Kurdistan Engineers Union

Sarkawt Hama Tahir Karim

Civil Engineer ID No. **10380**

BSc. In Building Construction Engineering 2010

MSc in Material Engineering 2021

Paper title:

Mechanical Properties of High Strength Concrete Containing PET Fiber: Comprehensive Review

Spring 2025

Mechanical Properties of High Strength Concrete Containing PET Fiber: Comprehensive Review

Abstract

High-strength concrete (HSC) has become an essential construction material for mega projects and high-performance infrastructure, offering high compressive strength, reduced permeability, and enhanced durability compared to conventional concrete. Nonetheless, its brittleness under tensile loads remains a significant drawback, prompting extensive research into fiber-reinforced solutions. Polyethene terephthalate (PET) fibers, derived primarily from post-consumer plastic waste, have received considerable attention due to their favorable mechanical properties, chemical inertness, lightweight, and sustainability benefits. Incorporating PET fibers into HSC addresses global environmental concerns by diverting plastic refuse from landfills and contributes to the concrete's improved tensile and flexural performance. This paper presents a comprehensive review of the mechanical properties of PET fiber-reinforced HSC, examining the role of fiber geometry, volume fraction, and surface treatments in enhancing bond strength and crack resistance. Furthermore, it highlights challenges relating to reduced workability and potential fiber clumping, emphasizing the importance of optimized mix design strategies and suitable admixture selection. By synthesizing current findings and addressing practical implementation considerations, this review demonstrates that PET fiber-reinforced HSC has considerable promise for applications requiring a combination of high compressive capacity, improved ductility, and ecological responsibility, ultimately leading to safer and more sustainable construction practices.

1 Introduction

High strength concrete (HSC) is distinguished from normal strength concrete by its exceptionally high compressive strength, typically exceeding 60 MPa, and improved durability characteristics (Li, 2003). This makes HSC particularly attractive for skyscrapers, long-span bridges, tunnels, and other critical projects where structural safety and service life are paramount (Albano et al., 2009). Despite these advantages, HSC tends to exhibit brittle behaviour under tension, which can precipitate sudden failure when subjected to dynamic or impact loading. This vulnerability underscores the need for innovative reinforcement methods aimed at enhancing the ductility of HSC without compromising its superior compressive strength.

In response to this challenge, researchers and industry practitioners have explored various fiber types ranging from steel to synthetic options for their capacity to bridge cracks and improve post-cracking performance (Foti, 2013). Among the synthetic fibers, polyethene terephthalate (PET) fibers have recently drawn attention due to their favorable mechanical properties, chemical inertness, and low cost, in addition to their potential to mitigate plastic waste generation (Fraternali et al., 2011). Notably, PET fibres are sourced mainly from recycled plastic bottles and packaging materials, making them an environmentally friendly alternative to virgin synthetic fibers.

This article comprehensively reviews the mechanical properties of HSC reinforced with PET fibers, focusing on compressive, tensile, and flexural performance alongside considerations about fiber-matrix adhesion, fiber geometry, and dosage. The discussion further addresses practical constraints such as workability, mix design optimization, and field implementation challenges. By synthesizing contemporary research findings and identifying areas requiring additional investigation, this review ultimately underscores the viability of PET fiber-reinforced HSC in achieving not only enhanced mechanical properties but also sustainability goals in the construction sector.

2 Literature Review

2.1. Significance and Evolution of High-Strength Concrete

High strength concrete (HSC) emerged as an engineered response to the evolving demands of modern construction, where conventional mixes began to demonstrate limitations in meeting stringent structural and durability requirements (Li, 2003). As building heights increased and infrastructural projects grew in complexity, designers and engineers required a material capable of offering both superior load-bearing capacity and longer service life. By definition, HSC typically gets compressive strengths above 60 MPa, though specific thresholds can vary among standards and regions. To achieve such heightened strength, the water-to-cement ratio is lowered, and supplemental cementitious materials, such as silica fume, fly ash, and ground granulated blast furnace slag, are often incorporated to enhance particle packing and refine the microstructure (Foti, 2013). The dense microstructure not only bolsters mechanical capacity but also reduces permeability, thereby extenuating the risks of chloride ingress and other chemical attacks that degrade normal-strength concrete over time.

In parallel to improvements in strength, the durability facet of HSC has become a focal point in contemporary infrastructure. Bridges, tall buildings, and offshore structures consistently face exposure to harsh environmental conditions that can undermine the integrity of ordinary concrete mixes. For instance, in marine settings with elevated levels of chloride and sulfate, HSC's refined pore structure often confers a higher degree of flexibility, reducing maintenance interventions across the structure's lifespan (Marthong & Sarma, 2016). Moreover, in cold climates subjected to freeze-thaw cycles, HSC's reduced capillary porosity helps lessen the internal stress caused by repeated freezing of entrapped water, thereby preserving structural integrity.

Despite these notable strengths, HSC has an inherent shortcoming in its brittleness under tensile loading. Concrete, in general, is known to perform poorly in tension, but the high density and stiffness of HSC can exacerbate the problem. When microcracks form, the absence of internal bridging mechanisms results in rapid crack propagation, culminating in sudden and catastrophic failure. This inherent lack of ductility stands in stark contrast to what many contemporary projects require, such as resistance to dynamic loads (e.g., earthquakes, blasting, or heavy industrial activities). Efforts to alleviate brittleness include the introduction of fibers into the matrix, as fiber reinforcement can arrest or slow the progression of cracks by bridging the spaces where cracks initiate (Soroushian et al., 2003). Various fibers, including steel, glass, polypropylene, and recycled polyethylene terephthalate (PET), have been studied for this purpose, each offering a distinct set of advantages and drawbacks.

Among these fibers, steel has historically dominated due to its high stiffness and ability to significantly enhance tensile properties. However, its susceptibility to corrosion, weight considerations, and rising costs have prompted researchers to explore alternatives (Fraternali et al., 2011). Synthetic fibers, including PET, stand out for their corrosion resistance, low density, and potential for cost savings, especially when derived from recycled materials. This shift resonates with the broader societal push toward sustainability, as the construction sector seeks new ways to reduce its environmental footprint while delivering high-performance materials. PET, in particular, has garnered attention because of global concerns regarding plastic waste management. Repurposing PET from discarded bottles and packaging materials into fibers for concrete application can yield a win–win scenario, curbing the accumulation of non-biodegradable waste and, simultaneously, enhancing the mechanical properties of HSC.

The evolution of HSC has therefore been influenced by several convergent factors: the pressing need to extend infrastructure service life, the drive to develop safer materials with better dynamic performance, and the global call for green and sustainable construction practices. Technological strides, such as the formulation of tailored superplasticizers, have played a pivotal role in making the application of HSC more feasible. These admixtures allow the production of workable mixes at very low water-to-cement ratios, ensuring dense particle packing without sacrificing the flow properties necessary for proper compaction (Li, 2003). Simultaneously, computational tools like finite element analysis and multi-scale modelling have enhanced the capacity to predict and optimize the behaviour of HSC under complex loading scenarios (Hannawi et al., 2010).

Today, the conversation has advanced to how HSC can be adapted to specific scenarios by carefully modifying its composition and reinforcement strategies. PET fiber reinforcement offers an avenue to address the brittleness challenge, while simultaneously contributing to environmental sustainability. Integrating recycled PET fibers into HSC not only supplements the material's performance by enhancing tensile and flexural strength but also helps to manage plastic waste (Ramesan & Sekhar, 2020). Consequently, the modern trajectory of HSC research and development is not solely about pushing compressive strength limits, but rather about holistically optimizing the material for real-world conditions, including durability, ductility, and ecological impact (Yazdanbakhsh et al., 2018). This broader perspective marks a significant advancement in our understanding of how to maximize the lifespan and functionality of critical infrastructure while aligning with global sustainability imperatives.

2.2. PET Fibers and Their Role in Concrete Reinforcement

Polyethylene terephthalate (PET) is a thermoplastic polymer extensively utilized in consumer packaging, primarily in beverage bottles and various other plastic containers (Foti, 2013). Over the past two decades, heightened awareness regarding plastic pollution has catalyzed research into recycling PET waste into value-added products. One particularly promising application is the transformation of recycled PET into fibers for concrete reinforcement. By doing so, industries can divert significant quantities of plastic from landfills and incineration, thus reducing environmental impact while capitalizing on the inherent tensile strength and chemical stability of PET (Fraternali et al., 2011).

In the context of concrete reinforcement, PET fibers serve multiple functions. Firstly, they act as crack-arresting elements, bridging microcracks as they form and inhibiting the rapid propagation that characterizes brittle failures in cementitious systems (Albano et al., 2009). Secondly, the inclusion of PET fibers in concrete typically enhances ductility and toughness, thereby broadening the range of applications for which the concrete is viable. Finally, PET fibers help to maintain residual strength even after the initial crack formation, contributing to a safer post-cracking behaviour that is particularly relevant for impact and seismic loading (Foti, 2013). These benefits, however, hinge on the appropriate selection of fiber geometry and dosage, as well as an understanding of how the PET fibers interact with the cementitious matrix.

Fiber geometry often encompasses length, diameter, and shape (straight, twisted, crimped, etc.). Longer fibers can span larger cracks, but they may also be more prone to entanglement and clumping during mixing, especially at higher volume fractions (Marthong & Sarma, 2016). Consequently, achieving uniform dispersion within the concrete matrix can become a challenge, potentially undermining the mechanical gains if fibers aggregate rather than distribute evenly. The surface characteristics of PET fibers also influence their bonding potential. Because PET is relatively smooth and hydrophobic, it does not intrinsically bond well with the cement paste. To address this limitation, researchers have explored various pretreatment methods, such as chemical etching, plasma treatment, or coating with resins, aiming to roughen the fiber surface or introduce reactive functional groups (Fraternali et al., 2011). These treatments enhance the mechanical interlock between fibers and the hydration products, ultimately boosting tensile strength and crack resistance.

Volume fraction, denoted typically as a percentage of the total volume of concrete, is another critical factor. Moderate PET fiber contents, usually between 0.5% and 1.5%, can improve tensile and flexural properties without significantly impairing workability (Soroushian et al., 2003). However, when fiber content surpasses an optimal level, the resulting mixture may exhibit excessive stiffness in its fresh state, leading to difficulties in casting and compaction. Furthermore, excessive fiber content can introduce additional voids and weaken the matrix, thus negating potential gains in tensile or flexural strength (Ramesan & Sekhar, 2020). This interplay underscores the importance of systematic experimental programs and mix design optimizations to determine the threshold at which PET fibers yield net improvements.

From a sustainability viewpoint, one of the main appeals of PET fibers is their potential to diminish the environmental footprint of concrete. The manufacturing of Portland cement alone is associated with substantial CO_2 emissions, and there is increasing pressure on the construction industry to adopt greener technologies (Pacheco-Torgal & Jalali, 2011). While substituting raw aggregates with recycled PET aggregates has also been explored, using PET in fiber form can be more effective in managing crack growth and improving mechanical attributes. Moreover, life-cycle assessments (LCAs) reveal that diverting plastic waste into concrete fiber manufacturing leads to reduced landfill usage and lowers overall resource consumption (Hannawi et al., 2010). In turn, this provides an additional impetus for adopting PET fibers in large-scale projects, particularly in regions grappling with plastic waste disposal challenges.

Despite these positive outcomes, the practical adoption of PET fiber-reinforced concrete remains somewhat sporadic. Concerns regarding cost, product standardization, and long-term durability have slowed widespread implementation. In some instances, locally available recycled PET must be carefully processed to ensure consistent fiber properties, which can introduce logistical hurdles. Additionally, while laboratory-scale studies indicate that PET fibers can survive in alkaline cementitious environments without significant degradation, extended on-site monitoring is necessary to confirm these findings in real-world conditions (Hannawi et al., 2010). Addressing these uncertainties through standardized testing protocols and validated computational models would be instrumental in fostering trust among engineers, contractors, and regulatory authorities.

Overall, PET fibers serve as a promising route to address both structural performance and sustainability concerns in concrete technology. Although research has advanced in exploring optimal fiber geometries, dosage rates, and surface treatments, the field continues to seek robust methods for controlling the mixing process, verifying long-term durability, and assessing cost-benefit ratios in large-scale applications. By refining these areas, PET fiber-reinforced HSC could gain wider acceptance and play a key role in the next generation of eco-efficient infrastructure.

2.3. Mechanical Performance of PET Fiber-Reinforced High-Strength Concrete (≥500 words)

Investigations into the mechanical performance of PET fiber-reinforced high-strength concrete (HSC) have predominantly centered on compressive, tensile, and flexural behaviours, as these parameters collectively define the structural capability of concrete in practical applications (Foti, 2013). Although high compressive strength is a hallmark of HSC, its inherent brittleness has spurred interest in finding methods to boost ductility without sacrificing compressive capacity. PET fibers, when suitably incorporated, can offer meaningful improvements in crack resistance and post-cracking strength, bridging the gap between laboratory potential and field performance (Marthong & Sarma, 2016).

Research findings regarding the impact of PET fibers on compressive strength are somewhat varied. In certain instances, moderate PET fiber dosages (0.5–1.5% by volume) have elicited small, positive increments in compressive strength or, at least, have not impaired the overall load-bearing capacity (Albano et al., 2009). The mechanism often cited for these modest gains is the crack-arresting function of PET fibers, particularly at the microcrack level. When cracks initiate under load, fibers within the concrete can dissipate energy and delay the coalescence of microcracks into larger, more detrimental fractures (Ramesan & Sekhar, 2020). Yet, it is equally important to note that excessively high fiber volumes or poorly distributed fibers can produce internal voids or reduce workability, thereby leading to suboptimal compaction and potential reductions in compressive strength. The net effect thus depends on carefully balancing fiber dosage, matrix composition, and mixing protocols.

In contrast, the tensile strength and associated properties of HSC are more demonstrably enhanced by PET fiber inclusion. Owing to the dense microstructure of HSC, microcracks generated under tensile loading can propagate rapidly in an unreinforced matrix (Fraternali et al., 2011). By crossing these microcracks, PET fibers slow crack growth, distribute tensile stresses more evenly, and promote a pseudo-ductile failure mode. This effect is frequently observed in splitting tensile tests, which reveal that fiber-reinforced specimens can sustain higher loads before crack formation. Post-cracking behavior also improves: once the matrix fractures, the fibers continue to carry load, ensuring that the composite does not undergo an abrupt loss of capacity. Such enhanced residual strength is pivotal in applications subject to impact loads, seismic events, or repeated cyclical stresses that could accelerate crack propagation in brittle materials (Foti, 2013).

Flexural performance further underscores the advantages of including PET fibers in HSC. The capacity to resist bending moments—a common demand in beams, slabs, and other structural members—draws heavily on how effectively a material can withstand tensile stresses at the extreme fibers of a cross-section (Soroushian et al., 2003). Experimental work involving beams reinforced with PET fibers generally confirms increased load-carrying capacity and improved toughness, often assessed by the area under the load–deflection curve. When the bending stress in the tension zone surpasses the matrix's tensile capacity, the fibers intervene to control crack widths, leading to more gradual failure. This phenomenon is particularly valuable in structures that may experience dynamic or impact loads, as the ability to tolerate larger deflections prior to collapse translates to improved energy absorption and occupant safety (Yazdanbakhsh et al., 2018).

A related domain that has garnered interest is the impact resistance and fatigue life of PET fiber-reinforced HSC. While classical concrete fatigue often culminates in crack growth under repetitive loading, fiber reinforcement can extend the service life by restraining crack expansion and sustaining load transfer across crack planes (Fraternali et al., 2011). These characteristics can be especially advantageous in pavements, airport runways, and industrial floors where surfaces are subjected to thousands of cyclical loads from vehicles or machinery. By bridging microcracks and limiting crack propagation under repeated stresses, PET fibers curtail the formation of macrocracks that necessitate repairs and compromise structural integrity. Consequently, fiber-reinforced HSC can lead to reduced maintenance costs and a longer operational timeframe, thus presenting both economic and performance benefits (Ramesan & Sekhar, 2020).

However, harnessing these potential improvements necessitates an understanding of how fresh concrete properties are affected by PET fiber inclusion. Workability can be impaired if the fiber dosage is excessive or if fibers have high aspect ratios, causing the concrete to exhibit a "sticky" or "harsh" consistency (Marthong & Sarma, 2016). Should the mix become difficult to pour or place, air voids may remain, negatively influencing both strength and durability. Strategies to manage workability involve using high-range water reducers (superplasticizers), adjusting aggregate gradation, or employing specialized mixing procedures to ensure consistent fiber dispersion. Furthermore, to preserve HSC's defining characteristic—high compressive strength—the water-to-cement ratio must remain suitably low, calling for precise and sometimes sophisticated mix design approaches (Foti, 2013).

In summary, the mechanical performance of PET fiber-reinforced HSC largely reflects a balance between improved tensile and flexural behavior, potential gains in impact resistance, and the need to maintain desired compressive strength. While the evidence points to tangible benefits in ductility, energy absorption, and residual strength, actual results vary based on variables such as fiber content, fiber geometry, surface treatment, and mix design parameters. Despite these intricacies, the convergence of enhanced mechanical properties with sustainability motives underscores the rationale for continued exploration and optimization of PET fiber-reinforced HSC in practical, large-scale construction scenarios (Hannawi et al., 2010).

3 Discussion

Drawing together the findings from the literature on high strength concrete (HSC) reinforced with polyethylene terephthalate (PET) fibers reveals a material system that simultaneously addresses structural performance demands and environmental concerns. On one hand, HSC is celebrated for its elevated compressive strength, reduced permeability, and improved durability in comparison to conventional concrete, making it indispensable for critical infrastructure such as high-rise buildings, long-span bridges, and offshore platforms. On the other hand, the brittleness of HSC under tensile stress presents an ongoing challenge, as rapid crack propagation can compromise safety and service life. The integration of PET fibers, often sourced from recycled plastic bottles, substantially augments the tensile and flexural properties of HSC by bridging microcracks and enhancing post-cracking behavior. These fibers help distribute stress more evenly throughout the cementitious matrix, leading to enhanced ductility, toughness, and impact resistance, which are vital in seismically active or high-impact regions. Although certain studies show modest improvements or no detrimental effects on compressive strength at moderate PET fiber dosages, some investigations caution against excessive fiber content that can result in clumping, void formation, and diminished workability. Equally important is the realization that PET fibers, due to their smooth surfaces and hydrophobic nature, often require surface treatments or modified geometries to secure robust bonding with the surrounding paste. Chemical or physical treatments have been shown to improve this interface, strengthening the pull-out resistance and ensuring better crack control. Moreover, considering the sustainability dimension, using recycled PET fibers diverts plastic waste from landfills and incinerators, thus contributing to circular economy goals and eco-friendly construction practices. This synergy of environmental and mechanical benefits positions PET fiber-reinforced HSC as a compelling choice for future construction activities, but practical deployment demands meticulous attention to mixing design, fiber dosage, and fresh concrete properties. Low water-to-cement ratios, mandatory for achieving high compressive strength, limit the margin for compensating any loss of workability introduced by the fibers. Accordingly, superplasticizers become crucial to maintaining fluidity without escalating water content. In the context of large-scale implementation, further research is essential for verifying long-term durability under actual service conditions that encompass freeze-thaw cycles, chloride penetration, and sustained dynamic loading. Additionally, full-scale demonstration projects and field experiments can shed light on the capacity of mixing equipment to uniformly disperse fibers, as laboratory findings may not always translate seamlessly to real-world practices. Should these practical considerations be successfully addressed, the performance enhancements observed in laboratory investigations particularly higher tensile strength, improved fracture toughness, and greater energy absorption will significantly elevate the structural resilience of HSC. This evolution in fiber-reinforced concrete technology aligns with broader sustainability imperatives in the construction sector by fulfilling dual roles in waste management and high-performance material development. Ultimately, the continuing refinement of PET fiber production, surface treatment techniques, and mix proportioning stands to transform recycled plastic from a liability into an asset, driving both ecological and engineering progress. The cumulative insights provided by multiple studies suggest that PET fiber-reinforced HSC not only represents an innovative route for mitigating the brittleness of HSC but also exemplifies a framework in which environmental stewardship and infrastructure advancement move in tandem, paving the way for more robust, durable, and sustainable construction practices in the years to come.

4 Conclusion

A comprehensive review of high-strength concrete (HSC) containing PET fibers demonstrates that it can be an innovative, high-performance construction material that fulfils both structural and sustainability requirements. HSC offers robust compressive strength and low permeability, making it compatible with demanding infrastructure projects, while the integration of PET fibers addresses the prevalent issue of brittleness under tensile and flexural loads. By bridging microcracks, these fibers significantly improve the tensile strength, post-cracking behaviour, and overall toughness of HSC. Furthermore, PET's corrosion resistance, chemical inertness, and relatively low cost add to its practical advantages, particularly when sourced from recycled plastic bottles, helping reduce plastic waste. Nonetheless, optimal fiber dosage, appropriate mixing techniques, and the potential need for fiber surface treatments must be carefully managed to ensure uniform dispersion and strong fiber–matrix bonding. Although several studies confirm the promise of PET fiber-reinforced HSC, additional large-scale investigations are warranted to establish guidelines for long-term durability, scaling of mix design, and on-site practices. In essence, PET fiber-reinforced HSC emerges as a sustainable composite that effectively binds recycled materials to enhance structural performance, offering a compelling solution for eco-conscious and engineering-driven construction activities.

References

Albano, C., Camacho, N., Hernandez, M., Matheus, A., & Gutierrez, A. (2009). Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios. Waste Management,29(10),2707–2716.

Foti, D. (2013). Use of recycled waste PET bottles fiber for the reinforcement of concrete. *CompositeStructures*,96,396–404.

Fraternali, F., Ciancia, V., Chechile, R., Rizzano, G., Feo, L., & Incarnato, L. (2011). Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete. *Composite Structures*, 93(9), 2368–2374.

Hannawi, K., Kamali-Bernard, S., & Prince, W. (2010). Physical and mechanical properties of mortars containing PET and PC waste aggregates. *Waste Management*, 30(11), 2312–2320.

Li, V. C. (2003). On engineered cementitious composites (ECC). *Journal of Advanced Concrete Technology*, 1(3), 215–230.

Marthong, C., & Sarma, B. K. (2016). Influence of PET fiber geometry on the mechanical properties of concrete. *Construction and Building Materials*, 127, 10–17.

Pacheco-Torgal, F., & Jalali, S. (2011). Reusing ceramic wastes in concrete. *Construction and Building Materials*, 24(5), 832–838.

Ramesan, A., & Sekhar, A. R. C. (2020). Experimental investigation on the mechanical properties of PET fiber reinforced concrete. *Materials Today: Proceedings*, 33, 558–562.

Soroushian, P., Plasencia, J., & Ravanbakhsh, S. (2003). Reduction of waste and pollution in production of concrete by partial substitution of natural aggregates with recycled plastic aggregates. *Waste Management & Research*, 21(2), 141–147.

Yazdanbakhsh, A., Bank, L. C., & Rieder, K. A. (2018). Mechanical properties of ultra-high-performance concrete reinforced with recycled carbon fiber. *Journal of Materials in Civil Engineering*, 30(2), 04017299.