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EDITED BY
Lei Xu,
Swiss Federal Institute of Technology Lausanne, Switzerland

REVIEWED BY
Xiangxing Zhang,
Hebei University of Technology, China
Xiangbo Xu,
Weifang University, China

*CORRESPONDENCE
Jozef Švajlenka,
jozef.svajlenka@tuke.sk
Taher A. Tawfik,
taher@savba.sk

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Recycled polymer fibers in concrete: a sustainability-focused review of environmental benefits and challenges

Zehra Funda Akbulut[1], Soner Guler[2], Mehmet Akif Arvas[3], Faruk Osmanoğlu[4], Jozef Selín[5], Jozef Švajlenka[5]* and Taher A. Tawfik[6,7]*

[1]Department of Mining Engineering, Faculty of Engineering, University of Van Yüzüncü Yıl, Van, Türkiye, [2]Department of Civil Engineering, Faculty of Engineering, University of Van Yüzüncü Yıl, Van, Türkiye, [3]Department of Economics, Faculty of Economics and Administrative Sciences, University of Van Yüzüncü Yıl, Van, Türkiye, [4]Department of Architecture, Faculty of Architecture, University of Van Yüzüncü Yıl, Van, Türkiye, [5]Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia, [6]Institute of Construction and Architecture, Slovak Academy of Sciences, Bratislava, Slovakia, [7]Department of Construction and Building Engineering, High Institute of Engineering, October 6 City, Egypt

The growing demand for sustainable and low-carbon construction materials has intensified interest in incorporating waste-derived materials into cement-based systems. Among these alternatives, recycled polymer fibers (RPFs) obtained from post-consumer plastics such as polyethylene terephthalate (PET) and polypropylene (PP) have attracted increasing attention due to their potential to simultaneously mitigate plastic waste pollution and reduce the environmental footprint of concrete. This review critically evaluates recycled polymer fiber-reinforced concrete (RPFRC) from a sustainability perspective, with particular emphasis on environmental impacts rather than solely on mechanical performance enhancement. A comprehensive assessment of recent literature indicates that the use of recycled polymer fibers can substantially reduce environmental burdens associated with conventional fiber production. Life cycle assessment (LCA) studies report that recycled polymer fibers may reduce energy consumption by approximately 40%–85% and decrease global warming potential by 25%–75% compared with virgin polymer fibers. In addition, the incorporation of recycled fibers reduces demand for virgin raw materials and supports circular economy strategies in construction materials. Despite these advantages, the environmental performance of RPFRC is strongly influenced by factors such as fiber processing methods, transportation distances, substitution efficiency, and system boundaries considered in LCA studies. Furthermore, variability in recycled fiber properties, lack of standardized specifications, and limited large-scale field validation remain important barriers to practical implementation. This review synthesizes current knowledge on the environmental performance of RPFRC, identifies key research gaps, and outlines future directions to improve sustainability assessment frameworks and facilitate the broader adoption of recycled polymer fibers in concrete applications.

KEYWORDS
environmental impact, fiber-reinforced concrete, PET fibers, polypropylene fibers, recycled polymer fibers

1 Introduction

Concrete remains one of the most widely used construction materials worldwide and plays a central role in the development of modern infrastructure, including buildings, bridges, transportation networks, and hydraulic structures. Its widespread application is largely attributed to its durability, structural capacity, and relatively low cost (Ma et al., 2025). Nevertheless, the environmental implications of conventional concrete production have become a growing concern. In particular, cement manufacturing, which provides the binding phase in concrete, is responsible for approximately 7%–8% of global carbon dioxide (CO_2) emissions (Nejad et al., 2025). The regional distribution of global cement production in 2022 is shown in Figure 1, highlighting the dominance of certain regions, with China alone accounting for nearly 54% of global cement output (Guo et al., 2022).

The large-scale extraction of natural aggregates for concrete production contributes to ecosystem disturbance and resource depletion, while the manufacturing and transportation of construction materials consume considerable energy. These challenges have intensified the need for sustainable construction strategies to reduce the environmental footprint of concrete without compromising its structural performance. At the same time, the world is experiencing a rapidly escalating plastic waste crisis. Global plastic production has reached approximately 400 million tons annually, a significant portion of which ultimately accumulates in landfills, incineration facilities, or natural ecosystems (Javed et al., 2025). Among the most widely used polymers are polyethylene terephthalate (PET), commonly utilized in beverage bottles and containers, and polypropylene (PP), which is extensively used in packaging materials and textile products (Friedrich et al., 2005). As illustrated in Figure 2, plastic waste can be recycled and processed into polymer fibers, which may subsequently be incorporated into fiber-reinforced concrete, offering a promising pathway for both waste valorization and improved material functionality.

Plastics such as polyethylene terephthalate (PET) and polypropylene (PP) are characterized by high durability and resistance to biological and chemical degradation. While these properties make them valuable for industrial and consumer applications, they also create serious disposal challenges. The long-term persistence of plastic waste in the environment contributes to terrestrial pollution, marine contamination, and greenhouse gas emissions associated with degradation and incineration processes (Nicholson et al., 2021). Consequently, increasing attention has been directed toward diverting plastic waste from conventional disposal pathways and reutilizing it in value-added applications, including construction materials.

One promising strategy is to incorporate recycled polymer fibers into cementitious composites. Recycled polymer fibers (RPFs), typically derived from post-consumer or industrial plastic waste streams, have gained significant attention as sustainable reinforcement materials, with PET and PP fibers being among the most extensively investigated (Shen et al., 2012). Unlike virgin synthetic fibers, whose production requires additional petrochemical resources and energy, RPFs utilize existing waste materials and therefore help reduce environmental burdens associated with plastic disposal (Siddique et al., 2008). This approach aligns closely with circular economy principles, which emphasize resource efficiency, waste minimization, and the reintegration of end-of-life materials into productive systems.

Although the use of polymer fibers in concrete is not new, synthetic fibers such as polypropylene and nylon have long been used to enhance crack resistance, toughness, and post-cracking performance of cement-based materials (Signorini and Volpini, 2021). In this context, recycled polymer fibers represent an important link between plastic waste management and sustainable concrete production within a circular economy framework. The conceptual relationship between plastic waste recycling and fiber-reinforced concrete applications is illustrated schematically in Figure 3.

The transition from virgin synthetic fibers to recycled alternatives is increasingly aligned with global decarbonization and resource-efficiency strategies. The substitution of virgin fibers with recycled polyethylene terephthalate (PET) or polypropylene (PP) fibers can significantly reduce the embodied energy and greenhouse gas emissions associated with fiber production (Tay et al., 2024). Several life cycle assessment (LCA) studies have demonstrated that incorporating recycled polymer fibers into concrete can reduce carbon emissions, fossil fuel depletion, and cumulative energy demand compared with conventional concrete or systems reinforced with virgin fibers (Marinelli et al., 2021). These findings highlight the potential of recycled polymer fibers to contribute simultaneously to environmental sustainability and material performance.

In addition to reducing emissions, recycled polymer fibers also offer an effective way to address the growing global plastic waste problem. The incorporation of plastic waste streams, including PET bottles and PP packaging materials, into cement-based composites can significantly reduce the amount of plastic sent to landfills or incineration facilities (Cappucci et al., 2020). Considering that global concrete production exceeds 10 billion tons annually, even a partial replacement with recycled fibers could divert millions of tons of plastic waste from disposal routes (Meyer, 2009). Consequently, the use of recycled polymer fibers in concrete provides a promising large-scale recycling pathway that supports circular economy objectives and improves the environmental profile of construction materials.

Despite these advantages, several technical and practical challenges remain. One of the main limitations arises from the heterogeneous nature of recycled polymer fibers. Their geometry, aspect ratio, and mechanical properties may vary

Abbreviations: BREEAM, Building Research Establishment Environmental Assessment Method; CE, circular economy; CO_2, carbon dioxide; FRP, fiber-reinforced polymer; GWP, global warming potential; HDPE, high-density polyethylene; HD, hydrophobic–hydrophilic interaction; LCA, life cycle assessment; LDPE, low-density polyethylene; LEED, Leadership in Energy and Environmental Design; OECD, Organisation for Economic Co-operation and Development; PC, Portland cement; PE, Polyethylene; PET, polyethylene terephthalate; PP, polypropylene; PVC, polyvinyl chloride; RPF, recycled polymer fiber; RPFRC, recycled polymer fiber-reinforced concrete; SDG, Sustainable Development Goal.

significantly depending on the waste source, recycling process, and cutting methods used during fiber production (Soni et al., 2024). Such variability complicates performance prediction and hinders the development of standardized material specifications. Furthermore, PET and PP fibers are inherently hydrophobic, which results in weak interfacial bonding with the hydrophilic cementitious matrix (Suksiripattanapong et al., 2022). Without surface modification or chemical treatment, insufficient fiber–matrix adhesion may reduce stress-transfer efficiency and limit the fibers' crack-bridging capacity.

Another challenge concerns the adoption of recycled polymer fiber-reinforced concrete (RPFRC) in practical construction applications. Engineers and stakeholders often remain cautious about introducing new materials unless their long-term performance and durability are clearly demonstrated (Kim et al., 2008). Durability aspects such as freeze–thaw resistance, chloride penetration, and chemical attack require further systematic investigation when recycled fibers are used in cementitious composites (Bhogayata and Arora, 2018). Moreover, most existing studies remain limited to laboratory-scale investigations, while field-scale validation and long-term monitoring are still relatively scarce. This gap between experimental research and practical application highlights the need for closer collaboration between researchers, industry stakeholders, and policymakers to establish standardized guidelines and design recommendations for RPFRC (Bui et al., 2018).

Nevertheless, the potential environmental benefits of recycled polymer fiber-reinforced concrete continue to attract increasing research interest. The utilization of recycled polymer fibers directly contributes to several United Nations Sustainable Development Goals (SDGs), particularly those related to responsible consumption and production, climate action, and sustainable cities and communities (Kumar et al., 2021). In addition, green building certification systems such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) encourage the use of recycled materials and low-carbon technologies in construction projects (Kuttima et al., 2025). These frameworks further support the integration of recycled fibers into sustainable building practices.

Recent studies have also explored various strategies to overcome the technical limitations associated with recycled polymer fibers. Surface modification techniques, including plasma treatment, alkali treatment, and nanomaterial coatings, have been investigated to enhance fiber–matrix interfacial bonding and improve mechanical performance (Lee et al., 2015). Furthermore, hybrid reinforcement strategies that combine recycled polymer fibers with natural fibers or supplementary cementitious materials have demonstrated promising potential to balance mechanical performance and environmental sustainability (Balea et al., 2021). Advances in characterization methods and modeling techniques have also provided new insights into fiber reinforcement mechanisms and the environmental performance of recycled fiber systems (Tawiah et al., 2016).

Despite these advances, a comprehensive evaluation focusing specifically on the environmental sustainability of recycled polymer fiber-reinforced concrete remains limited. Most previous studies have primarily concentrated on mechanical performance or durability aspects, while the broader environmental implications of recycled polymer fibers have received comparatively less attention. Therefore, a critical synthesis of the environmental performance, sustainability benefits, and remaining challenges associated with recycled polymer fibers in concrete is required.

Accordingly, this review aims to provide a comprehensive sustainability-oriented evaluation of recycled polymer fibers in cement-based composites. The study focuses on environmental aspects, including waste valorization, carbon footprint reduction, and life cycle assessment outcomes. In addition, the review identifies key challenges related to fiber variability, interfacial bonding, and standardization that may hinder large-scale implementation. By summarizing current knowledge and identifying future research needs, this study aims to provide guidance for researchers, engineers, and policymakers seeking to promote the adoption of recycled polymer fibers in sustainable concrete applications. As summarized in Table 1, recycled polymer fibers offer significant sustainability advantages through CO_2 emission reduction, plastic waste valorization, and support for circular economy strategies, while challenges remain regarding fiber heterogeneity, interfacial bonding, and standardization.

2 Sources, properties, and processing of recycled polymer fibers for concrete

2.1 Fiber sources

The use of recycled polymer fibers in cementitious composites relies primarily on identifying and collecting suitable plastic waste streams. Among the various polymer types, polyethylene terephthalate (PET) and polypropylene (PP) represent the most widely available and extensively studied sources for recycled fiber production. PET is typically obtained from post-consumer beverage bottles, food containers, and packaging films, whereas PP originates from packaging materials, textiles, automotive components, and consumer products (Marcelino et al., 2025; EPA, 2022).

Marcelino et al. (2025) reported that PET recycling in Brazil involves three main industrial actors: recyclers, which exclusively process PET waste (26%); integrators, which both recycle and utilize recycled PET (13%); and applicators, which only use recycled PET in manufacturing processes (61%). According to data from the Brazilian Association of the PET Industry (ABIPET), the recycling rate of PET packaging reached 56.4% in 2021, up 15.4 percentage points from 2019. The beverage packaging sector accounts for approximately 29% of recycled PET consumption, followed by the textile sector (25%) and solid packaging applications (17%).

These polymers also constitute a substantial portion of global municipal solid waste (MSW). According to the United States Environmental Protection Agency (EPA), approximately 35.7 million tons of plastic waste were generated in the United States in 2018, representing 12.2% of total MSW, with nearly 27 million tons disposed in landfills (EPA, 2022). Despite the large volume of plastic waste generated, only about 4.5% of plastic packaging is recycled, highlighting the need for alternative

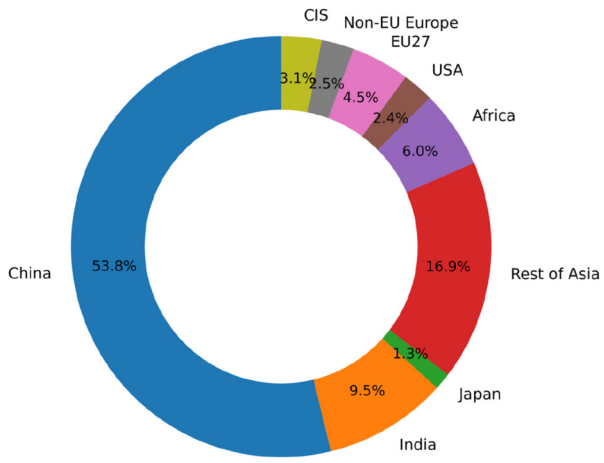

FIGURE 1
Regional distribution of global cement production in 2022: Quantitative assessment.

valorization strategies such as the use of recycled polymer fibers in construction materials.

Bajracharya et al. (2014) further reported that plastic waste accounts for approximately 10%–16% of municipal solid waste by weight in several industrialized countries, including Australia, the United Kingdom, and the United States. Due to their relatively low density, plastics occupy a disproportionately large volume within waste streams, creating significant waste management challenges.

2.2 Processing workflow

Municipal solid waste constitutes the primary source of PET and PP used for recycled fiber production. As illustrated in Figure 4, plastic waste is converted into recycled polymer fibers through a multi-stage processing pathway.

The recycling process typically begins with collection and sorting of plastic waste streams. PET bottles and packaging materials are separated from mixed waste using density-based separation methods, optical sorting technologies, or advanced sensor-based systems such as infrared spectroscopy and Raman spectroscopy (Ángeles-Hurtado et al., 2021). Ángeles-Hurtado et al. (2021) emphasized that effective plastic waste management systems are essential for improving recycling efficiency. In Mexico, for example, recycling activities provide income for more than 35,000 workers, and approximately 60% of PET bottles are recycled.

Following sorting, the plastic waste undergoes washing and cleaning processes to remove labels, adhesives, and other contaminants. The cleaned plastic is subsequently shredded into flakes, which are melted and extruded into continuous filaments before being cut into fibers of the desired length.

For polypropylene waste, mechanical recycling methods are typically used, involving shredding, granulation, and extrusion, followed by cutting of the extruded strands into discrete fibers (Burgada et al., 2021).

2.3 Key characteristics of recycled polymer fibers

Depending on the intended application, fibers may be produced in different geometric forms, such as straight, crimped, or fibrillated. Depending on the intended application, fibers may vary in geometry, including straight, crimped, or fibrillated forms, with lengths ranging from 6 mm to 60 mm and diameters between 0.01 mm and 0.5 mm. The physical and mechanical properties of recycled polymer fibers are crucial to their performance in concrete. PET fibers are characterized by relatively high tensile strength, ranging from 300 to 600 MPa, and an elastic modulus of 5–12 GPa (Guo and Ashida, 1993). PP fibers, while exhibiting lower tensile strength (150–400 MPa), offer superior chemical resistance and lower density (Kunugi, 1999). Both fibers are hydrophobic, which limits their interaction with the hydrophilic cement matrix (Wu and Qiu, 2022). This lack of affinity often results in weak interfacial bonding and limited stress transfer across cracks. To address this, researchers have investigated various surface modification techniques, such as alkali treatment, plasma treatment, or coating with nanomaterials, to enhance the fiber–matrix interface (El-Sayed and Abou-Taleb, 2023). Another important aspect of fiber performance is geometry. The aspect ratio (length-to-diameter ratio) of fibers influences their ability to bridge cracks, improve ductility, and control shrinkage. Short fibers (<12 mm) are generally effective for controlling plastic shrinkage cracking (Bertelsen et al., 2019), while longer fibers (20–50 mm) contribute more significantly to post-cracking toughness and

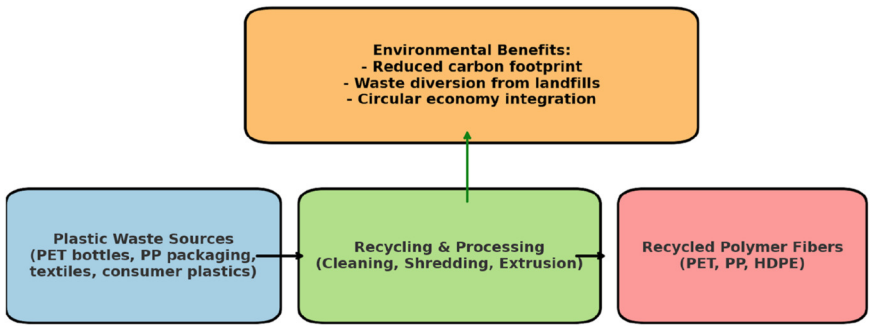

FIGURE 2
Conceptual framework illustrating the pathway from plastic waste to recycled polymer fiber-reinforced concrete and its environmental benefits.

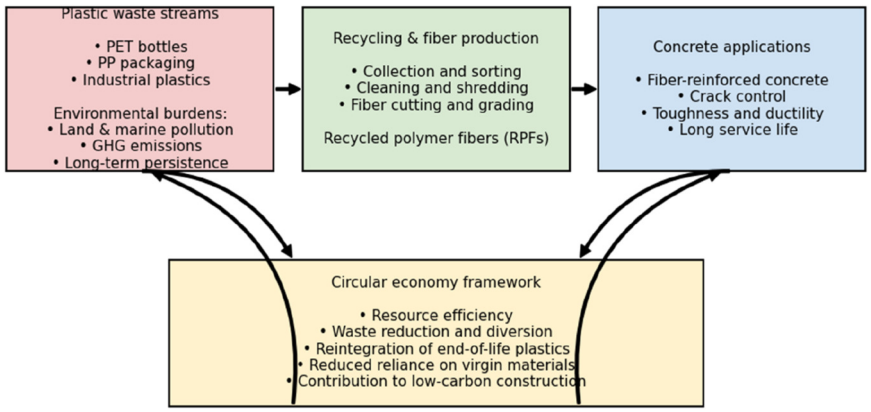

FIGURE 3
Conceptual illustration of the circular economy–based integration of recycled polymer fibers (RPFs) into concrete, highlighting the transformation of plastic waste into value-added reinforcement materials and their contribution to sustainable cementitious composites.

TABLE 1 Environmental benefits and challenges of incorporating recycled polymer fibers in concrete.

Aspect	Environmental benefits	Challenges/Limitations
Waste Management	Diverts plastic waste (PET, PP, etc.) from landfills and oceans, supporting the circular economy	Heterogeneous waste streams complicate fiber consistency and large-scale standardization
Carbon Footprint	Reduces CO_2 emissions and energy demand through partial replacement of virgin fibers	Variability in processing techniques may offset some of the environmental gains
Resource Efficiency	Promotes valorization of post-consumer plastics and industrial waste	Requires infrastructure for collection, segregation, and processing of waste plastics
Performance Enhancement	Improves toughness, crack resistance, and impact strength in concrete mixtures	Inconsistent geometry, poor dispersion, and weak fiber–matrix interfacial bonding
Life Cycle Assessment	LCA studies confirm reductions in greenhouse gas emissions and cumulative energy demand	Limited number of standardized LCA studies; results vary depending on regional practices
Sustainability Outlook	Aligns with UN Sustainable Development Goals (SDGs) and global decarbonization pathways	Lack of international guidelines and quality assurance protocols for recycled fibers

flexural performance (Garg et al., 2021). However, excessively long fibers may lead to poor dispersion, fiber balling, and reduced workability of fresh concrete. Optimizing the balance between fiber length, volume fraction, and workability remains a critical challenge in designing recycled polymer fiber-reinforced concretes (Lopez-Manchado and Arroyo, 2001). Processing conditions also affect fiber quality. For example, mechanical recycling of PET often leads to polymer chain degradation due to repeated heating and cooling cycles (Kawai et al., 2019). This results in reduced tensile strength and stiffness compared to virgin PET fibers. Similarly, contamination from other plastics, such as polyvinyl chloride (PVC) or polyethylene (PE), can compromise the uniformity of recycled fibers (Maou et al., 2021).

2.4 Modification techniques for fiber–matrix interaction

To improve the interfacial bonding between recycled polymer fibers and the cement matrix, several surface modification techniques have been investigated. These methods aim to enhance fiber roughness, increase surface energy, and improve mechanical interlocking at the fiber–matrix interface.

Common modification techniques include alkali treatment, plasma treatment, and nanomaterial coatings, which have been shown to improve fiber–matrix adhesion and increase crack-bridging efficiency (Rashwan et al., 2023). In addition, hybrid reinforcement approaches combining recycled polymer fibers with natural fibers or supplementary cementitious materials have shown promising results in balancing mechanical performance with sustainability objectives (Signorini and Volpini, 2021).

Advanced characterization techniques and numerical modeling approaches are also being applied to better understand the mechanisms of fiber reinforcement and environmental performance (Shen et al., 2020).

Figure 5 illustrates the load–deflection responses of plain concrete and fiber-reinforced concrete containing short and long fibers. The plain concrete specimen exhibits brittle behavior,

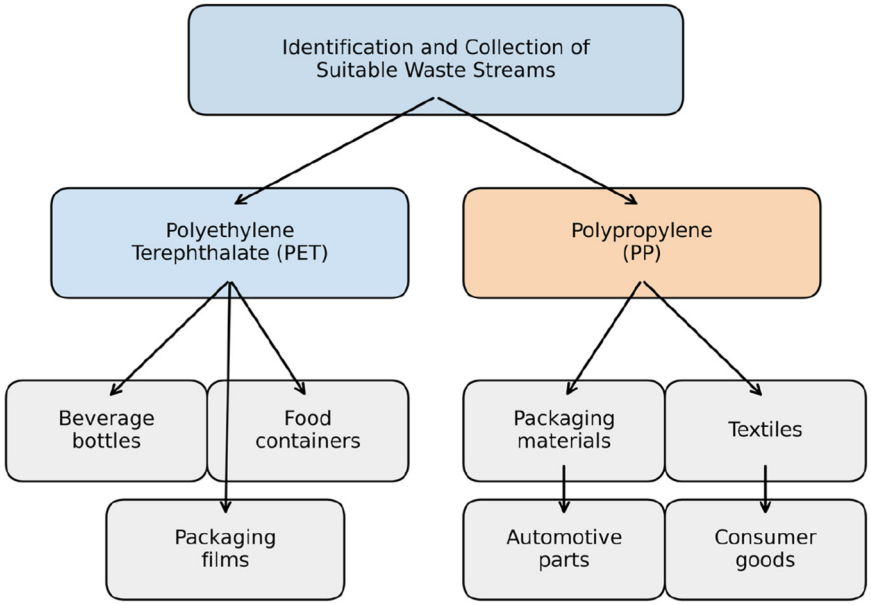

FIGURE 4
Sources of PET and PP wastes for potential reuse in cementitious composites.

characterized by a sudden drop in load-carrying capacity immediately after reaching peak load. In contrast, incorporating fibers significantly enhances post-peak performance.

The mixture with short fibers shows improved peak load and a more gradual reduction in load after cracking; however, a noticeable drop remains due to limited crack-bridging capacity. On the other hand, the use of long fibers provides a more pronounced improvement in ductility and energy absorption capacity. The long fibers effectively bridge cracks, resulting in a sustained load-carrying capacity even at higher deflection levels.

2.5 Comparative environmental considerations

From an environmental perspective, producing recycled polymer fibers generally requires significantly less energy than producing virgin fibers. For instance, recycled PET fibers may require up to 60% less energy and generate approximately 30%–40% lower CO_2 emissions compared with virgin PET fibers (de Assis et al., 2024; Katre et al., 2024).

However, it should be noted that the present study does not include a detailed life-cycle inventory analysis of plastic waste collection, transportation, and processing. Therefore, the reported environmental benefits are based on generalized findings from previous LCA studies rather than a system-specific assessment.

In this context, the environmental advantages of recycled PET fibers should be interpreted with caution, as factors such as transportation distance, recycling technology, and processing efficiency may significantly influence the overall impact. Comprehensive life cycle assessment (LCA) studies are therefore essential for accurately evaluating the sustainability of recycled polymer fiber systems (Intini and Kühtz, 2011).

In addition to PET and PP, other recycled polymers such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), and nylon fibers have also been explored for cementitious applications, although to a lesser extent (Laria et al., 2023; Ferr et al., 2025). Furthermore, recent research has investigated hybrid fiber systems that combine recycled and virgin fibers in order to balance mechanical performance and sustainability benefits (Singh and Demirsöz, 2022).

To provide a comprehensive overview of the environmental characteristics of recycled polymer fibers, Table 2 summarizes the main fiber types, waste sources, energy demand, potential CO_2 emission reductions, and key limitations reported in the literature.

3 Environmental benefits of recycled polymer fiber-reinforced concrete

3.1 Life cycle assessment framework

The integration of recycled polymer fibers into cement-based materials has attracted growing attention due to its potential environmental advantages. Recycled polymer fiber-reinforced concrete (RPFRC) utilizes plastic waste streams such as polyethylene terephthalate (PET) and polypropylene (PP) as reinforcing elements, thereby providing an opportunity to simultaneously address plastic waste management and reduce the environmental footprint of construction materials. The reuse of polymer waste in cementitious composites contributes to resource efficiency and promotes the development of more sustainable material cycles in the construction industry (Xanthopoulou et al., 2023).

To quantitatively evaluate the environmental implications of RPFRC, life cycle assessment (LCA) has become an essential analytical tool. LCA enables a systematic assessment of

environmental impacts associated with materials across their entire life cycle, including raw material extraction, processing, manufacturing, transportation, construction, service life, and end-of-life stages. In the context of fiber-reinforced concrete, LCA studies commonly examine environmental indicators such as global warming potential (GWP), cumulative energy demand, fossil resource depletion, and waste reduction potential.

When recycled fibers are used instead of virgin polymer fibers, several stages of the life cycle are directly affected. In particular, the substitution of virgin polymer production with recycling processes can substantially reduce the environmental burdens associated with petrochemical feedstocks and energy-intensive manufacturing operations. As a result, RPFRC has been increasingly investigated as a strategy to reduce the environmental impacts of concrete production while simultaneously improving waste management practices.

3.2 Core environmental benefits

3.2.1 Carbon footprint reduction

One of the most widely recognized environmental benefits of recycled polymer fiber-reinforced concrete is its potential to reduce greenhouse gas emissions associated with the production of fibers and concrete (Balea et al., 2021). The production of virgin synthetic fibers, particularly polypropylene (PP), requires substantial energy and relies heavily on petrochemical feedstocks, resulting in significant carbon emissions during manufacturing (Aslani and Nejadi, 2013).

Replacing virgin polymer fibers with recycled alternatives can significantly reduce these emissions. Several studies have reported that recycled PET fibers provide substantial environmental advantages compared with virgin PET production. For example, recycled PET fibers have been shown to achieve energy savings ranging from 40% to 85% and reductions in global warming potential (GWP) of approximately 25%–75% relative to virgin polymer production (Butyrin et al., 2024). These reductions primarily result from avoiding the energy-intensive polymerization processes associated with virgin plastic manufacturing.

Figure 6 presents the normalized CO_2 emissions of the investigated mortar systems expressed as $kgCO_2$ per MPa of compressive strength, enabling a performance-based comparison. Unlike the previous version, which provided only percentage values, the revised figure incorporates normalization based on mechanical performance, enabling a more realistic assessment of environmental efficiency. In addition, variability ranges (±5%) are included to reflect the inherent uncertainty associated with literature-based data. As shown in the figure, incorporating silica fume (SF) and coconut shell activated carbon (CSAC) results in a progressive reduction in normalized CO_2 emissions, indicating an improved balance between environmental impact and mechanical performance. This trend highlights the effectiveness of these materials in enhancing the sustainability of mortar systems when evaluated using performance-oriented indicators.

It should be noted that the mixtures labeled as K0–K8 in Figure 6 do not correspond to a single experimental dataset but represent a conceptual classification derived from literature findings. In this framework, SF content is considered constant (≈10%), while CSAC content increases progressively to reflect commonly reported replacement ranges. The normalized CO_2 values ($kgCO_2$/MPa) are used to provide a performance-based environmental comparison.

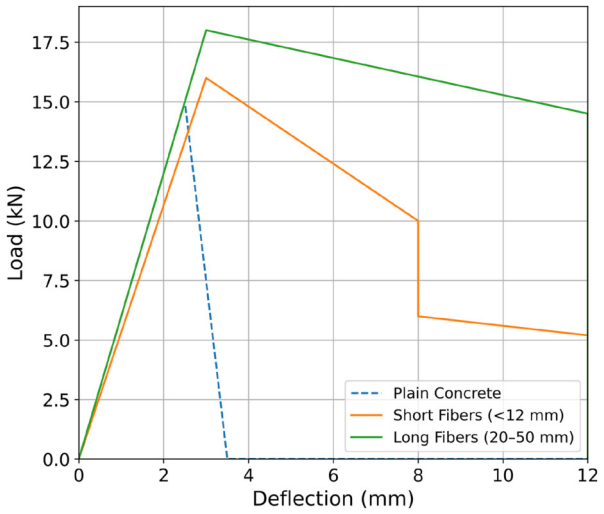

FIGURE 5
Schematic load–deflection response of plain concrete compared with short and long fiber-reinforced concrete.

3.2.2 Energy savings

In addition to reducing carbon emissions, recycled polymer fibers can significantly lower the energy demand associated with material production. The manufacturing of virgin polymer fibers involves multiple energy-intensive stages, including polymer synthesis, melt processing, extrusion, and fiber formation. These processes require substantial energy inputs and contribute to the overall environmental footprint of fiber-reinforced concrete.

In contrast, recycled polymer fibers are typically produced through mechanical recycling processes that involve collecting, sorting, washing, shredding, and extruding plastic waste. These recycling operations generally require considerably less energy than virgin polymer production.

As illustrated in Figure 6, virgin polymer fibers exhibit the highest energy consumption and CO_2 emissions due to the intensive petrochemical processes involved. Recycled polymer fibers produced through mechanical recycling routes demonstrate significantly lower environmental impacts. Although chemical recycling technologies can restore polymer quality, they typically involve additional processing stages and therefore may require higher energy inputs compared with mechanical recycling methods. Consequently, the environmental performance of recycled fibers depends strongly on the recycling technology employed and the associated processing conditions.

3.2.3 Waste diversion and resource recovery

The incorporation of recycled polymer fibers into concrete also helps reduce the environmental impacts associated with plastic waste disposal. According to data reported by the Organisation

TABLE 2 Environmental and sustainability aspects of recycled polymer fibers used in concrete.

Fiber type	Waste source	Energy demand compared to virgin fiber	CO_2 emission reduction	Main sustainability benefit	Key limitation
Recycled PET	Post-consumer bottles, industrial plastic waste	Up to ~60% lower	~30–40% lower	Significant reduction in GHG emissions and landfill diversion	Cleaning, transportation, and processing energy demand
Recycled PP	Packaging waste, industrial plastic by-products	Moderate reduction	Moderate reduction	Low density and wide availability	Variability in fiber geometry and quality
Recycled HDPE	Industrial plastic waste	Low to moderate reduction	Low to moderate reduction	High chemical stability and durability	Limited mechanical contribution
Recycled LDPE	Plastic films and packaging waste	Low reduction	Low reduction	Cost-effectiveness and flexibility	Weak fiber–matrix interfacial bonding
Recycled nylon	Textile and industrial waste	Moderate reduction	Moderate reduction	Good abrasion resistance and durability	Higher processing complexity
Hybrid recycled fiber systems	Mixed polymer waste or recycled–virgin blends	Variable	Variable	Balanced sustainability and performance	Lack of standardization and quality control

for Economic Co-operation and Development (OECD), global plastic waste generation increased from 156 Mt in 2000 to approximately 353 Mt in 2019 (Sonke et al., 2025). A significant portion of this waste is disposed of through landfilling, incineration, or uncontrolled dumping, leading to environmental pollution and resource loss.

Incorporating recycled plastic materials into concrete provides a high-volume application for waste valorization. Considering the enormous global demand for concrete, estimated at approximately 30 billion tons per year, even small substitution rates of recycled fibers could redirect millions of tons of plastic waste from landfills into construction materials (Uutel et al., 1990). Such applications transform plastic waste streams into value-added engineering materials and contribute to more sustainable waste management strategies.

3.3 Synergistic environmental benefits

Beyond the direct environmental benefits related to carbon emission reductions, energy savings, and waste diversion, recycled polymer fiber-reinforced concrete also provides several indirect environmental advantages. One of the most important contributions is its alignment with circular economy principles, which emphasize resource efficiency, waste minimization, and the reintegration of end-of-life materials into productive applications (Aldosari et al., 2024; Gracida-Alvarez et al., 2023).

By incorporating recycled PET and PP fibers into concrete structures, plastic materials that would otherwise enter waste streams can be immobilized within durable infrastructure systems. Due to the long service life of concrete structures, recycled polymers embedded within the cement matrix can remain encapsulated for decades, effectively preventing their release into the environment (Venkatachalam et al., 2022).

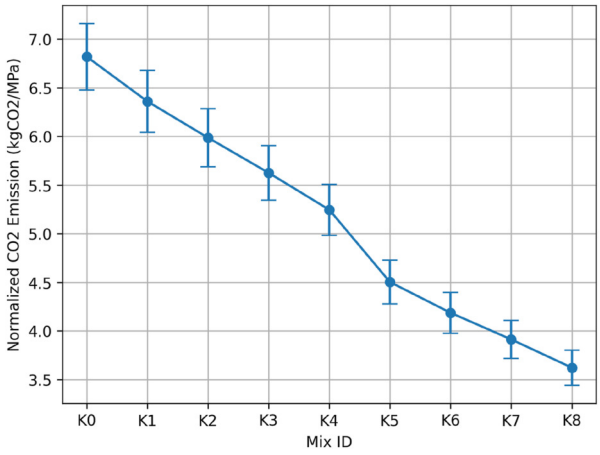

FIGURE 6
Normalized CO_2 emissions ($kgCO_2$/MPa) of mortar systems with variability ranges (±5%) for performance-based comparison. K0–K8 denote a literature-based conceptual classification, where SF is kept constant (≈10%), and CSAC content increases progressively.

The environmental advantages of RPFRC also support broader sustainability initiatives. For instance, the reuse of plastic waste and the reduction of embodied carbon contribute to the objectives of the United Nations Sustainable Development Goals (SDGs), particularly Goal 12 (responsible consumption and production) and Goal 13 (climate action) (Chatziparaskeva et al., 2022). Similarly, green building certification systems such as LEED and BREEAM encourage the use of recycled materials and low-carbon construction technologies, which can further promote the adoption of RPFRC in sustainable construction projects (Przybek, 2025).

In addition, recycled polymer fibers can help conserve natural resources by partially replacing resource-intensive materials such as

TABLE 3 Environmental drivers, circular economy contributions, and life-cycle implications of recycled polymer fiber–reinforced concrete (RPFRC).

Environmental aspect	Key indicator/ Concept	Quantitative or qualitative evidence	Sustainability implication	Representative references
Global plastic waste generation	Plastic waste volume	Increased from 156 Mt (2000) to 353 Mt (2019)	Urgent need for large-scale recycling pathways	Sonke et al. (2025)
Concrete production scale	Global concrete output	~30 billion tons annually	High potential for large-volume plastic waste utilization	Uutel et al. (1990)
Waste valorization	Use of recycled polymer fibers in concrete	Millions of tons of plastics can be repurposed with low substitution rates	Transformation of waste into value-added resources	Uutel et al. (1990)
Circular economy integration	Resource recirculation	End-of-life plastics reintegrated into durable infrastructure	Long-term material retention and waste reduction	Aldosari et al. (2024), Gracida-Alvarez et al. (2023), Venkatachalam et al. (2022)
Material immobilization	Long service life of concrete	Plastics remain locked in structures for decades	Sustained environmental benefit over time	Venkatachalam et al. (2022)
Alignment with global goals	UN Sustainable Development Goals	Supports SDG 12 (responsible consumption) and SDG 13 (climate action)	Policy and sustainability alignment	Chatziparaskeva et al. (2022)
Green building certification	LEED and BREEAM credits	Use of recycled materials and low-carbon technologies	Increased attractiveness for sustainable construction	Przybek (2025)
Natural resource conservation	Substitution of steel or virgin fibers	Reduced reliance on energy-intensive steel and petroleum-based fibers	Lower embodied energy and emissions	Mastali et al. (2018)
Recycling process impacts	Energy and emissions from recycling	Collection, sorting, cleaning, and processing require energy	Need for optimized recycling routes	Valverde-Burneo et al. (2025), Das et al. (2021)
Life cycle performance	Durability and service life extension	Improved crack control and reduced deterioration	Lower maintenance, repair, and life-cycle emissions	Hahladakis and Iacovidou (2019), Ahmad et al. (2022)

virgin synthetic fibers or steel fibers (Mastali et al., 2018). However, the environmental benefits of recycled fibers must be evaluated alongside the impacts associated with recycling processes themselves. Activities such as collection, sorting, cleaning, and processing of plastic waste require energy and may generate emissions (Valverde-Burneo et al., 2025). Therefore, comprehensive life cycle assessment studies are necessary to evaluate the balance between recycling benefits and processing impacts (Das et al., 2021).

Another indirect environmental benefit of RPFRC relates to improved durability and service life of concrete structures (Hahladakis and Iacovidou, 2019). Fiber reinforcement helps control shrinkage cracking and limits the propagation of microcracks, thereby reducing the ingress of aggressive agents such as chlorides and sulfates. Although improvements in mechanical strength may vary depending on fiber type and dosage, enhanced crack control can delay deterioration mechanisms and extend the service life of structures. Consequently, longer service life leads to reduced maintenance requirements, lower material consumption, and decreased life-cycle emissions (Ahmad et al., 2022).

The key environmental drivers, circular-economy contributions, certification relevance, and life-cycle implications of recycled polymer fiber-reinforced concrete are summarized in Table 3.

4 Technical and application challenges of recycled polymer fiber-reinforced concrete

Although recycled polymer fiber-reinforced concrete (RPFRC) offers considerable environmental and sustainability advantages, several technical and practical challenges still limit its widespread adoption in construction practice (Hamad et al., 2013). These limitations arise mainly from the variability of recycled materials, weak interfacial bonding between polymer fibers and cementitious matrices, uncertainties in engineering performance, and the absence of standardized specifications for recycled fiber applications (Ev et al., 2002). A comprehensive understanding of these challenges is essential for improving the reliability, scalability, and practical implementation of RPFRC in structural and non-structural concrete systems (Gu and Ozbakkaloglu, 2016).

4.1 Material-level challenges

4.1.1 Fiber performance variation

One of the primary challenges associated with recycled polymer fibers is the variability in their mechanical and geometric properties. Unlike virgin synthetic fibers, which are produced under controlled industrial conditions, recycled fibers originate from diverse waste

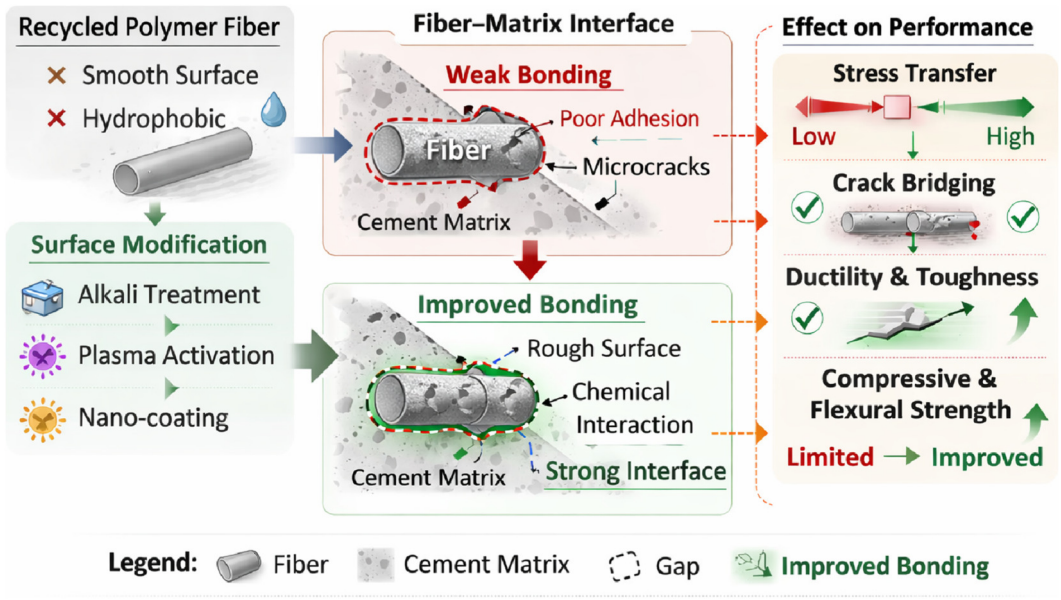

FIGURE 7
Fiber–matrix interfacial bonding mechanisms in recycled polymer fiber-reinforced concrete.

streams with different chemical compositions, manufacturing histories, and degradation levels. As a result, recycled fibers often exhibit irregular geometries, varying aspect ratios, and inconsistent tensile strength and stiffness (Rebeiz et al., 1993).

Differences in recycling processes can further influence fiber properties. Mechanical recycling, which involves shredding and extrusion of plastic waste, may lead to polymer chain degradation due to repeated thermal cycles. Consequently, recycled fibers may demonstrate reduced mechanical performance compared with their virgin counterparts. This variability complicates predicting fiber performance in concrete mixtures and introduces uncertainties in mix design optimization and structural reliability (Dehghan et al., 2017).

4.1.2 Weak interface bonding

Recycled polymer fibers often exhibit relatively weak interfacial bonding with the cementitious matrix, which represents a critical limitation for their effective reinforcement performance (Jo et al., 2008). In general, polymer-based fibers are inherently hydrophobic and chemically inert, which reduces their compatibility with the hydrophilic cement paste. Moreover, the relatively smooth surface texture of many recycled fibers further limits mechanical interlocking with the surrounding matrix (Kou and Poon, 2013). The weak interfacial bonding between recycled polymer fibers and the cementitious matrix is mainly attributed to their hydrophobic surface and limited mechanical interlocking with the surrounding matrix, as illustrated in Figure 7.

Weak fiber–matrix adhesion can reduce the efficiency of stress transfer across cracks and limit the fibers' crack-bridging capacity. Consequently, although recycled polymer fibers may improve ductility and crack resistance, their influence on enhancing compressive and flexural strength is often limited (Shourijeh et al., 2022). To address this limitation, several surface modification techniques have been investigated, including alkali treatment, plasma activation, and nanocoating, to increase surface roughness and improve fiber–matrix interfacial bonding (Farhangi and Karakouzian, 2020).

4.1.3 Impact on engineering performance

The incorporation of recycled polymer fibers may also influence several engineering properties of fresh and hardened concrete. From a fresh concrete perspective, high fiber dosages or long fiber lengths may reduce workability and cause fiber clustering or balling during mixing. This can result in non-uniform fiber dispersion and increased mixing energy requirements (Ulu et al., 2022).

The potential influence of recycled polymer fibers on fresh and hardened concrete properties is schematically illustrated in Figure 8.

In hardened concrete, the effects of recycled fibers on mechanical properties can vary depending on fiber type, dosage, and geometry. While improvements in crack control and post-cracking ductility are frequently reported, the influence on compressive and flexural strength remains inconsistent across different studies. Furthermore, the long-term durability performance of RPFRC requires further investigation. Environmental exposure conditions, such as freeze–thaw cycles, chloride penetration, sulfate attack, and chemical corrosion, may affect the long-term behavior of recycled polymer fibers embedded in the cement matrix (Harle, 2024).

4.1.4 Barriers to standardization and scaling

Another important barrier to the large-scale adoption of RPFRC is the lack of standardized specifications and design guidelines for recycled polymer fibers in concrete applications. While steel fibers and virgin synthetic fibers are covered by existing international standards, recycled polymer fibers are not yet supported by

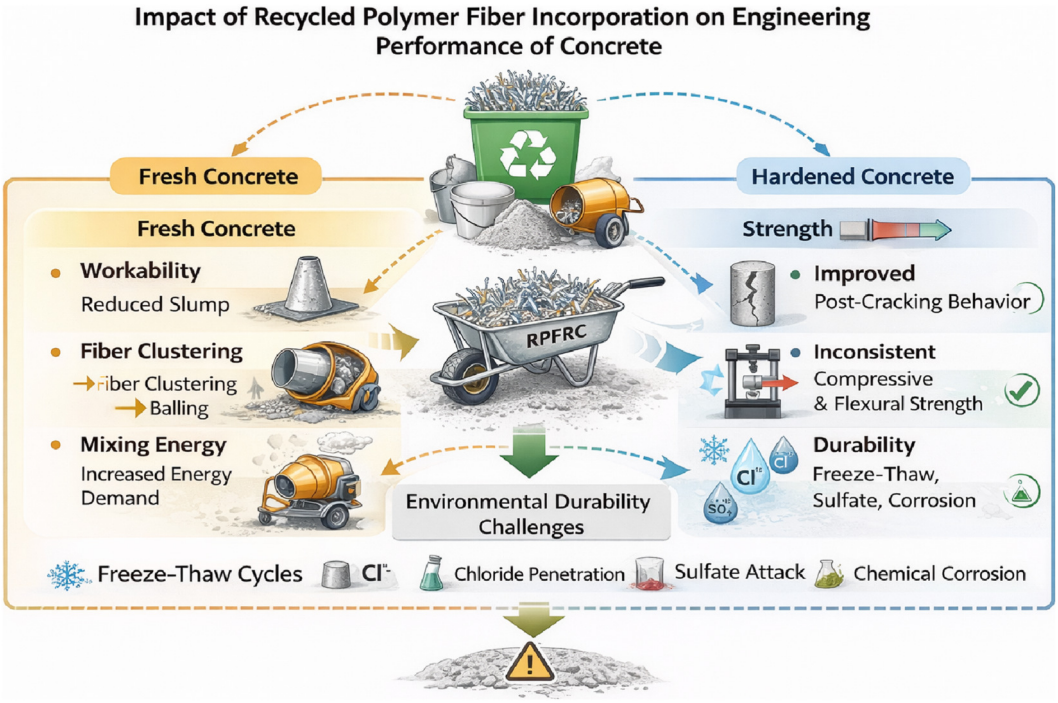

FIGURE 8
Effects of recycled polymer fibers on the engineering performance of concrete, including fresh concrete workability, fiber dispersion behavior, and hardened concrete mechanical and durability properties.

comprehensive material quality classifications or structural design recommendations (Jafari et al., 2018).

The absence of standardized testing protocols and material specifications creates uncertainties for engineers and practitioners when designing concrete mixtures incorporating recycled fibers. In addition, large-scale field applications and long-term performance data remain relatively limited, as most studies are currently confined to laboratory-scale experiments. Overcoming these barriers requires coordinated efforts among researchers, industry stakeholders, and regulatory organizations to establish standardized guidelines, quality-control procedures, and demonstration projects that validate the performance of recycled polymer fiber-reinforced concrete under real-world conditions (Odeh et al., 2025). The main standardization and scaling challenges of RPFRC and their possible solutions are summarized in Table 4.

5 Challenges and limitations of recycled polymer fiber-reinforced concrete

Although the integration of recycled polymer fibers (RPFs) into concrete offers clear sustainability advantages, several technical and practical challenges still limit their broader implementation in construction. These limitations are mainly due to material variability, weak fiber–matrix interactions, processing difficulties, and the absence of standardized testing and design guidelines (Suchorab et al., 2020). Understanding these constraints is essential for developing strategies to improve the reliability and practical adoption of recycled polymer fiber-reinforced concrete (RPFRC) (Sasi et al., 2024).

One of the key challenges arises from the heterogeneity of recycled fibers. Unlike virgin synthetic fibers produced under controlled industrial conditions, recycled fibers originate from diverse waste streams with varying chemical compositions, contamination levels, and mechanical properties (de Assis et al., 2024). For example, PET bottles may differ in additives and molecular orientation depending on manufacturing processes and intended applications (Lee et al., 2025), while recycled PP waste can originate from textiles, packaging, or automotive components with distinct mechanical characteristics (Frankenbach et al., 2025). Consequently, recycled fibers often exhibit irregular geometries, inconsistent aspect ratios, and variable tensile strengths, which complicates mix design optimization and may result in inconsistent performance in both laboratory and field applications (Seifali Abbas-Abadi et al., 2025).

Another important limitation is the relatively weak interfacial bonding between polymer fibers and the cementitious matrix. Both PET and PP fibers are hydrophobic and chemically inert, which reduces their affinity with the hydrophilic cement paste and limits efficient stress transfer (Marković et al., 2025). Smooth fiber surfaces may further reduce crack-bridging effectiveness and restrict improvements in mechanical strength (El-Messiry and Eid, 2025). As a result, recycled fibers generally contribute more to crack control and ductility than to enhancing compressive or flexural strength (Liu et al., 2025).

Several mitigation strategies have been proposed to overcome these challenges. Surface modification methods such as alkali treatment, plasma activation, and nanocoatings have been shown to improve fiber–matrix interactions and enhance stress-transfer mechanisms (Laib et al., 2025). However, these treatments may

TABLE 4 Standardization and scaling challenges associated with recycled polymer fiber-reinforced concrete (RPFRC) and potential mitigation strategies reported in the literature.

Challenge	Description	Impact on concrete performance	Potential mitigation strategies
Lack of standardized fiber specifications	Recycled polymer fibers originate from diverse waste streams with varying geometry, mechanical properties, and chemical composition	Difficulties in predicting fiber behavior and ensuring consistent performance in concrete mixtures	Development of standardized classification systems for recycled fibers based on geometry, tensile strength, and polymer type
Absence of design guidelines	Unlike steel or virgin synthetic fibers, recycled fibers are not yet included in most structural design codes and standards	Limited confidence among engineers and designers when specifying recycled fibers in structural applications	Development of design recommendations and inclusion of recycled fibers in international standards and codes
Limited large-scale field applications	Most studies on RPFRC remain limited to laboratory-scale investigations	Uncertainty regarding long-term structural performance under real environmental conditions	Implementation of pilot projects and full-scale field demonstrations to validate laboratory findings
Quality control challenges	Variability in recycling processes may result in inconsistent fiber properties and contamination	Reduced reliability and repeatability of concrete performance	Establishment of quality-control procedures for recycling processes and fiber production
Insufficient long-term durability data	Long-term performance of recycled fibers under aggressive environmental conditions is still under investigation	Uncertainty regarding freeze–thaw resistance, chemical durability, and long-term structural behavior	Long-term durability studies and monitoring of real infrastructure applications

increase processing complexity, energy demand, and cost, which must be carefully considered when evaluating the overall sustainability benefits of recycled fibers (Schultz et al., 2025). Lessons from other recycled materials used in concrete, such as recycled aggregates and construction waste, suggest that standardized processing procedures, improved quality control, and optimized mix design approaches can significantly reduce variability and improve performance consistency.

Workability issues also remain an important practical concern. Recycled fibers, particularly when used at high dosages or with large aspect ratios, may lead to fiber agglomeration and balling during mixing (Shater et al., 2025). Optimizing fiber content, adjusting mixing procedures, and using suitable admixtures may help mitigate these issues and improve fiber dispersion within the cementitious matrix.

The main technical and practical challenges associated with recycled polymer fibers in concrete, together with their underlying causes and potential mitigation strategies, are summarized in Table 5.

As illustrated in Figure 9, alkali treatment, plasma activation, and nano-coating represent the most common approaches to improve fiber–matrix interactions, each contributing to enhanced interfacial bonding.

The incorporation of recycled polymer fibers may also influence the workability of fresh concrete mixtures. Fiber agglomeration and balling can reduce flowability, increase mixing energy requirements, and lead to non-uniform fiber dispersion, particularly in mixtures requiring high workability such as self-compacting concrete. Adjusting fiber dosage, optimizing mixing procedures, and employing suitable chemical admixtures can partially mitigate these issues; however, such measures may introduce additional complexity into the mix design process (Hou et al., 2025).

Another important barrier to practical implementation is the absence of standardized specifications and quality control procedures for recycled polymer fibers. While steel fibers and virgin synthetic fibers are covered by established standards such as ASTM, EN, or ISO, recycled polymer fibers currently lack universally accepted material classifications and testing guidelines (Khan and Abbas, 2025). This limitation limits engineers' confidence in designing with recycled polymer fiber-reinforced concrete (RPFRC), as performance predictions remain uncertain without standardized evaluation methods. Similar challenges were previously observed during the early adoption of other recycled materials in concrete, such as recycled aggregates, where the development of standardized processing and testing procedures significantly improved reliability and acceptance.

Furthermore, large-scale field validation of RPFRC remains limited, as most available studies are based on laboratory-scale experiments (Deutz et al., 2025). Demonstration projects and pilot applications could therefore play an important role in evaluating long-term durability, structural performance, and constructability under real service conditions. Such initiatives may also help bridge the gap between academic research and practical implementation.

Economic and perception-related factors also influence the adoption of recycled polymer fibers. Although recycled fibers are typically less expensive than virgin fibers, variability in material quality may require additional processing, sorting, or quality assurance procedures, which can increase overall costs (Seifali Abbas-Abadi et al., 2025). In addition, skepticism within the construction sector regarding the durability and reliability of waste-derived materials can slow their acceptance in structural applications (Jaczynska and Mehta, 2025). Overcoming these barriers will require not only improved technical performance but also robust experimental data, successful pilot projects, and supportive regulatory frameworks (Li et al., 2024).

The main technical challenges and potential mitigation strategies associated with recycled polymer fiber-reinforced concrete are summarized in Table 6.

Although recycled polymer fiber-reinforced concrete (RPFRC) offers important environmental and sustainability advantages, several technical and practical challenges still limit its large-scale

TABLE 5 Technical and practical challenges limiting the widespread adoption of recycled polymer fiber–reinforced concrete (RPFRC).

Challenge category	Description	Underlying cause	Impact on concrete performance	Potential mitigation strategy	Representative references
Material variability	Heterogeneous fiber properties	Diverse waste sources, varying additives, contamination levels	Inconsistent mechanical and durability performance	Improved sorting, classification, and quality control	Gu and Ozbakkaloglu (2016), Rebeiz et al. (1993), Dehghan et al. (2017), Jo et al. (2008)
Geometric inconsistency	Irregular fiber length and aspect ratio	Non-uniform shredding and cutting processes	Difficulty in mix design optimization	Controlled fiber sizing and grading protocols	Jo et al. (2008)
Weak fiber–matrix bonding	Limited adhesion between fibers and cement paste	Hydrophobic and chemically inert nature of PET and PP	Reduced stress transfer and crack-bridging efficiency	Surface treatments (alkali, plasma, coatings)	Kou and Poon (2013), Shourijeh et al. (2022), Farhangi and Karakouzian (2020), Ulu et al. (2022)
Limited strength contribution	Marginal effect on CS and FS	Poor interfacial bonding and smooth fiber surfaces	Minimal improvement in peak mechanical strength	Hybrid reinforcement strategies	Farhangi and Karakouzian (2020)
Increased processing demand	Additional fiber treatments required	Surface modification and cleaning processes	Higher energy use and cost	Low-energy or mechanical treatment methods	Harle (2024)
Workability reduction	Fiber clumping and balling	High fiber dosage and long aspect ratios	Reduced flowability and poor fiber dispersion	Optimized dosage, hybrid fibers, use of admixtures	Jafari et al. (2018)
Lack of standardization	Absence of unified guidelines	Limited codes and testing standards for RPFRC	Restricted large-scale application	Development of standardized testing and design frameworks	Hamad et al. (2013), Ev et al. (2002)

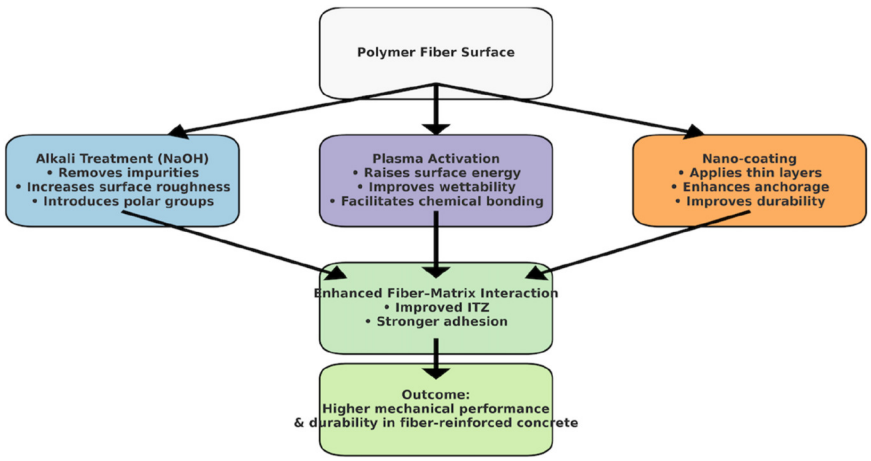

FIGURE 9
Process-oriented schematic of surface modification techniques to improve fiber–matrix interactions in cementitious composites.

implementation in construction practice. These limitations arise from material variability, weak fiber–matrix interaction, uncertainties in engineering performance, and the lack of standardized design approaches. To better understand the balance between environmental benefits and engineering constraints, the key issues reported in the literature are summarized through benefit–challenge comparison and trade-off analyses. The environmental advantages of recycled polymer fiber-reinforced concrete are often accompanied by several technical and practical challenges that must be considered during material design and application. While the use of recycled polymer fibers contributes to waste reduction, resource efficiency, and lower carbon emissions, these benefits may also introduce certain limitations related to material variability and performance consistency. In particular, differences in fiber geometry, surface characteristics, and recycling processes can influence fiber dispersion and mechanical behavior in concrete mixtures. Moreover, the hydrophobic nature of polymer fibers and the lack of standardized material classifications may create additional uncertainties in engineering applications. Addressing these

TABLE 6 Key challenges of RPFRC and corresponding mitigation strategies.

Identified challenge	Detailed description	Possible mitigation strategy
Heterogeneity of fibers	Recycled fibers vary in length, aspect ratio, and mechanical properties, leading to inconsistent performance	Fiber pre-sorting, blending techniques, or combining with virgin fibers to balance quality
Weak interfacial bonding	Surface impurities and the smooth texture of recycled fibers reduce bonding with cement paste	Surface modification (alkali treatment, plasma activation, nano-coating) to enhance adhesion
Reduced workability	Irregular geometry and a higher fiber content can hinder flowability and placement of fresh mixes	Use of superplasticizers and optimized mix designs to maintain workability
Durability uncertainties	The long-term performance of recycled fibers under harsh chemical or environmental conditions remains unclear	Extended durability testing, accelerated aging studies, and protective coatings for fibers
Lack of standardization	No globally accepted guidelines exist for the processing, classification, and quality control of recycled fiber	Development of international standards and certification systems for recycled fibers
Limited large-scale validation	Most research is confined to laboratory tests, with insufficient field applications and structural-scale validation	Pilot projects, full-scale demonstrations, and industrial collaborations to prove feasibility

TABLE 7 Benefit–challenge comparison for recycled polymer fiber-reinforced concrete (RPFRC).

Environmental/Sustainability benefit	Corresponding technical or application challenge	Implications for concrete performance	Possible mitigation strategies
Reduction of plastic waste through recycling of polymer materials	Variability in recycled fiber properties due to different waste sources and recycling processes	Inconsistent fiber dispersion and mechanical behavior	Development of standardized fiber classifications and quality control procedures
Lower carbon footprint compared with virgin synthetic fibers	Additional recycling steps such as sorting, cleaning, and processing	Potential increase in energy demand during recycling	Optimization of recycling technologies and energy-efficient processing
Contribution to circular economy and resource efficiency	Lack of standardized design guidelines for recycled polymer fibers	Limited confidence among engineers for structural applications	Development of design standards and technical guidelines
Improved crack resistance and ductility in concrete	Weak fiber–matrix interfacial bonding	Reduced efficiency in stress transfer across cracks	Surface modification techniques (alkali treatment, plasma treatment, nanocoating)
Conservation of natural resources by replacing virgin materials	Workability reduction at higher fiber contents	Fiber clustering and mixing difficulties	Optimization of fiber dosage and mixing procedures

issues requires careful optimization of fiber dosage, improvement of fiber–matrix bonding, and the development of appropriate design guidelines. The relationship between the environmental benefits of recycled polymer fibers and the associated technical challenges is summarized in Table 7.

The application of recycled polymer fibers in concrete also involves several important trade-offs between environmental benefits, engineering performance, and practical implementation. While recycled fibers can improve crack control and contribute to sustainability goals, increasing fiber content may negatively affect workability and mixing efficiency. Similarly, surface modification techniques can enhance fiber–matrix bonding and mechanical performance, but these treatments may introduce additional processing steps and environmental costs. In addition, although recycled fibers support circular economy principles by utilizing plastic waste, variability in fiber properties may introduce uncertainty into concrete performance. Balancing these competing factors is therefore essential to achieve both environmental and engineering benefits in recycled polymer fiber-reinforced concrete systems. The key trade-offs associated with the use of recycled polymer fibers in concrete are summarized in Table 8.

6 Conclusion and future outlook

This review has critically examined the role of RPFs, particularly PET and PP, in enhancing the sustainability of cementitious composites. While conventional research on fiber-reinforced concrete has largely emphasized mechanical and durability aspects, this study placed primary focus on the environmental benefits and challenges of using recycled fibers. By synthesizing current findings, the review demonstrated that recycled fibers help reduce the carbon footprint of concrete, divert plastic waste from landfills, and support circular economy practices. At the same time, technical, economic, and standardization challenges were identified, highlighting areas requiring further research to achieve widespread adoption.

TABLE 8 Key trade-off relationships in recycled polymer fiber-reinforced concrete (RPFRC).

Trade-off category	Positive effect	Associated challenge	Implications
Surface treatment vs. environmental impact	Improved fiber–matrix bonding and mechanical performance	Additional processing steps and chemical usage	Possible increase in environmental footprint and cost
Fiber content vs. workability	Increased crack resistance and toughness	Reduced flowability and potential fiber balling	Need for optimized fiber dosage
Sustainability vs. economic feasibility	Utilization of recycled materials reduces environmental impact	Additional processing and quality control requirements	Potential increase in production cost
Durability improvement vs. material variability	Enhanced crack control and potential durability benefits	Variability in recycled fiber properties	Requires improved quality control and standardization

The major conclusions of this review can be summarized as follows:

- Recycled polymer fibers, particularly PET and PP, provide a viable pathway to integrate large volumes of plastic waste into concrete, thereby reducing environmental pollution and landfill accumulation.
- LCA studies indicate that recycled fibers reduce energy demand and greenhouse gas emissions compared to virgin synthetic fibers, contributing significantly to sustainability targets.
- The addition of recycled polymer fibers supports circular economy principles by reintegrating end-of-life plastics into long-lived infrastructure, locking waste materials into durable applications.
- Despite sustainability benefits, fiber heterogeneity and inconsistent properties remain critical barriers, leading to variable performance outcomes in fresh and hardened concrete.
- Weak interfacial bonding between hydrophobic polymer fibers and the cementitious matrix limits mechanical efficiency, necessitating surface modification or hybrid reinforcement strategies.
- Workability challenges, such as fiber clumping and reduced flowability, require careful optimization of fiber geometry, dosage, and admixture use.
- The absence of standardized guidelines for recycled polymer fibers restricts large-scale application and industry confidence, underscoring the need for harmonized testing protocols and specifications.
- Future research should prioritize large-scale field studies, improved recycling and processing methods, and innovative surface treatments to enhance bonding and reliability, while maintaining the sustainability benefits of using recycled fibers.

Author contributions

ZA: Writing – original draft, Writing – review and editing. SG: Writing – original draft, Writing – review and editing. MA: Writing – original draft, Writing – review and editing. FO: Writing – original draft, Writing – review and editing. JS: Writing – original draft, Writing – review and editing. JŠ: Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. TT: Writing – original draft, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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