extruded plastic sack waste in green concrete via micro-silica and recycled polypropylene fibers," 2026.
- [21] K.-K. Yu, T.-Q. Zhao, Q.-L. Luo, and Y. Ping, "Recycled PET fibers with dopamine surface modification for enhanced interlayer adhesion in 3D printed concrete," 2024.
- [22] A. Alismael, A. Alzlfawi, W. Alattyih, R. Ullah, J. Ahmad, and H. J. Qureshi, "Polyethylene terephthalate fiber reinforcement for enhanced concrete mechanical and durability performance: a review," 2019.
- [23] R. I. Umasabor and S. C. Daniel, "The effect of using polyethylene terephthalate as an additive on the flexural and compressive strength of concrete," 2020.
- [24] C. Albano, N. Camacho, M. Hernández, A. Matheus, and A. Gutiérrez, "Influence of content and particle size of waste PET bottles on concrete behavior at different w/c ratios," 2009.
- [25] D. Foti, "Use of recycled waste PET bottles fibers for the reinforcement of concrete," 2013.
- [26] F. Fraternali, V. Ciancia, R. Chechile, G. Rizzano, L. Feo, and L. Incarnato, "Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete," 2014.
- [27] R. K. Sandhu and R. Siddique, "Strength properties and microstructural analysis of self-compacting concrete incorporating waste foundry sand," *Construction and Building Materials*, vol. 225, pp. 371–383, 2019.
- [28] A. Hadj Mostefa and M. Slimane, "Study of concretes reinforced by plastic fibers based on local materials," 2019.
- [29] B. G. Girija, R. R. N. Sailaja, and G. Madras, "Thermal degradation and mechanical properties of PET blends," 2005.
- [30] L. Gu and T. Ozbakkaloglu, "Use of recycled plastics in concrete: a critical review," 2016.
- [31] IS 10262:2019, Concrete Mix Proportioning — Guidelines, Bureau of Indian Standards, New Delhi.
- [32] IS 456:2000, Plain and Reinforced Concrete — Code of Practice, Bureau of Indian Standards, New Delhi.
- [33] IS 516:1959, Method of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi.
- [34] IS 15388:2003, Specification for Silica Fume, Bureau of Indian Standards, New Delhi.