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Review

Polypropylene Fibers in Pavement Concrete: Mechanical, Durability, and Sustainability Review

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ABSTRACT

Polypropylene fibers (PPF) are attracting growing interest as a reinforcement for concrete pavements, where their low cost, corrosion resistance, and chemical inertness address several of the intrinsic weaknesses of plain Portland cement concrete. This review consolidates laboratory, field, and standardized-test evidence on how PPF influence the mechanical performance, durability, and sustainability of pavement concrete. Across the collected studies, PPF contribute only modest gains in compressive strength but substantial improvements in flexural and tensile behavior, fracture toughness, and energy absorption, together with marked reductions in plastic and drying shrinkage and enhanced resistance to impact, abrasion, skid wear, and freeze–thaw and chemical exposure. These effects are most pronounced within an effective dosage range of roughly 0.3%–1.0% by volume, beyond which reduced workability, dispersion difficulties, and the low elastic modulus of polypropylene begin to offset the benefits. Collectively, they extend service life and lower maintenance demand, particularly under the repeated and moving loads characteristic of pavements, and can permit thinner sections at equivalent load capacity. Hybrid systems combining PPF with steel, basalt, nano-silica, or recycled constituents recover complementary properties and perform well in high-demand applications such as airport runways, bridge decks, and tunnel linings. From a sustainability standpoint, PPF reduces plastic waste and carries lower embodied energy and carbon than steel reinforcement, and life-cycle assessments report emissions and cost savings at optimized dosages. The review identifies fiber surface treatment, mix-design optimization, and machine-learning-based performance prediction as the principal routes to overcoming current limitations, and highlights hybrid and multi-scale composites, self-monitoring fiber systems, and improved PPF formulations as priorities for future research toward durable, low-impact pavement infrastructure.

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ABBREVIATIONS

PPF, polypropylene fiber; PPFRC, polypropylene fiber-reinforced concrete; PCC, Portland cement concrete; NSC/HSC, Normal-/high-strength concrete; RAC, recycled-aggregate concrete; SCC, self-compacting concrete; GPC, geopolymer concrete; UHPC, ultra-high-performance concrete; RCC, roller-compacted concrete; LECA, lightweight expanded clay aggregate; ITZ, interfacial transition zone; FBG, fiber Bragg grating

INTRODUCTION

Concrete pavements are used across nearly all infrastructure networks for their stiffness, durability, and long service life. Yet Portland cement concrete (PCC) carries intrinsic weaknesses—low tensile strength, limited crack resistance, and susceptibility to shrinkage and environmental deterioration—that manifest in service as premature cracking, surface wear, and a rising maintenance burden as pavements age. Fiber reinforcement has emerged as an effective response to these limitations, improving the mechanical response and post-cracking behavior of concrete and thereby extending its useful life [1–4]. As illustrated in Figure 1, polypropylene fiber-reinforced concrete (PPFRC) sustains higher load and deflection than plain concrete at both serviceability and ultimate states, owing to its greater ductility and post-crack load-carrying capacity [5]. These improvements translate directly into longer service life, lower maintenance cost, and a stronger sustainability case for PPFRC in pavement applications.

Fiber reinforcement acts as an internal, discontinuous reinforcement distributed throughout the matrix. Both natural and synthetic fibers are used for this purpose, including steel, polypropylene, glass, carbon, aramid, and basalt [6–9]. Acting as micro-reinforcements, the fibers bridge microcracks and restrain their propagation, improving ductility and durability while also enhancing resistance to freeze–thaw damage and to plastic and drying shrinkage [1,2,10]. Macro-synthetic fiber-reinforced concrete, in particular, combines high durability with effective crack control and has been applied in pavements, slabs, tunnels, and bridge decks where these attributes are decisive [11].

Among synthetic fibers, polypropylene fiber (PPF) has been studied most extensively, owing to a combination of low cost, corrosion resistance, tensile durability, chemical inertness, and ready dispersion within a cementitious matrix [11–14]. Distributed through the matrix, PPF form a three-dimensional network that limits microcrack development and reduces permeability, improving durability and longevity [15,16]. These properties are especially valuable in pavement engineering, where cyclic traffic loads and environmental exposure are the governing challenges [13,17,18], and PPF have accordingly been applied not only in pavements and overlays but also in canals, dams, and repair works [10,11,17]. Their potential extends to emerging binder systems as well: in geopolymer concrete (GPC), PPF have been reported to improve tensile behavior and cracking resistance [19].

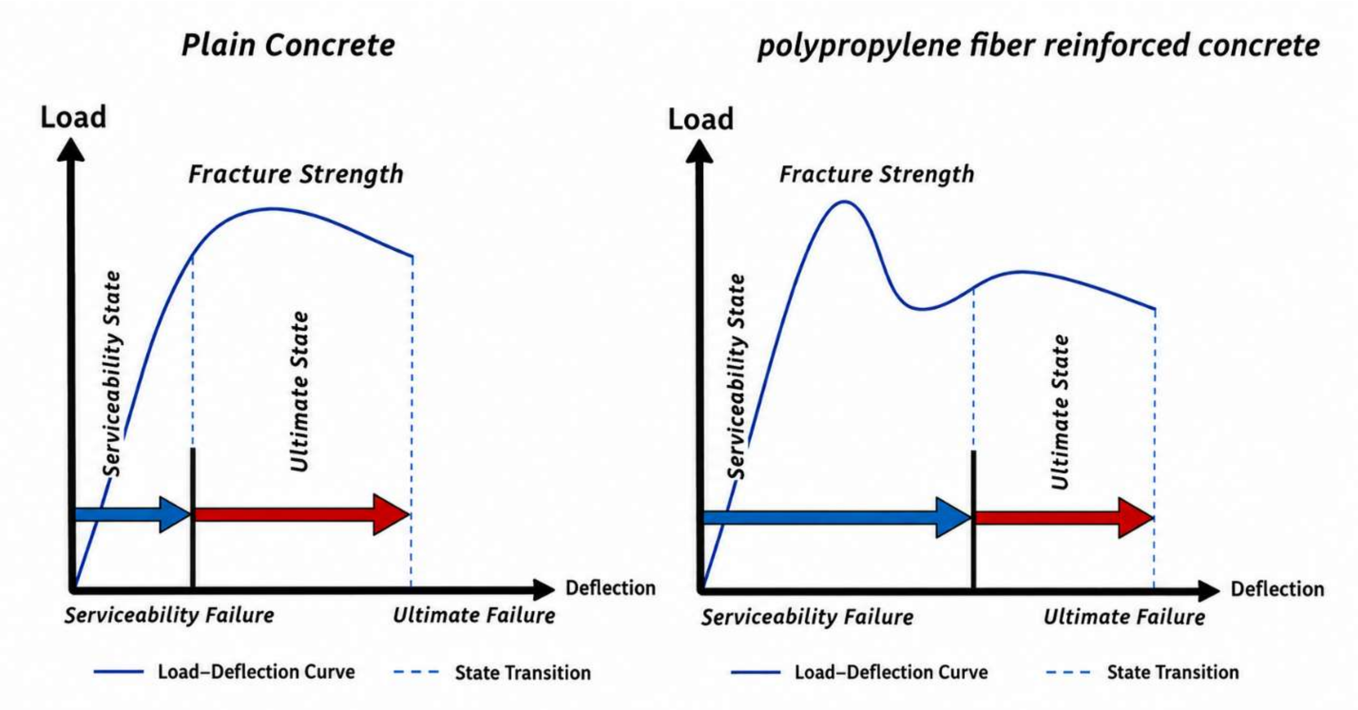

Figure 1. States of behavior of plain concrete vs. PPF-reinforced pavement [5].

This review examines comprehensively the influence of PPF on the performance of concrete pavements, integrating laboratory, field, and standardized-test evidence. Its objectives are to synthesize the effects of PPF on fresh and hardened properties, shrinkage and crack control, durability, and structural and field behavior, and to connect these findings to sustainability and to practice. Its contribution is to bring these strands together in a single pavement-focused account: where existing reviews of PPFRC are largely confined to a single theme, this work spans the full property chain, foregrounds the dose–response behavior that recurs across property classes, and treats hybrid PPF systems and life-cycle performance alongside the mechanical evidence. The remainder of the paper is organized as follows. Section Methodology of Literature Review describes the literature search, screening, and analysis methodology. Section Polypropylene Fibers: Properties and Types examines the physical, chemical, and morphological properties of PPF and its principal forms. Sections Effects on Fresh Concrete Properties through 8 address, in turn, fresh-state behavior, mechanical performance, shrinkage and crack control, durability, and structural and field performance. Section Sustainability and Economic Aspects considers sustainability and economic aspects, Section Practical Considerations and Limitations discusses practical considerations and limitations, and Sections Future Research Directions and Conclusions present future research directions and conclusions.

METHODOLOGY OF LITERATURE REVIEW

A structured review methodology was adopted to characterize the use of polypropylene fiber (PPF) in concrete pavements systematically and reproducibly. Peer-reviewed literature was retrieved from four databases, Scopus, Web of Science, Google Scholar, and ScienceDirect, covering journal articles, conference proceedings, and technical reports published between 2000 and 2025. This window was chosen because modern macro-synthetic polypropylene fibers for structural and pavement use, and the specifications governing them (notably ASTM C1116), consolidated from around 2000 onward, making this period the most relevant to current pavement practice; a small number of foundational earlier studies were retained by hand-selection where they underpin the mechanisms discussed [3,20–22]. Searches combined Boolean operators with the keywords “polypropylene fiber,” “concrete pavement,” “fiber reinforced concrete,” “durability,” “mechanical properties,” “PP fibers,” “pavement performance,” “macro-synthetic fibers,” and “crack resistance.”

Retrieved records were screened first by title and abstract and then by full text to assess technical relevance and methodological robustness. Inclusion and exclusion criteria were defined in advance to ensure rigor and reproducibility, and are summarized in Table 1. In brief, a study was included if PPF was a primary experimental variable, if the matrix was concrete or geopolymer concrete intended for pavement or structural application, and if empirical results were reported for mechanical performance, durability, shrinkage, or field implementation. Studies were excluded if PPF was not used directly, if no comparison against a control or alternative fiber was provided, or if the application was non-pavement and non-structural, such as masonry or mortar. Only English-language experimental, numerical, or field-based studies were considered.

Table 1. Inclusion and exclusion criteria.

Criterion	Included	Excluded
Fiber	PPF as a primary variable	PPF absent or incidental
Matrix/application	Concrete or geopolymer concrete for pavement or structural use	Non-concrete matrices (masonry, mortar); non-structural use
Evidence	Empirical results on mechanical, durability, shrinkage, or field performance	No empirical data; no control or comparative baseline
Study type	Experimental, numerical, or field-based	Opinion pieces; non-peer-reviewed unless a technical report of record
Language/period	English; 2000–2025 (plus seminal earlier works)	Other languages

The screening and selection process is documented in the PRISMA flow diagram of Figure 2. Database searching identified 1842 records (Scopus, 598; Web of Science, 469; ScienceDirect, 388; Google Scholar, 387), from which 514 duplicates were removed, leaving 1328 records for title-and-abstract screening. Screening excluded 1022 records as clearly outside scope, and 306 reports were sought for full-text retrieval, of which 19 could not be obtained. The remaining 287 full texts were assessed for eligibility, and 122 were excluded with reasons: PPF not a primary variable (44), no control or comparative baseline (29), non-pavement or non-structural application such as masonry or mortar (22), insufficient empirical data (15), and overlapping or duplicated datasets (12). A further 23 studies were added through backward citation and hand-searching of foundational pre-2000 works and governing standards. In total, 188 studies met the inclusion criteria and were included in the synthesis.

Included studies were classified along two axes to support thematic and comparative analysis. The first grouped studies by performance domain: (i) fresh-state properties (workability, slump, bleeding); (ii) mechanical properties (compressive, flexural, and tensile strength); (iii) durability (freeze–thaw resistance, permeability, abrasion); (iv) crack control (plastic, drying, and thermal shrinkage); and (v) structural and field performance (fatigue resistance, joint behavior, long-term deformation). The second grouped studies by experimental scale, numerical simulation, laboratory-scale testing, and full-scale field work, so that findings could be compared within, as well as across, methodological levels.

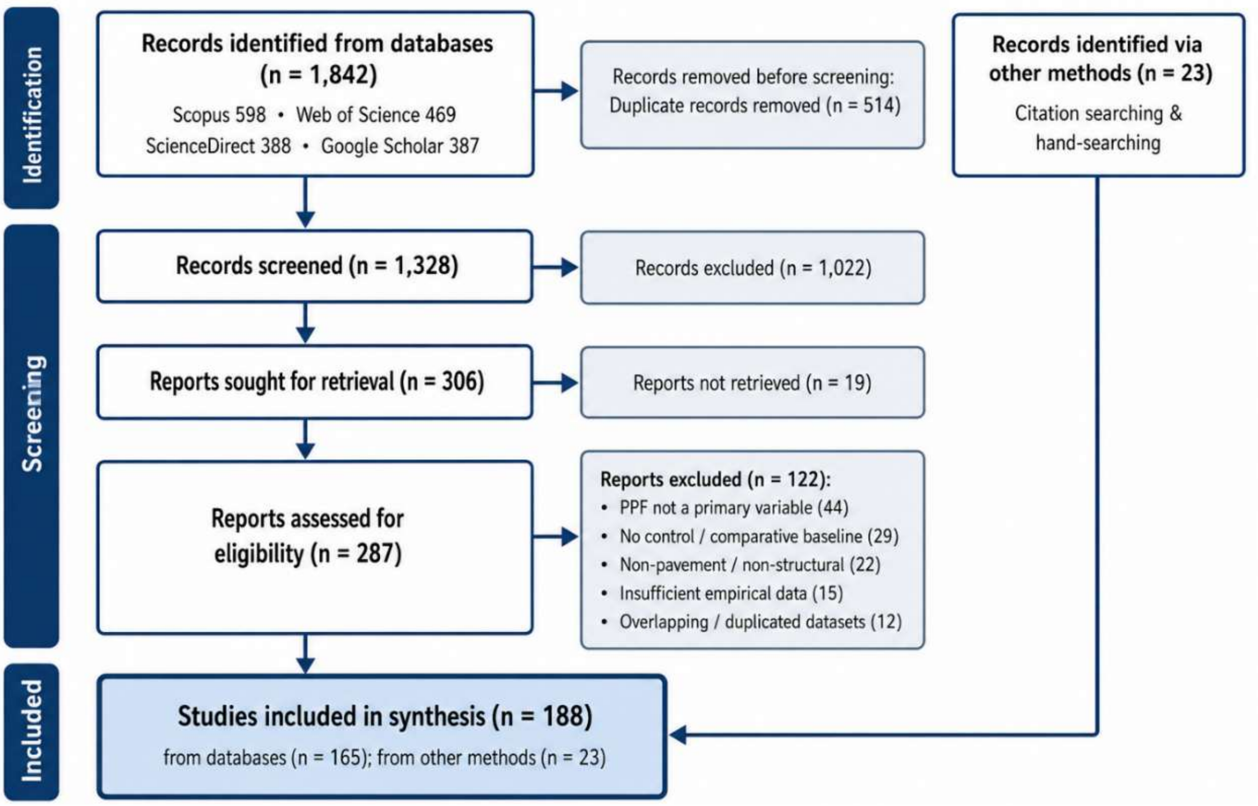

Figure 2. PRISMA flow diagram of the literature search and study selection process.

Data were extracted into a standardized comparison matrix to allow consistent qualitative and quantitative evaluation. Recorded variables included fiber dosage, aspect ratio, curing age, and test method. Where possible, reported outcomes were normalized against control mixtures to limit heterogeneity arising from differences in mix design and test protocol, and results were interpreted with reference to standardized methods such as ASTM C1116 and ACI 544. To reduce bias, geographically diverse studies were included, and reported outcomes were cross-checked against these reference procedures. The synthesis records not only performance improvements but also the limitations and inconsistencies present in the underlying data.

POLYPROPYLENE FIBERS: PROPERTIES AND TYPES

Chemical and Physical Properties

Polypropylene fibers are synthesized by polymerizing propylene, a petroleum by-product [23,24]. They are chemically inert, non-corrosive, hydrophobic, and of low thermal conductivity, which suits them to durable cementitious materials in chemically aggressive service [23]. Their density is approximately 0.91 g/cm^3, and their melting point is 165–170 °C, giving thermal stability in hardened concrete [25]. Reported tensile strength reaches about 350 MPa with an elastic modulus of roughly 9.5 GPa (e.g., TUF-Strand SF, Euclid) [25,26]. These characteristics enhance the ductility and energy-absorbing capacity of concrete and help mitigate shrinkage and impact-induced cracking [23,27].

Classification: Monofilament, Fibrillated, and Macrofibers

Commercial PPFs are classified chiefly by geometry and function. Microfibers, usually shorter than 30 mm and monofilament, control early-age microcracking and plastic shrinkage; their small diameter and large specific surface area promote uniform dispersion and reduce local weak points [24]. Macrofibers, typically 30–50 mm long, provide structural reinforcement, bridging cracks, improving post-cracking load transfer, and, under flexural and cyclic loading in pavements and slabs, functioning as an alternative to conventional steel reinforcement [24,28]. A third form, fibrillated fibers, is produced by mechanically splitting film-grade polypropylene into a net-like structure that improves mechanical interlock with the surrounding paste and thereby enhances bond and crack control. Figure 3 illustrates these geometries: Figure 3a microfibers for shrinkage control, Figure 3b macrofibers for structural support, and Figure 3c fibrillated fibers for matrix interlock.

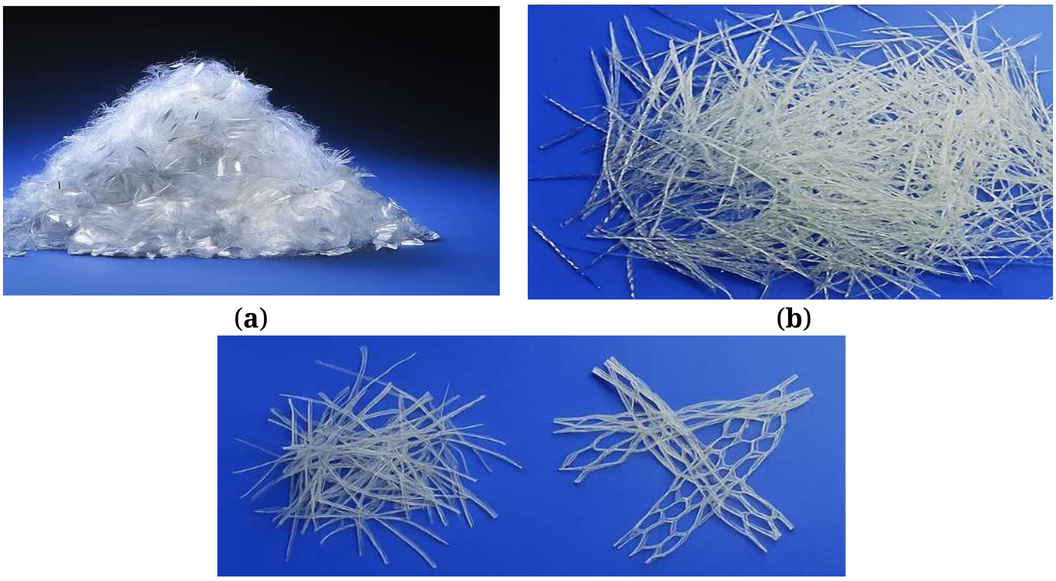

Figure 3. PPF applied to concrete: (**a**) microfibers for shrinkage alleviation [29,30]; (**b**) macrofibers for support [29,30]; (**c**) fibrillated fibers [31].

Manufacturing and Geometrical Features

Commercial PPFs are produced by melt spinning, in which molten polypropylene is extruded, drawn, and cut to specified lengths and shapes. Performance depends strongly on geometry, length, diameter, and aspect ratio (L/d). Reported lengths range from 18 mm [32] and 24 mm [28] to 50 mm [26], selected according to application, and aspect ratios typically fall between 50 and 100, with a value of 74 reported in comparative work [26]. Surface texture governs fiber–matrix adhesion: smooth fibers disperse readily but develop lower pull-out resistance, whereas embossed or crimped fibers improve mechanical interlock and post-cracking anchorage.

Advantages of PPF over Steel and Other Synthetic Fibers

PPF offers several advantages over steel, carbon, and glass fibers, particularly where chemical resistance and durability are decisive. Being non-metallic, they do not corrode and remain stable after prolonged exposure to moisture, salts, or aggressive chemicals that can severely degrade steel reinforcement [24,33]. Their low density reduces the weight of the composite and simplifies transport, mixing, and placement, a practical benefit in large paving projects [23]. Their chemical stability under both alkaline and acidic conditions further suits them to industrial and coastal environments [23]. Mechanically, PPF enhance energy absorption and post-cracking ductility, exceeding some mineral fibers such as glass in toughness and crack-bridging capacity [27]. Steel fibers remain superior in stiffness and ultimate load capacity; PPF are more effective at controlling shrinkage, distributing microcracks, and providing durability where corrosion resistance matters more than initial stiffness.

These attributes make PPF an economical, resilient, and low-maintenance reinforcement for concrete pavements and infrastructure.

Commercial Products and Standards

Commercial PPFs are manufactured to defined specifications, including TUF-Strand SF (Euclid) and comparable products from manufacturers such as Dostkimya (Türkiye), under ASTM C1116-03 (2017) for fiber-reinforced concrete [25]. These standards set out fiber classification, performance requirements, and compatibility for concrete use, and effective performance depends on uniform dispersion and chemical inertness during mixing and placement. A wide range of commercial products is available, differing in length, diameter, and micro/macro configuration according to their intended function: crack bridging, plastic-shrinkage control, or structural reinforcement. Table 2 compares representative products.

Table 2. Representative commercial PPFs and their properties.

Ref.	Fiber product	Length (mm)	Diameter (mm)	Type	Key properties
[25]	PP fiber (Dostkimya)	3	0.02	Micro	Tensile 350 MPa; melting 165–170 °C; ASTM C1116 compliant
[32]	PQC fiber	18	N/A	Macro	Used in pavement-quality concrete
[28]	Macrofiber	24	0.28	Macro	Crack-bridging; SCM-compatible
[23]	Generic PPF	Variable	N/A	Micro/Macro	Non-corrosive, hydrophobic, chemical/fire resistant, tough
[24]	PPF (micro & macro)	<30 (micro); 30–50 (macro)	N/A	Micro/Macro	Micro: shrinkage/crack control; macro: structural/load-bearing
[26]	TUF-Strand SF (Euclid)	50	N/A	Macro	Modulus 9.5 GPa; aspect ratio 74
[27]	Generic PPF	N/A	N/A	Macro	High energy absorption; corrosion-resistant
[33,34]	PP/Nylon	N/A	N/A	Synthetic	Improves impact resistance and impermeability; corrosion-resistant

Geometry and Its Influence on Pavement Performance

Taken together, the evidence shows that fiber geometry, not fiber chemistry alone, governs how PPF perform in pavement concrete, and the three geometric parameters act through distinct mechanisms. Length controls crack-bridging reach: reported compressive and split-tensile strengths rise almost linearly with fiber length up to about 50 mm and then plateau or decline as workability losses offset the bridging benefit, with longer macrofibers (50–60 mm) giving the strongest correlations at moderate-to-high fiber volumes [35]. Aspect ratio mediates the trade-off between anchorage and mixability: higher ratios improve pull-out resistance and load transfer across cracks, but excessive values promote entanglement and dispersion problems, so intermediate values (around 74 in the products reviewed here) balance the two [26]. Surface texture determines interfacial bond: smooth monofilaments disperse well but pull out at low load, whereas crimped, embossed, or fibrillated forms develop mechanical interlock that raises post-cracking residual strength and toughness. For pavements specifically, these geometric effects map onto the properties that matter most: flexural capacity, fatigue and impact resistance, and control of shrinkage and reflection cracking, so geometry should be selected against the governing design objective (early-age crack control favors fine microfibers; structural load-bearing and post-crack toughness favor longer, textured macrofibers) rather than by dosage alone.

EFFECTS ON FRESH CONCRETE PROPERTIES

Workability and Rheology

Adding PPF to concrete consistently reduces slump and workability, an effect that scales with dosage. Reported reductions range from about 6% at 0.25% fiber to 22% at 1% by volume [24], while a dosage of 0.4% has been reported to lower slump by roughly 10 cm [36]. The mechanism is physical rather than a loss of true flowability: the fiber network restrains the mobility of the cement paste, and the large specific surface area of the fibers captures additional paste and increases internal friction [37,38]. The effect is amplified in specialized systems, in lightweight expanded-clay-aggregate (LECA) concrete, PPF additions up to 1% reduced both workability and density while substantially increasing crack resistance and impact energy absorption relative to the fiber-free lightweight mix [39]. Because reduced workability is the most common practical objection to PPF, it is treated here as a design variable to be managed rather than an inherent barrier.

Segregation and Bleeding

Against this workability penalty, PPF improves mixture stability by reducing bleeding and segregation. The interwoven fiber network binds the aggregate skeleton and restricts upward water migration, a benefit most evident in high-fluidity mixtures such as self-compacting concrete (SCC). Across PPF dosages of 0.3%–1.2%, flow-test batteries (slump flow, L-box, J-ring, V-funnel) show only modest losses in flowability; for example, slump flow is reduced by about 3% and L-box ratio by about 2%, while the mixture remains cohesive and homogeneous [40,41]. Adding polypropylene fiber reduces the workability of the fresh mix by up to ~45% at fiber volume fractions near 0.9%, while shifting the failure mode from brittle to ductile through post-crack fiber bridging, representing a trade-off between ease of placement and toughness [42].

Restoring Workability: Admixtures and Fiber Treatment

The workability loss can be offset without reducing fiber content. Superplasticizers and viscosity-modifying admixtures restore the required flow while preserving cohesion, and fiber geometry can be tuned to limit rheological disruption; crimped macrofibers (e.g., 39 mm length, 0.92 mm diameter) alter flow behavior while improving mechanical interlock [43]. Pre-soaking the fibers and applying surface treatments further improves dispersion and suppresses fiber balling, both of which are essential to maintaining consistent performance at higher dosages.

Dosage–Workability Relationship

Read across studies, the workability response to PPF is monotonic but non-linear, steepening as dosage rises. In normal concrete, slump falls by roughly 6%–22% as fiber content increases from 0.25% to 1% [24]; in SCC, a representative mixture showed a 3% reduction in slump flow together with an 18% increase in T50 and a 12% increase in V-funnel time, indicating higher flow resistance rather than instability [41]; Polypropylene fiber reduces workability, with slump losses exceeding 50% reported at around 1 wt% fiber in some mixes [44].

This trend is summarized in Figure 4, where increasing dosage from 0 to 3.5 kg/m^3 reduces slump from 185 mm to 95 mm [45]. The consistent implication is that fiber content must be optimized to balance constructability against the mechanical and durability benefits, since the surface-area and entanglement effects that degrade workability are the same ones that later govern crack bridging. Table 3 summarizes the reported effects of PPF on fresh-state behavior.

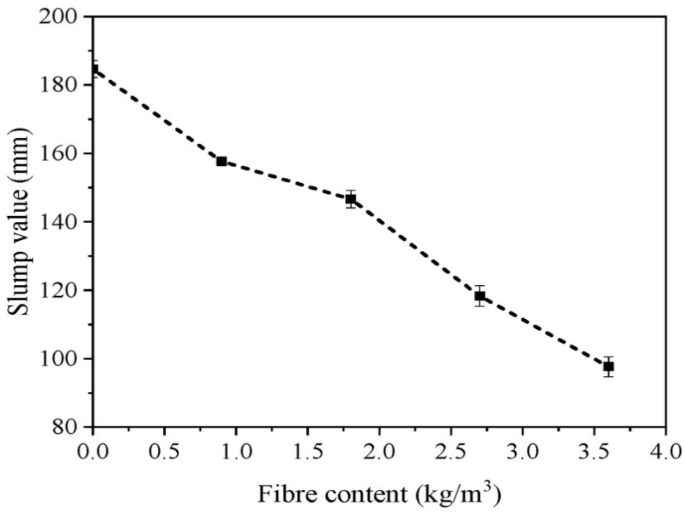

Figure 4. Effect of PPF dosage on concrete workability [45].

Table 3. Reported effects of PPF on fresh concrete properties.

Ref.	Concrete type	PPF dosage/form	Fresh-property outcome	Notes
[24]	Normal concrete	0.25%–1% by vol.	Slump ↓ ~6%–22%	Reduction increases with dosage.
[36]	Normal concrete	0.4% by vol.	Slump ↓ ~10 cm	Single-dosage datapoint
[37]	FPCC	Not specified	Fiber network restrains paste mobility	Workability limited by entanglement
[38]	FPCC	Not specified	High surface area stiffens mix	Mechanism of workability loss
[43]	Prismatic specimens	2–8 kg/m^3, 39 mm	Dosage-dependent workability change	Part of a broader mechanical study
[40]	SCC	0.3%–1.2% by vol.	Slump flow ↓ ~3%, T50 ↑ ~18%	Advanced flow tests (L-box, J-ring, V-funnel)
[39]	LECA concrete	Up to 1% by vol.	Density ↓ ~3.8%, workability ↓	Large toughness gain despite strength loss

Note: ↓ indicates a decrease; ↑ indicates an increase.

MECHANICAL PERFORMANCE

Reinforcing Mechanism

The mechanical role of PPF is best understood before the property-by-property data. Distributed as a discontinuous three-dimensional network, the fibers do little while the matrix is intact but become active once a crack forms: they span the crack faces, transfer tensile stress across the opening, and convert what would be an abrupt brittle separation into a gradual, energy-absorbing process. Because polypropylene has a low elastic modulus (~9.5 GPa) and bonds only weakly to the hydrophobic-corrected paste, pulling out rather than rupturing in most tests [22,36,46], its contribution is concentrated in the post-cracking regime rather than in peak strength. This single mechanism explains the pattern that recurs throughout this section: PPF add little to compressive capacity but substantially improve flexural and tensile response, toughness, impact resistance, and residual strength, and they do so most effectively within a moderate dosage window, beyond which entanglement and void formation reverse the benefit.

Compressive Strength

The effect of PPF on compressive strength is modest and strongly conditional on mix design and dosage, and the two competing outcomes reported in the literature reconcile once the governing condition is stated explicitly. In well-compacted normal- and high-strength concretes, moderate dosages of roughly 0.3%–1.0% produce small gains, commonly 3%–20%, through microstructural fortification and crack arrest [12,24,47]; roller-compacted concrete shows a similar optimum, with ~23% gains at 0.1%–0.3% [48–50], and PPF also help preserve residual compressive strength after high-temperature exposure (reported gains of 8.3%–11.9% post-heating) as melted fibers relieve pore pressure and suppress spalling [51–53]. Above about 1%, or in porous, lightweight, and high-water-demand systems, the trend reverses: entrapped air, added voids, and lost workability reduce matrix cohesion, so compressive strength falls, sharply in lightweight matrices (LECA/OPS reductions of 10%–65%) [39,54], and moderately in geopolymer and UHPC systems at high fiber content [19,55–58]. Compressive gains are therefore realized only where the matrix remains dense and fully compacted; elsewhere, PPF trade peak strength for the toughness and durability benefits developed below. Fiber geometry modulates this within the favorable window; longer macrofibers correlate more strongly with compressive gains up to about 50 mm before workability losses dominate [35,59], and hybridization with nano-silica or engineered fiber shapes can raise compressive strength by up to ~25% by improving fiber–matrix adhesion [60–62].

Flexural and Tensile Strength

It is in flexure and tension that PPF earn their place, and the improvements here are both more consistent and larger than in compression. Across normal, high-strength, pervious, geopolymer, and ultra-high-toughness concretes, appropriate PPF dosing raises flexural strength by roughly 10%–49% and tensile strength by up to about 30% at volumes of 0.5%–1.0% [12,19,63,64], with ultra-high-toughness systems reporting flexural gains of 184%–254% [65]. A representative optimum is reported at 0.5% dosage, where flexural and tensile strength rose by about 18% and 12%, respectively, without a meaningful workability penalty [24]. The mechanism is crack bridging: fibers intercept microcracks and redistribute tensile stress, shifting the failure mode from brittle to ductile and raising energy absorption [63,66]. Fiber length is decisive here; indirect (split) tensile strength rises almost linearly with fiber volume, and most strongly for 50–60 mm fibers [35], and long fibers in geopolymer concrete raised tensile strength by 38.8% through more effective bridging [59]. In pavement and layered systems, the absolute flexural and tensile gains are smaller but functionally important, since they act on post-crack ductility and residual capacity under repeated load [36,46,67–70]. Table 4 consolidates the strength effects across concrete types.

Table 4. Effects of PPF on compressive, flexural, and tensile strength.

Concrete type	PPF dosage	Compressive strength	Flexural/tensile strength	Mechanism/notes
NSC/HSC	0.5%–1.0%	↑ 3.3%–17.5%	FS ↑ ~7%–18%, TS ↑ ~4%–12%	Stiffened matrix; optimum near 0.5%
Pervious concrete	0.5%–1.0%	↑ 5.7%–18.8%	FS ↑ up to 15%, TS ↑ 10%–20%	Decline above ~1%
FPCC/layered pavement	~0.4%	No significant change	Neutral peak; ↑ post-crack ductility	Benefit is in residual capacity
RCC/RCCP	0.1%–0.3%	↑ up to 23%	Improved crack bridging	Optimum densification range
Geopolymer (GPC)	1.5% (long)/5%	↑ 38.8% (long)/↓ at 5%	↑ 38.8% (long fibers)/↓ at overdose	Geometry- and dosage-sensitive
UHPC/ultra-high-toughness	1%–2.3%	↓ at high dosage/ up to ~80 MPa	FS ↑ up to 184%–254%; TS ↓ at high dosage	Excellent shrinkage control
RAC	0.2%–0.6%	Slight/neutral	↑ split tensile; bridges RCA defects	Compensates weak ITZ
LECA/OPS lightweight	1%–5%	↓ 10%–65%	FS/TS stable or ↓	Large toughness gain
Manufactured-sand concrete	1.0%	↑	↑; carbonation resistance	Denser packing
Hybrid (nano-silica/wave-form/recycled PP)	Blended	↑ up to 25%	↑ FS & TS	Improved adhesion and load transfer
Elevated-temperature exposure	1%–2%	↑ 8.3%–11.9% (post-heating)	Retained ductility	Melt-induced pore-pressure relief

Note: ↓ indicates a decrease; ↑ indicates an increase.

Toughness, Energy Absorption, and Impact Resistance

The clearest and most consistent benefit of PPF is the increase in toughness, energy absorption, and impact resistance, since all three draw directly on the post-cracking bridging mechanism. In lightweight and porous matrices, the effect is dramatic; impact energy absorption in LECA and OPS systems rises by roughly an order of magnitude despite reduced compressive strength, because the fibers span the pores of a naturally weak matrix and sustain large deformation before failure [39,54,71]. In conventional and standard-strength concretes, modest dosages (0.4%–1.0%) raise flexural toughness, fracture energy, and residual strength while leaving peak strength largely unchanged, the behavior most relevant to fatigue-loaded pavements [12,23,46,68,69]. In recycled-aggregate concrete, the gain is proportionally largest, with fracture-energy increases of roughly 179%–381% that scale linearly with dosage, reflecting how effectively PPF compensate for the microdefects and weak interfacial zones of recycled aggregate [72]. Laboratory impact tests reported by Li et al. found that adding 0.8 kg/m^3 of polypropylene fiber increased the impact resistance of airport pavement concrete by about 250%, consistent with broader laboratory findings on PPF [73]. Steel fibers still exceed PPF in peak fracture toughness, but PPF offers economy, corrosion resistance, chemical inertness, and better dispersion, and hybrid steel–PPF systems combine the two: steel for stiffness, PPF for ductility and strain-rate resistance [72,74]. Beyond an optimum near 0.5%, toughness gains plateau or decline as fiber agglomeration degrades dispersion [75].

Post-Cracking Behavior and Residual Strength

The practical value of the toughness gains is expressed in post-cracking load-carrying capacity. Once the matrix cracks, PPF-reinforced sections retain a substantial fraction of peak load rather than failing abruptly: reported residual strengths reach roughly 30%–60% of peak in normal and prismatic specimens [24,43], and layered and roller-compacted pavement systems retain at least ~20% of peak load while shifting from brittle to progressive ductile failure [46,49,69]. This behavior is dosage- and geometry-dependent; longer fibers delay wide-crack formation and give slower post-peak load decay [59], and the effect strengthens with fiber volume: at higher dosages the load–deflection response develops a long, stable post-peak plateau (evident in the multiple-cracking behavior at Vf up to 2.0%) [5]. The comparison with steel is instructive: although PPF develop lower absolute residual strength than steel (roughly 27%–32%) or glass (~12%) fibers [12], a mixture with 0.78% PPF sustained a higher and more stable post-cracking load than one with 0.45% steel fiber, despite a lower initial peak [76], a profile well suited to pavements and slabs, where post-crack toughness and deflection tolerance matter more than peak capacity. Table 5 consolidates the toughness, impact, and post-cracking evidence.

Table 5. Toughness, impact, and post-cracking performance of PPF.

Concrete type	PPF dosage	Toughness/impact	Post-cracking/ residual behavior	Notes
Conventional concrete	0.4%	↑ energy absorption, ductility	Post-peak load retention	Crack bridging, gradual failure
NSC/HSC	1.0%	↑ residual strength (~7.5%–9%)	Maintains crack integrity	Fatigue-relevant
FPCC/layered pavement	0.4%	↑ fracture energy	Retains ~50% load post-peak; ductile transition	Structural mesh effect
RAC	2–6 kg/m^3	↑ fracture energy +179–381%	Residual capacity maintained despite RCA weakness	Scales with dosage
Hybrid steel–PPF	0.3%–0.5% + steel	↑ toughness, strain-rate resistance	↑ initial & final crack loads	Complementary stiffness/ductility
Prismatic (crimped)	39 mm, 2–8 kg/m^3	↑ toughness with dosage	Up to ~60% residual after cracking	Plateau beyond ~6 kg/m^3
Geopolymer (long PPF)	1.5%	↑ fracture toughness	Higher residual strength, slow load decay	Long fibers prevent wide cracks
UHTCC	Optimized	↑ energy dissipation	Excellent multi-crack post-peak strength	Hybrid matrix

Note: ↓ indicates a decrease; ↑ indicates an increase.

SHRINKAGE AND CRACK CONTROL

Plastic Shrinkage and Early-Age Cracking

The most consistent early-age benefit of PPF is the suppression of plastic shrinkage and the cracking it causes during the first hours after placement, before the matrix has developed tensile strength. The effect is largest in mixtures prone to rapid moisture loss, foam, high-water, and permeable concretes, where shrinkage stresses and moisture gradients are steepest. In low-density foam concrete, PPF reduced specimen failures during demolding within the first 24 hours, indicating that the fibers resist strain stresses before full tensile capacity develops [77]. The mechanism is a fine, self-dispersing microfiber network of low diameter and high specific surface area that bridges microcracks as they initiate [78–80], suppressing their development and coalescence [81].

The quantitative evidence is strong. In pervious concrete, 0.5%–1% PPF reduced early moisture loss and shrinkage [70]; in conventional concrete, PPF reduced drying shrinkage and water absorption while improving impermeability [23]; and in a controlled pavement study, 0.8 kg/m^3 PPF delayed first cracking by more than two hours and reduced cracked area by up to 62% relative to plain concrete [82]. Restrained-shrinkage testing across cement–sand–water proportions shows the dose effect directly: raising PPF from 0.1% to 0.3% progressively reduced crack area and maximum crack width, and at 0.2%–0.3% eliminated visible plastic-shrinkage cracks in most conventional mixes [83]. Reported plastic-shrinkage reductions reach 50%–100% depending on fiber and mix [4,84], though these gains depend on adequate dosage, dispersion, and matrix compatibility; excessive fiber or poor dispersion raises void content and can offset the benefit. In practice, PPF acts on early cracking through four linked effects: slowing crack initiation, delaying first-crack opening, limiting crack area and width by bridging nascent microcracks, and reducing permeability and moisture loss. These make PPF an economical route to durability in slabs, sidewalks, thin overlays, and restrained sections, and allow thinner pavements with reduced conventional reinforcement [85]. Table 6 summarizes the plastic-shrinkage evidence.

Table 6. PPF effectiveness in plastic shrinkage reduction and early-age cracking control.

Ref No.	Study Context	PPF Dosage	Observed Effect
[77]	Foam concrete	Various (low-density focus)	Reduced failure during demoulding at 24 h
[86,87]	General concrete	Not specified	Abrasion resistance ↑ 30%–60%; shrinkage cracking ↓
[81]	Microcracking control	Optimal range	Suppressed early microcracks
[78–80]	Durability enhancement	Not specified	Suppressed plastic cracking; prevented crack propagation
[70]	Pervious concrete	0.5%–1%	Shrinkage & moisture loss ↓; improved durability
[88]	Concrete with voids	Increased content	Bridging action reduced crack formation
[89]	Late-age shrinkage	Not specified	Reduced microcrack propagation
[4,84]	Durability enhancement	Not specified	Autogenous & plastic shrinkage ↓ ~50%–100%
[82]	Plastic shrinkage, crack indexing	0.4 vs. 0.8 kg/m^3	First crack was delayed by 2h17m; crack area ↓ by up to 62%
[90,91]	Economic & shrinkage control	Not specified	Shrinkage ↓; enhanced durability; cost-efficient
[55–57]	UHPC	2.30%	Free drying shrinkage was significantly reduced
[73]	Airport pavements	0.8 kg/m^3	Cracking area reduced by 55.6%

Note: ↓ indicates a decrease; ↑ indicates an increase.

Drying Shrinkage and Delayed Microcracking

PPF also restrains longer-term drying shrinkage through delayed microcracking and fiber bridging. By physically intercepting early tensile microcracks, the fibers prevent their coalescence during the critical early-drying stage [81], while the interwoven network reduces moisture loss, restrains shrinkage deformation, and improves matrix impermeability [23,89]. This is directly relevant to pavements, where restrained drying shrinkage drives slab curling, joint distress, and surface strain. The benefit extends across mix types: in pervious concrete, moderate fiber volumes (0.5%–1%) stabilize the interconnected pore structure during moisture evaporation [70]; in general fiber-reinforced concrete, an improved interfacial transition zone (ITZ) delays crack development under drying strain [88]; and in advanced systems, PPF reduce autogenous shrinkage by roughly 50% and improve late-stage tensile support [4,84]. Even in the dense microstructure of UHPC, dosages up to 2.3% meaningfully reduce free drying shrinkage, a benefit for thin overlays and specialized pavement panels, though with a minor compressive-strength penalty [55–57]. In geopolymer and recycled-aggregate concretes, longer fibers improve crack-bridging capacity and fracture toughness under drying-induced stress and bridge the microdefects inherent to recycled aggregates [59,92]. Reported optima cluster at 0.5%–0.75% PPF, beyond which fiber compaction or reduced workability can increase shrinkage [93]. Table 7 consolidates the drying-shrinkage evidence.

Table 7. PPF effectiveness in drying shrinkage and delayed microcracking & and fiber bridging.

Ref.	Concrete Type	PP Fiber Dosage	Drying Shrinkage Effects	Mechanisms: Delayed Microcracking & Fiber Bridging	Implications for Pavements
[81]	PP fiber concrete	Not specified	Reduced formation of early microcracks; delayed crack initiation.	PP fibers intercept during early drying and restrain microcracks from coalescing.	Controlling microcrack networks provides better results, less long-term slab degradation.
[23]	Conventional concrete	Not reported	Significant decrease in drying shrinkage; enhanced impermeability.	A dense fiber network reduces moisture loss and limits shrinkage deformation.	Reduced permeability delays shrinkage-induced distress and prolongs pavement service life.
[70]	Pervious concrete	0.5%–1% (vol.)	Reduction in early-age moisture loss; reduction in drying shrinkage.	Fiber bridging stabilizes the pore structure, supporting the paste skeleton under drying conditions.	Good durability for pavements exposed to evaporation cycles.
[88]	Fiber-reinforced concrete (general)	Not stated	Microcrack formation is reduced as air voids increase with fiber content.	Robust ITZ between the PP fiber and binder delays crack development under drying.	Increased fatigue and impact resistance in pavements in dry climates.
[89]	Conventional concrete	Not reported	Reduced shrinkage cracking at later drying stages.	Stabilizes the cement matrix and prevents microcrack propagation during drying shrinkage	Controls shrinkage cracking for the long term, reducing the need for saw cuts or sealants.
[1,2]	Fiber-reinforced concrete (multi-fiber studies)	Various	Various studies reduced drying shrinkage and improved structural stability.	By distributing tensile stresses uniformly, fibers prevent drying crack formation.	Suitable for slabs-on-grade applications where lower joint densities are required.
[4, 84]	PP fiber-reinforced concrete	Not reported	Autogenous shrinkage ↓ ~50%; later-stage shrinkage cracking reduced.	Fiber network restricts tensile strain concentrations, hence restricting volumetric contraction during drying.	Increases dimensional robustness during pavement curing.
[16]	Standard concrete	Not reported	Reduced plastic shrinkage & drying shrinkage, and high durability.	PP fibers behave as micro-reinforcement to resist tensile stresses induced by moisture gradients.	Provides optimal crack-free performance for long-term hot/dry environments.
[82]	Pavement concrete	0.8 kg/m^3 optimal	The crack area was significantly reduced during the drying stage.	The PP fibers provide efficient bridging, delaying crack initiation and reducing crack density.	Proven ability to work best in real pavement mixtures; recommended dosage range confirmed.
[55–57]	UHPC with PP fibers	Up to 2.3%	Free drying shrinkage decreased despite a minor loss in compressive strength.	Fibers impart internal restraint against early microcracking from desiccation.	Useful in UHPC pavements where shrinkage is critical (thin slabs, overlays).
[59]	Geopolymer concrete with short/long PP fibers	1.5% optimal	Reduced brittleness; higher fracture resistance under drying-induced strain.	Long PP fibers increase crack-bridging capability, preventing drying-induced crack growth.	Effective for sustainable geopolymer pavements with lower shrinkage tolerance.
[92]	Recycled aggregate concrete + PP fibers	Not reported	Reduced shrinkage and microcracking.	PPF mitigates RCA defects by bridging weak zones and restraining shrinkage microcracks.	Promotes recycled materials in pavement base slabs.

Note: ↓ indicates a decrease.

Thermal Cracking and Volume Change

Thermal gradients from cement hydration and environmental cycling cause cracking in temperature-sensitive elements such as airport pavements and large slabs, and PPF mitigates this through low thermal conductivity, flexibility, and crack bridging. By redistributing internal stresses generated during heating and cooling, the fibers reduce thermal shrinkage cracking and improve dimensional stability across temperature cycles [39,92]. Hybrid systems pairing PPF with steel or basalt further improve thermal fracture resistance and support the use of thinner slabs without loss of durability [94,95]. A distinct high-temperature benefit arises from polypropylene's melting behavior: above roughly 165–170 °C, the fibers melt to leave pressure-relief channels that vent vapor and combat explosive spalling [96,97], valuable for pavements exposed to high thermal stress such as airport aprons and tunnel linings. Microstructural studies of thermally damaged hybrid concrete show the sequence directly, from an intact fiber-reinforced matrix, through thermally induced ITZ and matrix cracking whose growth PPF restrains by stress redistribution, to partial crack healing under post-fire water re-curing [98]. In advanced binders (UHPC, geopolymer) with high heat of hydration, PPF provides internal restraint against thermally induced contraction and reduces early-age thermal cracking [55–57,59]. Table 8 summarizes the thermal-cracking evidence.

Table 8. Thermal cracking and volume change management in concrete with PPF.

Ref.	Concrete Type	PPF Dosage	Thermal Cracking/Volume Change Outcomes	Mechanisms (Thermal Stability & Volume-Change Control)	Implications for Pavement Performance
[23]	Conventional concrete	Not reported	Low permeability, thermal resistance to moisture loss.	Fibers delay internal moisture migration and decrease shrinkage-temperature coupling.	Improves the thermal stability of pavement slabs subjected to solar radiation.
[88]	Fiber-reinforced concrete	Not reported	Better resistance to cracking formation under heating-induced stresses.	Better ITZ improves matrix resistance to thermal changes in matrix volume and temperature control.	Alleviates the chances of thermal surface cracking in heat-sensitive environments.
[99]	Recycled aggregate concrete	Not reported	Delayed or prevented crack formation under thermal–shrinkage stress.	Fibers share internal stresses generated during heating/cooling cycles.	Enhances thermal resilience for sustainable RAC pavements.
[100]	Self-compacting recycled aggregate concrete	Various	More robust as a result of combined shrinkage-thermal deformation.	For instance, fibres reduce deformation gradients, which increases the uniformity of volume change effects.	The material is made for concrete pavements with less reinforcement.
[101]	PP microfiber concrete	Not specified	A large step reduction in early thermal-shrinkage cracks.	Microfibers capture microcracks initiated by thermal gradients.	Good for high-heat thin pavement overlays.
[4,84]	PP fiber concrete	Not reported	Autogenous + thermal shrinkage reduction in the vicinity of 50%.	PPF network restricts volumetric fluctuations by temperature rise and self-desiccation.	It improves the temperature stability of mass slabs and pavement panels at an early age.

[82]	Pavement concrete	0.4–0.8 kg/m^3	Early-age heat of hydration reduces cracking density.	Fibers are known to delay crack initiation as internal temperature increases, releasing strain energy.	Approved an effective, drug-like approach to prevent early-age thermal cracking.
[96,97]	Concrete with waste PP fibers	Not stated	Better fire resistance and lower high-temperature crack.	PP melts at high temperatures, and pressure relief channels prevent spalling.	Improves airport aprons and tunnel pavements' thermal safety.
[55–57]	UHPC with PP fibers	Up to ~2.3%	Minimized thermal-induced stresses and cracking during early hydration.	Fibers are a micro-reinforcement that resists temperature-related volume contraction.	Important for UHPC pavements because high cement content induces heat of hydration.
[59]	Geopolymer concrete	1.5% optimal	Improved resistance to thermal, resistance to shrinkage and fracture-resistant behavior under thermal conditions and fracture.	Long fibers facilitate crack-bridging during thermal strain generation	Enables geopolymer pavement slabs that are thermally stable.
[92]	Recycled aggregate concrete + PP fibers	Not specified	Minimal shrinkage and thermal microcracking.	Fibers reduce the change in the combined thermal and temperature, and uniformity of temperatures during drying.	Supports the sustainability of pavements via recycled materials.

Recycled and Pervious Concretes

The shrinkage and crack-control benefits of PPF are especially valuable in the recycled and pervious systems that support sustainable pavement design, where the base material is inherently more crack-prone. In recycled-aggregate concrete (RAC), even modest dosages (0.2%–0.6%) improve crack management and offset the performance losses associated with the porosity and weak ITZ of recycled aggregates, with consistent gains in bending, splitting-tensile, shear, and compressive strength sustained up to about 50% aggregate replacement [100,102–105]. In pervious concrete, PPF stabilize the paste skeleton, reduce shrinkage and moisture loss, and raise tensile and flexural strength while preserving permeability [70]. Hybrid steel–PPF systems recover the post-cracking strength that recycled matrices lack [106–108], and recycled-source PPF, including fibers recovered from single-use face masks, suppress shrinkage cracking and improve resistance to chloride penetration, carbonation, and fire in line with circular-economy goals [96,97].

Temperature moderates these benefits. In RAC, PPF gave the highest early strain capacity (up to ~0.5% at 23 °C), exceeding both plain and steel-fiber RAC in early ductility, but this advantage declined with rising temperature as the polypropylene approached its melting point, strain capacity fell to about 0.33% at 600 °C, so PPF are most effective for ambient and moderate-temperature crack control, with steel fibers more durable at high temperature [109]. Overall, PPF act as effective modifiers for both RAC and pervious concrete, enabling these sustainable materials to meet structural and durability requirements for pavements while reducing demand for virgin aggregate. Table 9 consolidates the RAC and pervious-concrete evidence.

Table 9. Performance of PPF in Recycled Aggregate Concrete (RAC) and Pervious Concrete (PC).

Ref.	Concrete Type	PPF Dosage	Performance Outcomes in RAC/PC	Mechanisms (Fiber Bridging, Matrix Stabilization, Durability)	Implications for Sustainable Pavements
[70]	Pervious concrete	0.5%–1.0% vol.	↑ Compressive strength (up to 18.8%); ↑ split tensile (up to 9.1%); ↓ moisture loss; ↓ early shrinkage.	Fibers strengthen the porous skeleton, limit early cracking, and inhibit deformation by drying.	Enhances the mechanical properties of PC for stormwater-friendly pavements.
[88]	Fiber concrete (general, with air voids)	Not stated	Crack resistance ↑; durability ↑ in the presence of high voids.	Powerful PP fiber–binder ITZ helps absorb energy, limiting crack growth in porous mixes.	Promotes high-void pavement mixes [pervious/low-density concrete].
[99]	Recycled concrete	Not reported	Strength improved; cracks delayed under stress.	PP fibers share internal stresses, stabilizing weaker RAC matrices.	Maintains the mechanical stability of RAC pavement bases.
[102,110]	Recycled concrete (various RAC mixes)	Not reported	↑ Bending & splitting tensile strength; compressive strength unchanged or slightly ↑.	Fibers bridge weak zones around RCA, improving tension-driven properties.	Allows RAC application in pavements with greater tensile requirements.
[103]	RAC with PP fibers	Not stated	↑ Compressive, split tensile, and shear strengths. RAC is feasible up to 50% replacement.	PPF compensates for microdefects and weak ITZs in recycled aggregates.	Supports medium-strength RAC pavements with lower virgin aggregate requirements.
[100]	Self-compacting RAC	Various	↓ Workability; ↑ mechanical properties; ↓ cracking.	Fibers restrain volumetric change and propagate stresses more uniformly.	Appropriate for pavement overlays based on recycled aggregates of SCC.
[104]	RAC (0–100% RCA)	0.6% PPF	Compressive strength ↑ by 11–21% depending on RCA content.	PPF bridges microcracks and strengthens the RAC matrix as the RCA percentage increases.	Supports the structurally practical application of high-RCA mixtures in pavement layers.
[105]	RAC with high PPF content	>0.2% PPF	Excessive PPF ↓ peak compressive stress.	Too many fibers create voids/agglomerations.	Should be optimized for dosage to balance RAC ductility & strength.
[106–108]	Steel + PP hybrid RAC (SPRAC)	Hybrid	Improved compressive, flexural & shear properties; mitigates RCA defects.	Synergy: PP fibers control shrinkage & microcracks; steel improves post-cracking strength.	Suited to heavily loaded RAC pavements.
[96,97]	Waste PP fiber concrete	Not reported	↓ shrinkage cracks; ↑ durability, fire resistance, chloride & carbonation resistance.	Waste PP fibers improve pore structure & bridging; melt at high temperature forming micro-channels.	Sustainable option for green pavements & circular-economy materials.
[55–57]	UHPC with PP fibers	Up to 2.3%	Drying shrinkage ↓; crack growth suppressed; compressive strength ↓ at high fiber content.	PP fibers add internal restraint & delay microcracking even in dense matrices.	Supports UHPC-based pervious overlay or thin panel.

Ref.	Concrete Type	PPF Dosage	Performance Outcomes in RAC/PC	Mechanisms (Fiber Bridging, Matrix Stabilization, Durability)	Implications for Sustainable Pavements
[59]	Geopolymer concrete (long & short PP fibers)	1.5% optimal	↑ Fracture toughness; ↑ compressive strength (up to +38.8% with long fibers).	Long fibers enhance crack-bridging efficiency in alkali-activated RAC systems.	Strengthens sustainable geopolymer pavement performance.
[92]	RAC + PP fibers	Not reported	↓ shrinkage; ↓ microcracking; ↑ durability.	PPF improves weak RCA transition zones, redistributing tensile stresses.	Allows RAC pavements, which have a lower cracking tendency.

Note: ↓ indicates a decrease; ↑ indicates an increase.

DURABILITY

Densification: The Underlying Mechanism

The durability benefits of PPF rest on two linked effects: densification of the matrix and control of crack propagation. Combining fibers with an optimized target density produces smaller, more uniformly distributed pores, which lowers permeability and interrupts the transport paths that aggressive agents rely on [77,111]. On top of this, the fiber network bridges microcracks under load, limiting crack width, improving post-cracking ductility, and restricting the ingress routes that would otherwise accelerate deterioration (Figure 5) [112]. Every durability mechanism discussed below follows from this combination of a finer pore structure and an actively bridged crack system.

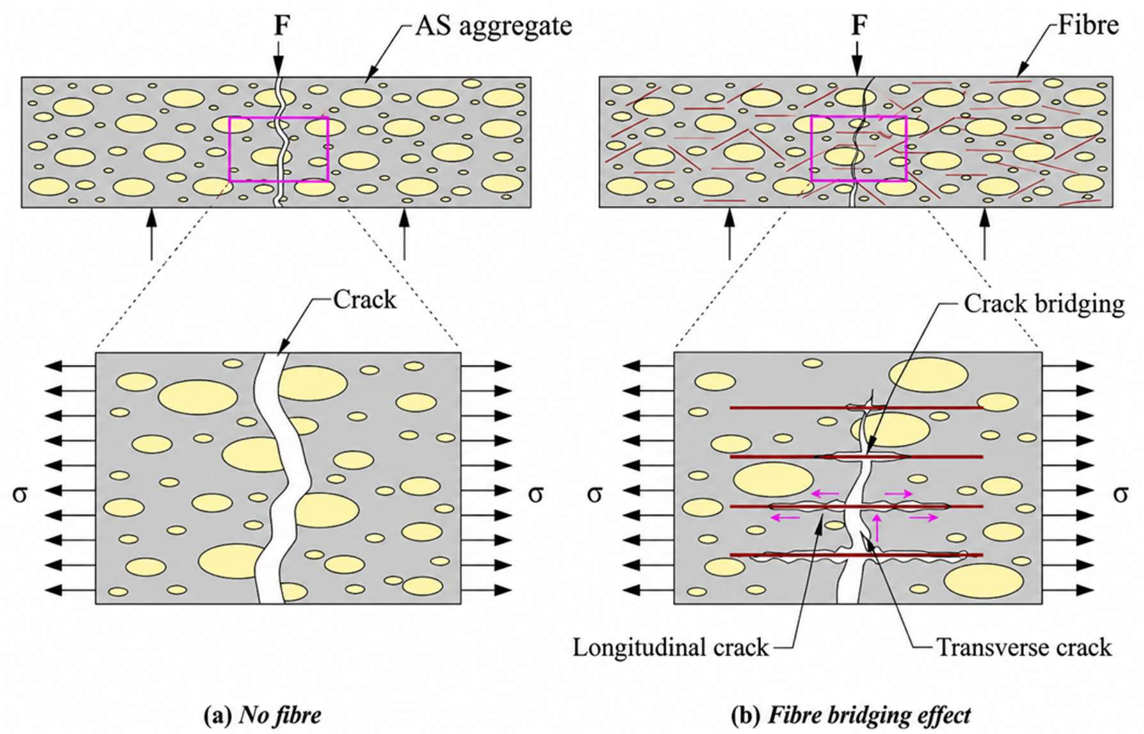

Figure 5. A schematic of the fiber bridging process in PPFRC. (**a**) With the lack of fibers, there is a direct crack path under the tensile stress. (**b**) In the presence of PPF, fibers intercept cracks & bridge them, reducing crack width and improving stress redistribution [112].

Freeze–Thaw Resistance

PPF improves resistance to cyclic freezing and thawing at volumes of about 0.5%–1.5%, chiefly by dissipating internal expansion stresses and mitigating frost heave [113–117]. Compared with glass fibers, PPF better preserves the dynamic elastic modulus and reduces mass loss in damage-sensitive materials such as dry-shotcrete composites [81].

Abrasion and Skid Resistance

Surface durability improves through the same crack-bridging action, which raises near-surface tensile capacity and resistance to wear. Around 1.25% fiber content has been reported to increase abrasion resistance by up to about 60% and tensile strength by about 30%, with skid resistance up to 25% higher than control mixtures. Regression analyses across studies show a consistent positive relationship between fiber volume fraction and surface-wear performance [118,119], which is directly relevant to the trafficked surfaces of pavements and industrial floors.

Permeability, Chloride, and Carbonation Resistance

Reduced permeability is a central durability benefit. Studies of self-compacting and geopolymer concretes report a clear inverse relationship between PPF content and water absorption, which in turn improves resistance to chloride ingress, carbonation, and acid attack [2,63,120,121]. This matters most in marine, freeze–thaw, and chemically aggressive settings, such as docks, dams, bridges, and pavements, where transport-driven degradation governs service life. Manufactured-sand concrete with 1% PPF, for example, showed improved carbonation resistance alongside its strength gains [121].

High-Temperature and Fire Performance

Although a full fire-design treatment lies outside a pavement-focused review, high-temperature behavior is retained here because specific pavement contexts, airport aprons, tunnel linings, and elements exposed to thermal cycling are genuinely fire- and heat-critical. Under elevated temperature, polypropylene melts to leave a network of fine channels that relieve internal pore pressure, reducing thermal spalling and preserving structural integrity [122,123]. Hybrid systems pairing PPF with steel or basalt improve ductility and reduce degradation at high temperature [51,94,124], and roller-compacted and high-strength concretes retain better post-crack behavior and fracture toughness under thermal and dynamic loading when PPF are added [49,51,53]. The benefit diminishes as temperature approaches and exceeds the fiber's melting range, so PPF are most effective against moderate thermal exposure and spalling rather than sustained high-temperature strength.

Chemical Resistance and Hybrid Systems

Because polypropylene is chemically inert and non-corroding, PPF contribute to chemical durability without the corrosion vulnerability of steel. Hybrid basalt–PPF systems in particular have shown improved splitting-tensile capacity, load distribution, and resistance to sulfate and carbonation attack [94,124,125], making PPFRC suitable for wastewater structures, foundations, and industrial slabs exposed to aggressive chemistry.

Field Durability in Pavements

These laboratory mechanisms translate into improved long-term field performance. Across pavement studies, PPFs are reported to reduce rutting, reflection cracking, and fatigue cracking and to improve impact resistance and service tolerance [126–131]. A six-month field study of rigid pavements incorporating polypropylene fiber reported improved durability and cost-effectiveness relative to unreinforced sections [132]. Collectively, the freeze–thaw, abrasion, permeability, thermal, and chemical benefits combine to extend pavement service life and reduce maintenance demand, which is the practical basis for the sustainability case developed in Section Sustainability and Economic Aspects. Table 10 summarizes the durability mechanisms and their pavement-relevant evidence.

Table 10. Durability Enhancement Mechanisms of PPF in Concrete Across Various Studies.

Durability Aspect	PPF Mechanism of Action	Key Findings from Literature	Relevant Applications	Refs.
Microstructural Densification & Crack Control	Improves pore structure; promotes pore distribution; reduces microcrack initiation.	Smaller, homogeneously distributed pores; minimized crack initiation and propagation; increased durability.	Structural concrete, pavements, SCC, GPC.	[111]
Freeze–Thaw Resistance	Fiber crack-bridging arrests microcrack propagation under freeze–thaw cycling, aided by increased entrapped-air content and relief of internal pressure from freezing pore water.	Frost resistance improves with PP fiber up to an optimum near 1% by volume, then declines beyond it. Macro-PP self-compacting concrete showed up to ~72% better freeze–thaw resistance (measured as reduced compressive-strength loss) at 1% fiber content. Hybrid steel–PP high-strength concrete retained 94.5% of its relative dynamic modulus with only 1.42% mass loss after 125 cycles, about a 41% improvement over non-fibrous concrete.	Cold-region pavements and freeze–thaw-exposed structural concrete.	[133,134]
Abrasion & Skid Resistance	Fiber–matrix bridging for resistance to surface wear and tensile properties.	Wear resistance was improved by about 60%; tensile strength by 30% in 1.25% of the same dosage; skid resistance was increased by more than 25%.	in industrial floors, pavements, and high foot-traffic slabs.	[3,22,46, 68,69]
Permeability and Water Ingress	Low-residual capillary continuity; inhibits migration pathways; increases impermeability.	A positive relationship can be established between PPF contents and water absorption; enhanced chloride, carbonation, and acid resistance.	in Marine, dams, retaining walls, SCC, and GPC.	[4,135, 136]

High-Temperature & Fire Performance	Fiber melting creates vapor-release channels; reduces pore pressure and spalling.	Reduction of thermal spalling; Improved post-crack behavior; improved fracture toughness; enhanced ductility in hybrid systems.	Tunnel, high-strength concrete, RCC, Fire-exposed elements.	[84,88,125,137–140]
Chemical Durability	Chemically inert fibers stave off corrosion; hybrid fibers promote load distribution.	Improved resistance to sulfates and carbonation; basalt–PPF systems exhibit superior splitting tensile strength and chemical durability.	Wastewater structures, foundations, and industrial slabs.	[12,137,141]
Field Performance in Pavements	Increases fatigue life, prevents rutting and reflection cracking; stability has been proven to be improved.	Documented mitigation of rutting and fatigue cracking; improved impact resistance; field study confirms cost-effectiveness and durability improvements.	Asphalt concrete, rigid pavements, overlays.	[21,65,126,127,142–144]

STRUCTURAL AND FIELD PERFORMANCE

From Mechanism to Structural Benefit

The laboratory behavior developed in Section Mechanical Performance, Section Shrinkage and Crack Control and Sections Durability carries through to structural and field performance. Through their random three-dimensional distribution, PPF bridge microcracks in the matrix improve crack resistance, and this translates into measurable structural gains in the applications that follow [81]. In geopolymer concrete, PPF improves tensile strength and crack control effectively enough to support GPC as a lower-carbon pavement alternative [19], and in rubberized concrete they raise tensile and compressive strength together with abrasion and skid resistance, the latter improved through better fiber–matrix bonding where pozzolanic additions such as palm-oil fuel ash are present [145].

Structural Optimization and Section Reduction

A practically important benefit is that PPF allows thinner pavement sections at equivalent load capacity. Incorporating 1% PPF in normal-strength concrete has been reported to reduce required pavement thickness by up to about 18% while preserving load-carrying capacity [12,20]. The fibers also improve flexural strength, impact resistance, and fatigue life, properties that govern performance under the cyclic loading of airport pavements and highways. In layered pavement systems, PPF raised peak load capacity and fracture energy [146], and hybrid steel–PPF systems improved both initial and final crack loads, giving synergistic fatigue resistance [36,147].

Performance under Thermal and Cyclic Loading

PPF improves mechanical resilience under combined thermal and mechanical exposure. In recycled-aggregate concrete tested across temperature, PPF-reinforced mixtures were more ductile, with delayed peak stress and improved post-peak strain capacity at 23 °C and 300 °C relative to plain and 25%-recycled RAC; performance in all systems declined at 600 °C as the polypropylene degraded, but the fiber-reinforced mixtures retained superior energy absorption and deformation capacity throughout (Figure 6) [109]. This ductility under thermal and cyclic loading underlies the successful use of PPFRC in tunnels, bridge decks, ground slabs, and airport pavements [11,43,148].

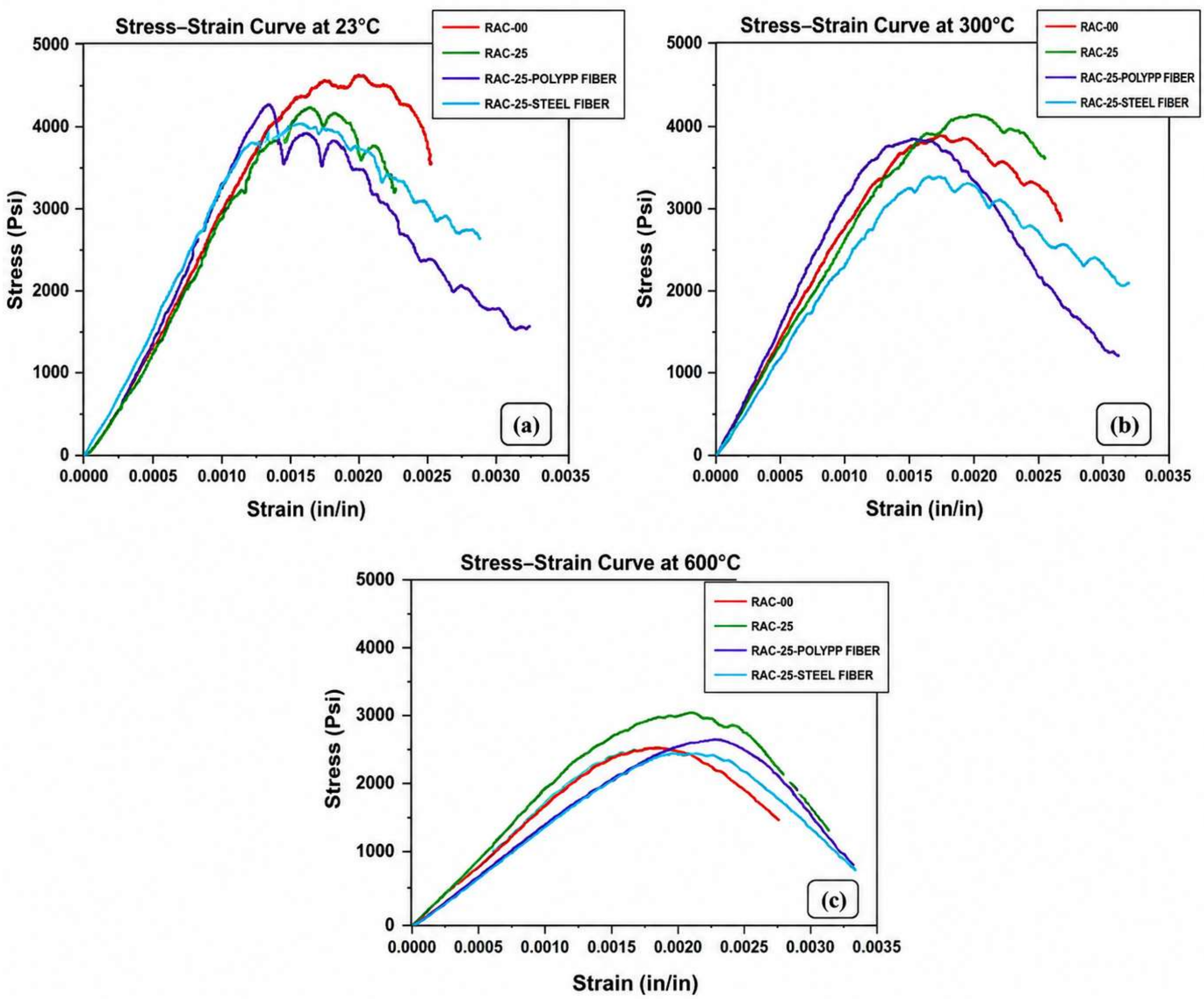

Figure 6. Stress–strain response of RAC mixes augmented with polypropylene and steel fibers at (**a**) 23 °C, (**b**) 300 °C, and (**c**) 600 °C [109].

Field Evidence and Long-Term Performance

Field studies broadly confirm the laboratory findings. Instrumented pavement sections have shown stable strain response under real traffic over time, and one field study of a polypropylene-fiber road pavement at a dosage of about 3.5 kg/m^3 reported performance consistent with a projected service life exceeding 30 years [132]. Monitoring technologies such as fiber-Bragg-grating (FBG) sensors now allow real-time measurement of strain, deformation, and crack evolution in PPF-reinforced pavements, supporting reliable long-term performance assessment in demanding infrastructure [149–151].

Environmental and Economic Dimension

PPF also carries an environmental and economic benefit at the structural scale, since thinner sections reduce cement and aggregate consumption and thereby lower embodied carbon and material cost [85,152]. The embodied energy and transport burden of PPF are considerably lower than those of steel fiber [85], and balanced hybrid systems combining PPF with basalt, steel, or PVA fibers provide improved compressive strength, shrinkage control, and crack resistance under both static and dynamic loading [153–155]. These points are developed quantitatively in Section Sustainability and Economic Aspects.

Application Range

Across the studies reviewed, PPF has been applied effectively in geopolymer and rubberized pavements, ordinary and layered pavement structures, lightweight systems (LECA, OPS), and recycled and rubberized mixes, with hybrid PPF systems showing the strongest crack resistance and fatigue tolerance under demanding dynamic loading [34,39,54,58,106,156]. Table 11 summarizes the structural and field evidence.

Table 11. Structural and Field Performance of PPFRC Across Various Studies.

Mix Type/ Application	PPF Dosage	Key Improvements Reported	Mechanisms/Notes	Refs.
Geopolymer Concrete	0.5%–1.0%	↑ Tensile strength, ↓ crack width; improved crack control	Enhanced fiber–matrix bonding in alkali-activated systems	[117]
Rubberized Concrete	0.5%–1.5%	↑ Tensile & compressive strength; ↑ abrasion & skid resistance (higher BPN)	POFA improves interfacial bonding; synergistic rubber–fiber interaction	[68, 128]
Normal Strength Concrete (NSC)	1.00%	Pavement thickness reduction up to 18%; ↑ load-carrying capacity	Effective energy absorption & improved crack bridging	[129, 157]
Layered Pavement Systems	1.0%–1.5%	↑ Peak load, ↑ fracture energy; improved fatigue performance	Toughening and bridging mechanisms under cyclic loading	[130]
Hybrid Steel–PPF Systems	0.5%–1.0% PPF + steel fibers	↑ Initial & final crack loads; ↑ fatigue resistance	Synergistic bridging: steel for stiffness, PPF for ductility	[58, 131]
Field Pavements (Roads/Airports)	~3.5 kg/m^3	Stable strain levels under traffic; service life > 30 years	Long-term fatigue stability under real traffic	[132]
Lightweight Concretes (LECA, OPS)	1.0%–1.5%	↑ Flexural toughness; ↑ impact resistance	Fibers compensate for weaker, lightweight aggregates	[158, 159]
Recycled Aggregate & Rubberized Mixes	0.5%–1.2%	↑ Tensile strength; ↑ post-crack ductility; ↑ fracture toughness	Strong synergy between rubber particles and PPF bridging	[160, 161]
Environmental & Economic Performance	0.5%–1.0%	↓ Pavement thickness; cement/aggregate use; ↓ CO_2 emissions; ↓ embodied energy vs. steel fibers	Sustainability advantage due to lower weight & transport energy	[33, 124]
Systems with FBG Sensors (Monitoring)	Various	Accurate monitoring of strain, crack evolution, and deformation	Enables long-term durability assessment	[162–164]

Note: ↓ indicates a decrease; ↑ indicates an increase.

SUSTAINABILITY AND ECONOMIC ASPECTS

The Sustainability Case

PPF supports more sustainable pavement concrete through three linked routes: enabling durable low-impact material systems, reducing material demand through thinner sections, and lowering embodied impact relative to steel reinforcement. In pervious and porous concrete, PPF improves mechanical performance and durability while preserving the permeability essential to stormwater management [70,125,165]. In recycled-aggregate concrete, they offset the intrinsic weaknesses of recycled aggregate, improving split-tensile and shear strength at replacement levels up to about 50% [99,102,103], and one optimized porous mix combining 40% marble powder, 16% silica fume, and 0.8% PPF achieved a favorable balance of strength, permeability, and cost [89]. PPF also improves the ductility and cyclic performance of low-carbon binder systems such as geopolymer concrete [59,166]. These benefits let sustainable materials meet pavement performance requirements while reducing demand for virgin aggregate and Portland cement. More broadly, data-driven and climate-adaptive design approaches are becoming central to sustainable-materials and low-carbon systems research, offering methodological templates, co-simulation across material-to-district scales, renewable integration, and intelligent operation that the pavement-materials field can adapt [167–169]. The circular-economy case for polypropylene extends beyond concrete: recycled polypropylene and its composites are being reprocessed into structural parts through routes such as material-extrusion additive manufacturing, indicating broad reuse pathways for the polymer stream that PPFRC draws on [170].

Material and Cost Efficiency

The economic case rests partly on polypropylene's low density, roughly 900 kg/m^3 against about 7750 kg/m^3 for steel fiber, which reduces handling, transport, and labor costs and improves the cost-to-performance ratio [12,157]. Substituting macro-synthetic fibers for conventional steel mesh further simplifies construction and reduces labor and energy demand [33,152]. Although natural fibers such as coconut and abaca are also low-impact, PPF remains preferred for its chemical inertness, durability, and processing consistency [26,171]. Reduced pavement thickness compounds these savings by cutting cement and aggregate use, and hence both cost and embodied carbon [85,124].

Life-Cycle Evidence, and its Limits

Life-cycle assessments point in a consistent direction but should be read as individual case results rather than settled values. One LCA reported that a 0.5% PPF dosage reduced CO_2-equivalent emissions by up to about 18% and pavement cost by about 8% relative to plain concrete, the gains arising mainly from reduced section thickness and cement content [64,172]. A separate cost analysis found that although polymer-fiber-reinforced pavement is roughly 15%–20% more expensive upfront, reduced rehabilitation over the service life yields a 30%–35% reduction in whole-life cost [173]. Recycled PPF, including fibers recovered from single-use masks, has been reported to match virgin PPF on mechanical and durability performance while reducing plastic waste [62,174].

These figures are encouraging but carry real trade-offs that qualify them. The savings are realized through durability and extended service life, not at the point of manufacture, so they depend on the pavement actually achieving its projected life; the upfront cost premium is genuine; and the fiber dosage that maximizes sustainability is not necessarily the one that maximizes mechanical performance, since higher dosages penalize workability and dispersion. The environmental case for PPF is therefore strongest when assessed on a whole-life basis and at optimized dosages, rather than as a uniform benefit at any dosage. Table 12 summarizes the sustainability and economic evidence.

Table 12. Sustainability and Economic Contributions of PPF in Concrete.

Sustainability/ Economic Aspect	Key Findings Across Studies	PPF Dosage/Mix Details	Impact on Performance	Refs.
Use in Pervious Concrete	Improves performance through increased strength and durability without compromising permeability.	Conventional dosages: 0.3%–1.0%.	Enhances filtration capacity and structural integrity for sustainable pavements.	[126,175]
Recycled Aggregate Concrete	Great improvement in the split tensile and shear strength, even with 50% RA replacing the mix	0.5%–1.2% PPF is commonly used.	Promotes ductility and crack resistance; mitigates weaknesses of RA.	[2,13,15,24, 66,101,176]
Optimal Mix in Porous Concrete	Perfect fiber-binder mixes can lead to better costs, microstructure, and permeability.	40% marble powder + 16% silica fume + 0.8% PPF.	Allows balance between strength, permeability, and material cost.	[116]
Cost–Material Efficiency vs. Steel Fibers	Substantially lighter than steel fibers (900 kg/m^3 versus 7750 kg/m^3).	Direct substitution.	Lower handling and transportation costs; better cost-to-performance ratio.	[157]
Natural vs. Synthetic Fiber Sustainability	Coconut and abaca fibers are practical, but PP fibers are preferred due to their high durability and chemical stability.	-	Better long-term performance, lower degradation risk.	[114,177]
Geopolymer, RCC, Rubberized & Recycled Mixes	PPF improves the ductility, impact resistance, and cyclic performance of low-carbon binders.	0.3%–1.0%.	Sustainability of alternative cementitious systems is improved.	[167,178]
Reduced Pavement Thickness	Thinner slabs without a drop in strength, thereby reducing cement and aggregates.	-	Reduce carbon footprint, reduce material cost, and cut construction times.	[124,179]
Replacement of Steel Mesh	Macro-synthetic fibers ease construction	Macrofibers at 0.4%–1.0%.	Cost-saving in labor, shorter building timelines, and a reduction in energy demand.	[33,180]

Life-Cycle Carbon Emissions	0.5% PPF (18% less CO_2) compared with the control mix.	0.5% PPF.	Less embodied carbon in light of lower thickness and lower cement.	[172]
Life-Cycle Economic Savings	Savings: PPFRC is 15%–20% more expensive in the short term but 30%–35% over time.	0.5%–1.0% PPF.	Lower maintenance and rehabilitation expenses.	[179]
Recycled Polypropylene Fibers	Recycled PPF (e.g., from masks) performs similarly to virgin fibers.	0.3%–1.0%.	Less plastic waste; encourages a circular economy.	[120,181]
Hybrid Fiber Systems	PPF combined with steel, basalt, or PVA fibers has synergistic gains.	Hybrid ratios vary.	Greater toughness, flexural strengths, and ductility.	[85,160,182]
Performance in SCC, RCC, and Pervious Concrete	Concrete improves ductility, abrasion resistance, freeze–thaw resistance, strength of freeze-thaw cycles, and sulfate resistance.	0.3%–1.2%.	Keeps workable mixes at the best dosage.	[6,183]
RAC Under Aggressive Environments	PPF protects against shrinkage and microcracking, leading to longer durability to chemical attacks.	0.5%–1.0%.	Good durability and better durability of recycled concretes for hardened recycled-based concretes in difficult situations.	[89,184]

PRACTICAL CONSIDERATIONS AND LIMITATIONS

While the benefits of PPF in pavement concrete are well supported, several practical constraints govern their translation from laboratory to field, and these are set out here honestly rather than minimized.

- Dosage optimization. Effective dosage is mix- and density-specific. Foam concrete requires markedly higher volumes (reported at 3.9%–6.4% across low-to-high target densities) [77], porous concrete performs best near 0.8% in an optimized blend [89], and roller-compacted pavement concrete peaks at 0.1%–0.15% by volume [49]. High-volume mixtures, for example 5% fiber in geopolymer concrete, lose substantial compressive strength through increased water demand and matrix disruption [19,58]. The recurring pattern is a narrow effective window, roughly 0.2%–0.6% for most conventional pavement mixes, above which strength declines even as toughness continues to rise.
- Workability and dispersion. PPF reduces slump by roughly 8%–24% depending on dosage, a larger penalty than basalt or glass fibers impose, through fiber entanglement and hydrophobic interaction [47]. Achieving uniform dispersion is critical and non-trivial: manual pre-dispersion followed by several minutes of mechanical mixing is needed to avoid fiber balling [28]. This is precisely the kind of quality-control step that is straightforward in the laboratory but harder to guarantee at production scale.
- The bond limitation. PPF interacts with the matrix largely through mechanical rather than chemical bonding, and pulls out rather than ruptures under load [22,36,46]. Combined with polypropylene's low elastic modulus (~7.6–9.5 GPa), this limits their contribution to high-

stress crack resistance and confines their strongest value to post-cracking toughness rather than peak strength [185,186]. Fibers such as PET, with higher intrinsic modulus, can outperform PPF in tensile applications [187], and PPF generally cannot serve high-strength structural demands without a stiffer co-fiber such as steel or basalt [74,188].

- The laboratory-to-field gap. Most of the quantitative gains reviewed here derive from controlled laboratory specimens, and several factors complicate their transfer to constructed pavements. Field dispersion and orientation are harder to control than in small specimens; fiber balling and workability loss are more consequential at production scale; and full-scale field studies remain comparatively scarce, with the widely cited pavement field evidence resting on a small number of studies and monitoring windows shorter than the service lives projected from them. Reported findings that fiber type (length, dosage, grade) exerts less influence on asphalt-concrete performance than binder content [143], and that modulus-of-rupture gains are marginal below about 0.5% dosage [183,189], further caution against extrapolating optimistic laboratory percentages directly to field performance. Closing this gap requires more full-scale, long-term field trials rather than additional laboratory characterization.
- Recycled-fiber variability. Recycled PPF from masks and bags can match virgin PPF mechanically, with meaningful environmental gains (reported reductions of about 1.45 kg CO_2-eq/kg and substantial water savings) [174,190], but bonding efficiency and mechanical uniformity vary more than for virgin fiber [72], so high-recycled-content mixes require optimization to balance sustainability against consistent performance. The long-term durability of any polymer reinforcement also depends on its resistance to aging and environmental degradation, a consideration well established for polymer composites more broadly [191] and one that reinforces the need for long-term field data on PPFRC specifically.

In sum, PPFs are best suited where toughness, crack resistance, and durability outweigh peak tensile strength: pavements, overlays, precast slabs, and wastewater structures, rather than heavily load-bearing elements [192]. Their limitations are real but largely manageable through dosage control, dispersion practice, and hybridization.

FUTURE RESEARCH DIRECTIONS

The priorities below are ordered from most to least developed, and each is tied to a specific gap identified earlier in this review.

1. Full-scale and long-term field validation. The most consequential gap (Section Practical Considerations and Limitations) is the shortage of field evidence relative to laboratory data. Priority should go to instrumented, multi-year field trials across climates and traffic levels,

using monitoring tools such as FBG sensors, to confirm the durability and service-life projections that currently rest on limited field studies.

2. Optimized hybrid and multi-scale systems. Because PPF alone cannot serve high-strength demands (Section Practical Considerations and Limitations) but excels at post-cracking toughness (Section Mechanical Performance), hybridization is a direct response to that limitation. Steel–PPF systems improve fatigue performance under cyclic loading [147], basalt–PPF systems improve stress distribution, splitting-tensile strength, and carbonation resistance [94,124], and multi-scale micro/macro PPF combinations enhance the tensile strength and ductility of roller-compacted concrete [193]. Systematic optimization of these combinations for pavement service is a near-term opportunity.
3. Fiber–matrix interface engineering. The weak mechanical bond identified as a core limitation (Section Practical Considerations and Limitations) is directly addressable through surface modification: plasma treatment has been shown to improve PPF wettability and bond, and hence composite performance [18], and this route deserves dedicated study for pavement mixes.
4. Machine-learning-based mix design and performance prediction. The dose–response behavior mapped throughout this review (the recurring ~0.3%–1.0% window) is well suited to data-driven modeling. SVM and ANN models already outperform regression in predicting the Marshall stability of PPF-reinforced asphalt concrete [143], and extending such models to mix-design optimization and multi-property prediction would reduce the trial-and-error currently required. Beyond mix design, machine-learning methods are increasingly applied to optimize the sustainability and performance of construction and energy-materials systems more broadly, spanning data-driven design, stochastic uncertainty-based analysis, and multi-objective optimization [194,195]. Transferring these established frameworks- surrogate modeling, uncertainty quantification, and multi-objective optimization- to PPFRC pavement design is a promising route beyond the trial-and-error dosage selection that currently dominates the field.
5. Sustainable and recycled formulations. Building on the sustainability case (Section Sustainability and Economic Aspects) and the variability caveat (Section Practical Considerations and Limitations), further work should address the consistency of recycled-PPF sources and the integration of industrial by-products (waste glass powder, microsilica, nano-silica) into PPF hybrids for improved ductility and impact resistance [196,197].

Together, these directions would extend PPFRC toward high-performance, durable, and low-carbon pavement infrastructure, with field validation as the pacing item.

CONCLUSIONS

This review synthesized laboratory, field, and standardized-test evidence on the use of polypropylene fibers in pavement concrete, spanning fresh-state behavior, mechanical performance, shrinkage and crack control, durability, structural and field performance, and sustainability. The principal conclusions, each drawn from evidence presented above, are as follows.

- PPF reduce slump and workability in proportion to dosage while improving mixture stability by limiting segregation and bleeding; the workability penalty is manageable through superplasticizers and fiber-geometry optimization.
- PPF contribute only modest, mix-dependent gains in compressive strength but substantial improvements in flexural and tensile strength, toughness, energy absorption, and residual post-cracking capacity, with the strongest effects at dosages of roughly 0.3%–1.0% by volume.
- PPF are highly effective at reducing plastic, drying, autogenous, and thermal shrinkage, delaying microcrack initiation and reducing crack area and width, which enhances the dimensional stability of pavements, overlays, and recycled and pervious systems.
- Through matrix densification and crack bridging, PPF improves resistance to freeze–thaw cycling, abrasion and skid wear, permeability, chloride and carbonation ingress, and thermal spalling, with the fibers' melting behavior providing pore-pressure relief at high temperature.
- At the structural scale, PPF improves load distribution, fracture energy, and fatigue life, and can permit pavement-thickness reductions of up to about 18% at equivalent capacity, with field studies indicating stable long-term strain behavior.
- The principal limitations are the workability and dispersion penalties at higher dosages, a weak fiber–matrix bond that confines PPF to post-cracking rather than peak-strength roles, and a shortage of long-term field validation relative to laboratory evidence.
- The most promising directions are full-scale field validation, optimized hybrid and multi-scale systems, fiber–matrix interface engineering, machine-learning-based mix design, and consistent sustainable and recycled formulations.

Overall, polypropylene fibers offer an economical, durable, and low-impact means of improving concrete pavement performance where toughness, crack control, and durability are the governing requirements.

DATA AVAILABILITY

All data generated from the study are available in the manuscript.

AUTHOR CONTRIBUTIONS

Conceptualization, AMM; methodology, AMM and BAT; formal analysis, AMM and BAT, writing—original draft preparation, AMM and BAT; writing—review and editing AMM and BAT; supervision, BAT; project administration, BAT; funding acquisition, AMM. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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REFERENCES

1. Karahan O, Atis CD. The durability properties of polypropylene fiber reinforced fly ash concrete. Mater Des. 2011;32(2):1044-9.
2. Zhang P, Li QF. Effect of polypropylene fiber on durability of concrete composite containing fly ash and silica fume. Compos Part B Eng. 2013;45(1):1587-94.
3. Soroushian P, Khan A, Hsu J. Mechanical properties of concrete materials reinforced with polypropylene or polyethylene fibers. ACI Mater J. 1992;89(6):535-40.
4. Saje D, Bandelj B, Šušteršič J, Lopatič J, Saje F. Shrinkage of polypropylene fiber-reinforced high-performance concrete. J Mater Civ Eng. 2011;23(7):941-52.
5. Wtaife S, Alsabbagh A, Eissa T, Alshammari E, Shaban A, Suksawang N. Effect of polypropylene fibers on serviceability and ultimate limit states on fiber reinforced concrete behavior. Proceedings of FBMSH 2019; 2019 Feb 2; Singapore, Singapore.
6. Risdanareni P, Karjanto A, Ekaputri JJ, Puspitasari P, Khakim F, Ramadhani I. Mechanical properties of volcanic ash-based geopolymer concrete. Mater Sci Forum. 2016;857:377-81.
7. Mohamed AM, Tayeh BA, Majeed SS, Aisheh YIA, Salih MNA. Steel fiber reinforced self-compacting concrete (SFSCC): a comprehensive review on strength, durability, and future prospects. Case Stud Constr Mater. 2026;24:e05993.
8. Okoye FN, Durgaprasad J, Singh NB. Effect of silica fume on the mechanical properties of fly ash-based geopolymer concrete. Ceram Int.2016;42(2):340-9.

9. Shaban AM, Alsabbagh A, Wtaife S, Suksawang N. Effect of pavement foundation materials on rigid pavement response. IOP Conf Ser Mater Sci Eng. 2020;671(1):012085.
10. Khalid H, Yasin Y, Farooq MU, Munir U, Qaisrani MA, Shahani S. An experimental investigation of mechanical properties of concrete composites reinforced with PET fibers as per ASTM standard. Sustain Chem Environ. 2025;10:100241.
11. Qin Y, Zhang X, Chai J, Xu Z, Li S. Experimental study of compressive behavior of polypropylene-fiber-reinforced and polypropylene-fiber-fabric-reinforced concrete. Constr Build Mater. 2019;194:216-25.
12. Hussain B, Ali B, Akhtar T, Jameel MS, Raza SS. Comparison of mechanical properties of concrete and design thickness of pavement with different types of fiber-reinforcements. Case Stud Constr Mater. 2020;13:e00429.
13. Pérez-Rocha D, Morales-Cepeda AB, Navarro-Pardo F, Lozano-Ramírez T, LaFleur PG. Carbon fiber composites of pure polypropylene and maleated polypropylene blends obtained from injection and compression moulding. Int J Polym Sci. 2015:493206.
14. Nili M, Afroughsabet V. Property assessment of steel-fibre reinforced concrete made with silica fume. Constr Build Mater. 2012;28(1):664-9.
15. Mahmoud AA, Elkatatny S. Improving class G cement carbonation resistance for applications of geologic carbon sequestration using synthetic polypropylene fiber. J Nat Gas Sci Eng. 2020;76:103184.
16. Manso-Morato J, Hurtado-Alonso N, Revilla-Cuesta V, Skaf M, Ortega-López V. Fiber-reinforced concrete and its life cycle assessment: A systematic review. J Build Eng. 2024;94:110062.
17. Khokhar SA, Memon S, Ahmed T, Basit MU, Najam FA, Khushnood RA. A comparative study on the seismic performance of long span engineered cementitious composite (ECC) structures. Case Stud Constr Mater. 2024;20:e03129.
18. Packialakshmi S, Krishnakumar A, Erskine S, Anuradha B. Performance evaluation of fire resistant characteristics in polypropylene fiber concrete. Mater Today Proc. 2021;81:1152-6.
19. Shah F, Oza R, Vyas D, Joshi T, Thakkar S, Dave U. Effect on mechanical properties of geopolymer concrete by addition of polypropylene fibers. Mater Today Proc. 2023. doi: 10.1016/j.matpr.2023.03.670
20. Wafa FF. Properties & applications of fiber reinforced concrete. Eng Sci. 1990;2(1):49-63.
21. Alhozaimy AM, Soroushian P, Mirza F. Mechanical properties of polypropylene fiber reinforced concrete and the effects of pozzolanic materials. Cem Concr Compos. 1996;18(2):85-92.
22. Bentur A, Mindess S, Vondran G. Bonding in polypropylene fibre reinforced concretes. Int J Cem Compos Lightweight Concr. 1989;11:153-8.
23. Mir AH, Kumar R. Experimental research on high strength concrete prepared by alccofine and polypropylene fiber. Mater Today Proc. 2024. doi: 10.1016/j.matpr.2024.03.047

24. Bhat AR, Vikram A. Performance of concrete with polypropylene fibre and polyvinyl chloride fibre. Mater Today Proc. 2023. doi: 10.1016/j.matpr.2023.03.104
25. ASTM International. Standard specification for fiber-reinforced concrete and shotcrete (ASTM C1116-03). West Conshohocken (PA, US): ASTM International; 2003.
26. Játiva F, Tamayo JM, Silva T, Granja O, Cabrera R, Arce X, et al. Experiments on concrete test beams with recycled aggregates and natural fibers. Procedia Struct Integr. 2024;64:1468-75.
27. Oh BH, Kim JC, Choi YC. Fracture behavior of concrete members reinforced with structural synthetic fibers. Eng Fract Mech. 2007;74(1-2):243-57.
28. Rambabu D, Sharma SK, Akbar MA. Development of pavement quality concrete with SCM's, fibers and graphite. Mater Today Proc. 2022;49:2374-81.
29. Liang Y, Cheng Y, Fu H, Li X, Li B, Chen Y. Research into the mechanical properties of wet-sprayed polypropylene fibre-reinforced concrete. Mag Concr Res. 2020;72(18):948-62.
30. Bautech Industrial SP. Reinforcing fibres. Polypropylene fibres. 2020 Available from: https://bautech.eu/industrial-flooring/products/fibre/baumex-3d. Accessed on 2026 Feb 17.
31. Broda J. Application of polypropylene fibrillated fibres for reinforcement of concrete and cement mortars. In: Yilmaz S, Ozmen HB, editors. High performance concrete technology and applications. London (UK): InTechOpen; 2016. p. 189-204.
32. Singh S, Pahsha E, Kalla P. Investigations on GUJCON-CRF nylon 6 fiber based cement concrete for pavement. Mater Today Proc. 2024. doi: 10.1016/j.matpr.2023.03.026
33. Sun Z, Xu Q. Microscopic, physical and mechanical analysis of polypropylene fiber reinforced concrete. Mater Sci Eng A. 2009;527(1-2):198-204.
34. Katkhuda H, Shatarat N. Improving the mechanical properties of recycled concrete aggregate using chopped basalt fibers and acid treatment. Constr Build Mater. 2017;140:328-35.
35. Almeida Del Savio A, La Torre D, Cedrón JP. Experimental volume incidence study and the relationship of polypropylene macrofiber slenderness to the mechanical strengths of fiber-reinforced concretes. Appl Sci. 2022;12(18):9126.
36. Ahmadi M, Shafabakhsh GA, Hassani A. Fracture and mechanical performance of two-lift concrete pavements made of roller compacted concrete and polypropylene fibers. Constr Build Mater. 2021;268:121144.
37. Yin S, Tuladhar R, Shi F, Combe M, Collister T, Sivakugan N. Use of macro plastic fibres in concrete: a review. Constr Build Mater. 2015;93:180-8.
38. Soroushian P, Plasencia J, Ravanbakhsh S. Assessment of reinforcing effects of recycled plastic and paper in concrete. Mater J. 2003;100(3):203-7.
39. Ja'e IA, Muda ZC, Almujibah H, Amaechi CV, Syamsir A, Alengaram UJ, et al. Structural-impact resilience of lightweight fiber-reinforced LECA concrete using ANN and RSM technique. Constr Build Mater. 2025;471:140699.

40. Ramesh B, Gokulnath V, Kumar MR. Detailed study on flexural strength of polypropylene fiber reinforced self-compacting concrete. Mater Today Proc. 2020;22:1054-8.
41. Katebi A, Asadollahfardi G, Salehi A, Ahmadi G, Soleymani-tushmanlo A. Investigation of the properties of self-compacting concrete using treated rubber powder, polypropylene fibers, and wash water. Case Stud Constr Mater. 2025;22:e04443.
42. Oguz M, Özen S, Yazıcı Ş, Mardani A. Influence of steel and polypropylene fibers on flexural strength and fracture properties of ambient-cured geopolymer concrete. Polymers. 2026;18(7):873.
43. Ponsi F, Bassoli E, Buratti N, Vincenzi L. Development of a hybrid regression model for predicting the mechanical behavior of macrosynthetic fiber reinforce concrete. Constr Build Mater. 2025;483:141582.
44. Małek M, Jackowski M, Łasica W, Kadela M. Characteristics of recycled polypropylene fibers as an addition to concrete fabrication based on portland cement. Materials. 2020;13(8):1827.
45. Chen M, Ren C, Liu Y, Yang Y, Wang E, Liang X. Effects of polypropylene fibre and strain rate on dynamic compressive behaviour of concrete. Materials. 2019;12:1797.
46. Castoldi RdS, Souza LM, Silva FA. Comparative study on the mechanical behavior and durability of polypropylene and sisal fiber reinforced concretes. Constr Build Mater. 2019;211:617-28.
47. Ye P, Chen Z, Su W. Mechanical properties of fully recycled coarse aggregate concrete with polypropylene fiber. Case Stud Constr Mater. 2022;17:e01352.
48. Yazıcı Ş, İnan G, Tabak V. Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. Constr Build Mater. 2007;21(6):1250-3.
49. Siamardi K, Shabani S. Evaluation the effect of micro-synthetic fiber on mechanical and freeze-thaw behavior of non-air-entrained roller compacted concrete pavement using response surface methodology. Constr Build Mater. 2021;295:123628.
50. Madhkhan M, Azizkhani R, Harchegani MT. Effects of pozzolans together with steel and polypropylene fibers on mechanical properties of RCC pavements. Constr Build Mater. 2012;26(1):102-12.
51. Kumar SV, Bhasker M. Experimental study on the thermal properties of fiber reinforced concrete (TPFRC). Mater Today Proc. 2023. doi: 10.1016/j.matpr.2023.06.114
52. Atashafrazeh M, Bingöl AF, Caf M. The influence of elevated temperatures on the mechanical properties of polypropylene fiber reinforced concrete. Chall J Struct Mech. 2017;3(3):116-22.
53. Mohod MV. Performance of polypropylene fiber reinforced concrete. IOSR J Mech Civ Eng. 2015;12(1):28-36.
54. Ja'e IA, Muda ZC, Amran M, Syamsir A, Amaechi CV, Al-Qadami EHH, et al. Modelling and optimisation of the structural performance of lightweight polypropylene fibre-reinforced LECA concrete. Results Eng. 2024;24:103149.

55. Feng Z, Shen D, Luo Y, Huang Q, Liu Z, Jiang G. Effect of polypropylene fiber on early-age properties and stress relaxation of ultra-high-performance concrete under different degrees of restraint. J Build Eng. 2023;68:106035.
56. Wang J, Kim YJ. Functional characteristics of ultra-high-performance concrete comprising various fibers. ACI Mater J. 2020;117(2):179-91.
57. Smarzewski P, Barnat-Hunek D. Property assessment of hybrid fiber-reinforced ultra-high-performance concrete. Int J Civ Eng. 2018;16(5):593-606.
58. Mohamed AM, Tayeh BA, Abu Aisheh YI, Alqurashi F. Production of novel reinforcing rods of waste polyester, polypropylene, and cotton as alternatives to reinforcement steel rods. Rev Adv Mater Sci. 2025;64(1):20250167.
59. Karthik S, Mohan KSR, Murali G, Abid SR, Dixit S. Impact of various fibers on mode I, III and I/III fracture toughness in slag, fly ash, and silica fume-based geopolymer concrete using edge-notched disc bend specimen. Theor Appl Fract Mech. 2024;134:104751.
60. Kilmartin-Lynch MS, Li RR, Zhang G. Preliminary evaluation of the feasibility of using polypropylene fibres from COVID-19 single-use face masks to improve the mechanical properties of concrete. J Clean Prod. 2021;296:126460.
61. Saberian M, Li J, Kilmartin-Lynch S, Boroujeni M. Repurposing of COVID-19 single-use face masks for pavements base/subbase. Sci Total Environ. 2021;769:145527.
62. Xu W, Tan C, Xu W, Zhang T, Xiong B, Wang S, et al. Mechanical properties and constitutive relation of recycled aggregate concrete reinforced with face mask fibre and basalt fibre under uniaxial cyclic compression. Structures. 2024;69:107364.
63. Hesami S, Hikouei IS, Emadi SAA. Mechanical behavior of self-compacting concrete pavements incorporating recycled tire rubber crumb and reinforced with polypropylene fiber. J Clean Prod. 2016;133:228-34.
64. Ali B, Qureshi LA, Kurda R. Environmental and economic benefits of steel, glass, and polypropylene fiber reinforced cement composite application in jointed plain concrete pavement. Compos Commun. 2020;22:100437.
65. Fang M, Chen Y, Deng Y, Wang Z, Zhu M. Toughness improvement mechanism and evaluation of cement concrete for road pavement: a review. J Road Eng. 2023;3:125-40.
66. Mashrei MA, Sultan AA, Mahdi AM. Effects of polypropylene fibers on compressive and flexural strength of concrete material. Int J Civ Eng Technol. 2018;9(11):2208-17.
67. Elango KS, Revathi V. Mechanical and durability studies on pervious concrete using different types of binders. Rev Romana Mater. 2020;50(2):258-67.
68. Yang EH, Wang S, Yang Y, Li VC. Fiber-bridging constitutive law of engineered cementitious composites. J Adv Concr Technol. 2008;6(1):181-93.
69. Kazemi MT, Golsorkhtabar H, Beygi MHA, Gholamitaba M. Fracture properties of steel fiber reinforced high strength concrete using work of fracture and size effect methods. Constr Build Mater. 2017;142:482-9.
70. Elavarasan S, Priya AK, Bharath S, Satheeshkanna R, Arunraj D. Experimental studies on pervious concrete reinforced with polypropylene fiber. Mater Today Proc. 2022;68:2280-3.

71. Bahmani H, Mostofinejad D. Sustainable high-performance concrete with sugar factory lime waste-activated slag and fiber reinforcement: mechanical properties and environmental impact. Constr Build Mater. 2025;464:140202.
72. Momotaz H, Rahman MM, Karim MR, Zhuge Y, Ma X, Levett P. Changes in flexural, tensile and impact characteristics of kerb concrete due to the addition of tyre-derived aggregates and polypropylene fibres. J Build Eng. 2024;83:108438.
73. Li M, Zhang W, Wang F, Li Y, Liu Z, Meng Q, et al. A state-of-the-art assessment in developing advanced concrete materials for airport pavements with improved performance and durability. Case Stud Constr Mater. 2024;21:e03774.
74. Li Y, Bao X, Chen X, Wu X, Cui H. Investigation of dynamic performance of hybrid fiber-reinforced concrete with low-fiber-content. Constr Build Mater. 2025;476:141144.
75. Yin Z, Shao Z, Qi C, Wu H, Wang J, Gao L. Static compressive properties of polypropylene fiber foam concrete with concave hexagonal unit cell. Appl Sci. 2023;13(1):132.
76. Yin S. Environmental benefits of using recycled PP fibre through a life cycle assessment. In: Development of Recycled Polypropylene Plastic Fibres to Reinforce Concrete. Singapore (Singapore): Springer; 2017.
77. Gökçe HS, Öksüzer N, Kamiloğlu HA, Eyüboğlu M, Yılmaz F. The toughness of polypropylene fiber-reinforced foam concrete under various uni- and tri-axial compression loads. KSCE J Civ Eng. 2023;27(7):2982-92.
78. Fu Q, Niu D, Li D, Wang Y, Zhang J, Huang D. Impact characterization and modelling of basalt-polypropylene fibre-reinforced concrete containing mineral admixtures. Cem Concr Compos. 2018;93:246-59.
79. Luo H, Yang D, Zhou X, Shan C, Liu X, Zhao F. Mechanical properties of polypropylene fiber reinforced concrete with different aspect ratios. Acta Mater Compos Sin. 2019;36(8):1935-48.
80. Shen D, Liu X, Zeng X, Zhao X, Jiang G. Effect of polypropylene plastic fibers length on cracking resistance of high performance concrete at early age. Constr Build Mater. 2020;244:117874.
81. Hou L, Jian S, Huang W. The effect of polypropylene fiber and glass fiber on the frost resistance of desert sand concrete. KSCE J Civ Eng. 2024;28(1):342-53.
82. Shen HR, She YX, Gao PW. The influence of polypropylene fiber on the performance of concrete pavement. Appl Mech Mater. 2012;178:1099-1103.
83. Bian RB, Jiang GQ, Shen J. Proposed restrained plastic shrinkage test for cementitious materials. Proceeding of the 3rd International Conference on Construction Materials: Performance, Innovations and Structural Implications (ConMat'05); 2005 Aug 22-24; Vancouver, BC, Canada.
84. Banthia N, Gupta R. Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete. Cem Concr Res. 2006;36(7):1263-7.
85. Ozturk OON. Sustainability and cost-effectiveness of steel and polypropylene fiber reinforced concrete pavement mixtures. J Clean Prod. 2022;363:132582.
86. Shuan-fa C, Deng-liang Z, Jie Z, Feng L. The study of the road performance of the polypropylene fiber concrete. Northeast Highway. 2001;24(2):23-5.

87. Chen L, Mindess S, Morgan DR, Shah SP, Johnston CD, Pigeon M. Comparative toughness testing of fiber reinforced concrete. Proceedings of the 1995 ACI Spring Convention, Testing of Fiber Reinforced Concrete; 1995 Mar 5-10; Salt Lake City, UT, US.
88. Silva RV, De Brito J, Dhir RK. Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete. J Clean Prod. 2016;112:2171-86.
89. Bagaria A, Juneja D. Experimental research on influence of marble powder, silica fume and polypropylene fiber on the porous concrete. Mater Today Proc. 2023. doi: 10.1016/j.matpr.2023.03.240
90. Marcos-Meson V, Fischer G, Edvardsen C, Skovhus TL, Michel A. Durability of steel fibre reinforced concrete (SFRC) exposed to acid attack–a literature review. Constr Build Mater. 2019;200:490-501.
91. Rashad AM. The effect of polypropylene, polyvinyl-alcohol, carbon, and glass fibres on geopolymers properties. Mater Sci Technol. 2019;35(2):127-46.
92. Feng S, Jiang Y, Lyu J, Xiao H, Zhang Q, Song R, et al. Effect of nanosilica and fiber on mechanical properties and microstructure of recycled coarse aggregates road concrete. Constr Build Mater. 2024;428:136404.
93. Mohamed AM, Tayeh BA, Majeed SS, Abu Aisheh YI, Salih MNA. A comprehensive review: The impact of recycling polypropylene fiber on lightweight concrete performance. Rev Adv Mater Sci. 2025;64(1):20250141.
94. Wang D, Ju Y, Shen H, Xu L. Mechanical properties of high performance concrete reinforced with basalt fiber and polypropylene fiber. Constr Build Mater. 2019;197:464-73.
95. El Ouni MH, Shah SHA, Ali A, Muhammad S, Mahmood MS, Ali B, et al. Mechanical performance, water and chloride permeability of hybrid steel-polypropylene fiber-reinforced recycled aggregate concrete. Case Stud Constr Mater. 2022;16:e00831.
96. Ali M, Elsayed M, Tayeh BA, Maglad AM, El-Azim AA. Effect of hybrid steel, polypropylene, polyvinyl alcohol, and jute fibers on the properties of ultra-high performance fiber reinforced concrete exposed to elevated temperature. Struct Concr. 2024;25(1):492-505.
97. Ghanim AAJ, Amin M, Zeyad AM, Tayeh BA, Agwa IS, Elsakhawy Y. Effect of polypropylene and glass fiber on properties of lightweight concrete exposed to high temperature. Adv Concr Constr. 2023;15(3):179-190.
98. He F, Biolzi L, Carvelli V, Feng X. A review on the mechanical characteristics of thermally damaged steel and polypropylene hybrid fiber-reinforced concretes. Arch Civ Mech Eng. 2024;24(2):69.
99. Buyukozturk O, Hearing B. Crack propagation in concrete composites influenced by interface fracture parameters. Int J Solids Struct. 1998;35(31-32):4055-66.
100. Aslani F, Hou L, Nejadi S, Sun J, Abbasi S. Experimental analysis of fiber-reinforced recycled aggregate self-compacting concrete using waste recycled concrete aggregates, polypropylene, and steel fibers. Struct Concr. 2019;20(5):1670-83.

101. Şimşek O. Concrete and concrete technology (types-properties-experiments). 5th ed. Ankara (Turkey): Seçkin Publishing Inc.; 2016.
102. Akça KR, Çakır Ö, İpek M. Properties of polypropylene fiber reinforced concrete using recycled aggregates. Constr Build Mater. 2015;98:620-30.
103. Hanumesh BM, Harish BA, Venkata Ramana N. Influence of polypropylene fibres on recycled aggregate concrete. Mater Today Proc. 2018;5(1):1147-55.
104. Ahmed TW, Ali AMA, Zidan RS. Properties of high strength polypropylene fiber concrete containing recycled aggregate. Constr Build Mater. 2020;241:118010.
105. Li F, Chen G, Xu G, Wu Y. An experimental study on the compressive dynamic performance of polypropylene fiber reinforced concrete for retaining structure under automobile collision magnitude. Adv Civ Eng. 2020;2020:1-10.
106. Hossain MFZ, Shahjalal M, Islam K, Tiznobaik M, Alam MS. Mechanical properties of recycled aggregate concrete containing crumb rubber and polypropylene fiber. Constr Build Mater. 2019;225:983-96.
107. Li B, Chi Y, Xu L, Zhu W. Experimental investigation on the flexural behavior of steel-polypropylene hybrid fiber reinforced concrete. Constr Build Mater. 2018;191:80-94.
108. Xu F, Wang S, Li T, Liu B, Li B. Mechanical properties and pore structure of recycled aggregate concrete made with iron ore tailings and polypropylene fibers. J Build Eng. 2021;33:101572.
109. Khan MS, Khan MI, Choudhry RM, Khahro SH, Memon ZA. Performance analysis of fiber reinforced recycled aggregate concrete at elevated temperatures using response surface methodology. Sci Rep. 2025;15(1):12916.
110. Das CS, Dey T, Dandapat R, Mukharjee BB, Kumar J. Performance evaluation of polypropylene fibre reinforced recycled aggregate concrete. Constr Build Mater. 2018;189:649-59.
111. Sarangi S, Sinha AK. Mechanical properties of hybrid fiber reinforced concrete. Indian J Sci Technol. 2016;9(30):1-4.
112. Wu F, Yu Q, Liu C, Brouwers JH, Wang L, Liu D. Effect of fibre type and content on performance of bio-based concrete containing heat-treated apricot shell. Mater Struct. 2020;53:137.
113. Cheng H, Gao D. Experimental study on damage of polypropylene fiber concrete in freeze-thaw cycles. J Southeast Univ Nat Sci Ed. 2010;40(S2):197-200.
114. Chen LZ, Zhang GT, Huang WM, Min PL, Guo CW, Liu WY. The injury research of fiber reinforced concrete under freeze-thaw cycles. Sci Technol Eng. 2015;15(5):145-50.
115. Nili M, Azarioon A, Danesh A, Deihimi A. Experimental study and modeling of fiber volume effects on frost resistance of fiber reinforced concrete. Int J Civ Eng. 2018;16(3):263-72.
116. Rostami R, Zarrebini M, Sanginabadi K, Mostofinejad D, Abtahi Forooshani SM, Fashandi H. An investigation into influence of physical and chemical surface modification of macro-polypropylene fibers on properties of cementitious composites. Constr Build Mater. 2020;244:118340.

117. Latifi MR, Biricik Ö, Mardani Aghabaglou A. Effect of the addition of polypropylene fiber on concrete properties. J Adhes Sci Technol. 2022;36(4):345-69.
118. Atis CD, Karahan O, Ari K, Sola ÖC, Bilim C. Relation between strength properties (flexural and compressive) and abrasion resistance of fiber (steel and polypropylene)-reinforced fly ash concrete. J Mater Civ Eng. 2009;21(8):402-8.
119. Horszczaruk E. Abrasion resistance of high-strength concrete in hydraulic structures. Wear. 2005;259(1-6):62-9.
120. Vaidya S, Allouche EN. Strain sensing of carbon fibre reinforced geopolymer concrete. Mater Struct. 2011;44(8):1467-75.
121. Kang J, Chen X, Yu Z. Effect of polypropylene fiber on frost resistance and carbonation resistance of manufactured sand concrete. Structures. 2023;56:104896.
122. Kalifa P, Menneteau FD, Quenard D. Spalling and pore pressure in HPC at high temperatures. Cem Concr Res. 2000;30:1915-27.
123. Kalifa P, Chéné G, Gallé C. High-temperature behaviour of HPC with polypropylene fibres from spalling to microstructure. Cem Concr Res. 2001;31(10):1487-99.
124. Li Y, Su Y, Tan KH, Zheng X, Sheng J. Pore structure and splitting tensile strength of hybrid basalt–polypropylene fiber reinforced concrete subjected to carbonation. Constr Build Mater. 2021;297:123779.
125. Wongprachum W, Sappakittipakorn M, Sukontasukkul P, Chindaprasirt P, Banthia N. Resistance to sulfate attack and underwater abrasion of fiber reinforced cement mortar. Constr Build Mater. 2018;189:686-94.
126. Tapkin S. The effect of polypropylene fibers on asphalt performance. Build Environ. 2008;43(6):1065-71.
127. Tapkin S, Usar U, Tuncan A, Tuncan M. Repeated creep behavior of polypropylene fiber-reinforced bituminous mixtures. J Transp Eng. 2009;135(4):240-9.
128. Tapkin S, Çevik A, Uşar Ü. Accumulated strain prediction of polypropylene modified Marshall specimens in repeated creep test using artificial neural networks. Expert Syst Appl. 2009;36(8):11186-97.
129. Kaloush KE, Biligiri KP, Zeiada WA, Rodezno MC, Reed JX. Evaluation of fiber-reinforced asphalt mixtures using advanced material characterization tests. J Test Eval. 2010;38(4):400-11.
130. Abtahi SM, Ghorban Ebrahimi M, Kunt MM, Hejazi SM, Esfandiarpour S. Production of polypropylene-reinforced asphalt concrete mixtures based on dry procedure and Superpave gyratory compactor. Iran Polym J. 2011;20(10):813-23.
131. Zachariah JP, Sarkar PP, Debnath B, Pal M. Effect of polypropylene fibres on bituminous concrete with brick as aggregate. Constr Build Mater. 2018;168:867-76.
132. Nobili A, Lanzoni L, Tarantino AM. Experimental investigation and monitoring of a polypropylene-based fiber reinforced concrete road pavement. Constr Build Mater. 2013;47:888-95.

133. Chen Y, Waheed MS, Iqbal S, Rizwan M, Room S. Durability properties of macro-polypropylene fiber reinforced self-compacting concrete. Materials. 2024;17(2):284.
134. Tao Y, Zhang Y, Zhao C, Bu C, Zhang R, Wang Q, et al. Freeze–thaw durability and damage evolution of high-strength concrete reinforced with steel–polypropylene hybrid fibers. Fibers. 2026;14(3):28.
135. Choi J, Zi G, Hino S, Yamaguchi K, Kim S. Influence of fiber reinforcement on strength and toughness of all-lightweight concrete. Constr Build Mater. 2014;69:381-9.
136. Mahmoud Hama S. Evaluations of strengths, impact, and energy capacity of two-way concrete slabs incorporating waste plastic. J King Saud Univ Eng Sci. 2021;33(5):337-45.
137. Al Qadi ANS, Al-Zaidyeen SM. Effect of fibre content and specimen shape on residual strength of polypropylene fibre self-compacting concrete exposed to elevated temperatures. J King Saud Univ Eng Sci. 2014;26(1):33-9.
138. Khalil E, Abd-Elmohsen M, Anwar AM. Impact resistance of rubberized self-compacting concrete. Water Sci. 2015;29(1):45-53.
139. Aslani F, Nejadi S. Self-compacting concrete incorporating steel and polypropylene fibers: Compressive and tensile strengths, moduli of elasticity and rupture, compressive stress–strain curve, and energy dissipated under compression. Compos Part B Eng. 2013;53:121-33.
140. Bagherzadeh R, Sadeghi AH, Latifi M. Utilizing polypropylene fibers to improve physical and mechanical properties of concrete. Text Res J. 2012;82(1):88-96.
141. Amran M, Lesovik V, Tolstoy A. Properties and performance of polypropylene fibered high-strength concrete with an improved composite binders. Case Stud Constr Mater. 2022;17:e01621.
142. Zeyad AM. Effect of fibers types on fresh properties and flexural toughness of self-compacting concrete. J Mater Res Technol. 2020;9(3):4147-58.
143. Jalota S, Suthar M. Modelling of Marshall stability of polypropylene fibre reinforced asphalt concrete using support vector machine and artificial neural network. Int J Transp Sci Technol. 2025;19:78-98.
144. Zhang H, Sarker P, Wang Q, Shaikh FUA. Strength and toughness of ambient-cured geopolymer concrete containing virgin and recycled fibres in mono and hybrid combinations. Constr Build Mater. 2021;304:124649.
145. Yoshitake I, Ueno S, Ushio Y, Arano H, Fukumoto S. Abrasion and skid resistance of recyclable fly ash concrete pavement made with limestone aggregate. Constr Build Mater. 2016;112:440-6.
146. Roesler J, Bordelon A, Gaedicke C, Park K, Paulino G. Fracture behavior and properties of functionally graded fiber-reinforced concrete. Proceedings of the 9th International Conference on Multiscale and Functionally Graded Materials (FGM IX); 2006 Oct 15-18; Oahu Island, HI, US.
147. Cui K, Xu L, Li L, Chi Y. Mechanical performance of steel-polypropylene hybrid fiber reinforced concrete subject to uniaxial constant-amplitude cyclic compression: fatigue behavior and unified fatigue equation. Compos Struct. 2023;311:116795.

148. Chen Y, Cen G, Cui Y. Comparative analysis on the anti-wheel impact performance of steel fiber and reticular polypropylene synthetic fiber reinforced airport pavement concrete under elevated temperature aging environment. Constr Build Mater. 2018;192:818-35.
149. Liu Y, Zhang Z, Xie J. Research on the propagation mechanisms and meso-mechanical responses of reflective cracking on the asphalt overlays on concrete airfield pavement. Measurement. 2024;226:114164.
150. Ozturk O, Ozyurt N. Effects of polypropylene fibers on the post-cracking cyclic shear response of concrete pavement mixtures. Int J Pavement Res Technol. 2025;19:2177-89.
151. Abdul-Rahman M, Al-Attar AA, Hamada HM, Tayeh B. Microstructure and structural analysis of polypropylene fibre reinforced reactive powder concrete beams exposed to elevated temperature. J Build Eng. 2020;29:101167.
152. Ochi T, Okubo S, Fukui K. Development of recycled PET fiber and its application as concrete-reinforcing fiber. Cem Concr Compos. 2007;29(5):448-55.
153. Yan S, Dong Q, Chen X, Li J, Wang X, Shi B. An experimental and numerical study on the hybrid effect of basalt fiber and polypropylene fiber on the impact toughness of fiber reinforced concrete. Constr Build Mater. 2024;411:134270.
154. Mao J, Liang N, Liu X, Zhong Z, Zhou C. Investigation on early-age cracking resistance of basalt-polypropylene fiber reinforced concrete in restrained ring tests. J Build Eng. 2023;70:106155.
155. Wang C, Du Z, Zhang Y, Ma Z. Elaborating the 3D microstructural characteristics and strength softening mechanical mechanism of fiber-reinforced recycled aggregate concrete. Constr Build Mater. 2024;436:137009.
156. Wang J, Zhao C, Li Q, Song G, Hu Y. The synergistic effect of recycled steel fibers and rubber aggregates from waste tires on the basic properties, drying shrinkage, and pore structures of cement concrete. Constr Build Mater. 2025;470:140574.
157. Yang JM, Min KH, Shin HO, Yoon YS. Effect of steel and synthetic fibers on flexural behavior of high-strength concrete beams reinforced with FRP bars. Compos Part B Eng. 2012;43(3):1077-86.
158. Thakur G, Singh Y, Singh R, Prakash C, Saxena KK, Pramanik A, et al. Development of GGBS-based geopolymer concrete incorporated with polypropylene fibers as sustainable materials. Sustainability. 2022;14(17):10639.
159. Bertelsen IMG, Ottosen LM, Fischer G. Influence of fibre characteristics on plastic shrinkage cracking in cement-based materials: a review. Constr Build Mater. 2020;230:116769.
160. Li YF, Lee KF, Ramanathan GK, Cheng TW, Huang CH, Tsai YK. Static and dynamic performances of chopped carbon-fiber-reinforced mortar and concrete incorporated with disparate lengths. Materials. 2021;14(4):972.
161. El-Abbasy AA. Production, behaviour and mechanical properties of ultra-high-performance fiber concrete–a comprehensive review. Case Stud Constr Mater. 2022;17:e01637.

162. Kakooei S, Akil HM, Jamshidi M, Rouhi J. The effects of polypropylene fibers on the properties of reinforced concrete structures. Constr Build Mater. 2012;27(1):73-7.
163. Atea RS. A case study on concrete column strength improvement with different steel fibers and polypropylene fibers. J Mater Res Technol. 2019;8(6):6106-14.
164. Li YF, Hsu CF, Syu JY, Chen FW, Wu JH. Experimental investigation on the mechanical characteristics of ultra-high-molecular-weight polyethylene (UHMWPE) based fiber-reinforced concrete. Case Stud Constr Mater. 2024;21:e03762.
165. Elango KS, Gopi R, Saravanakumar R, Rajeshkumar V, Vivek D, Raman SV. Properties of pervious concrete – a state of the art review. Mater Today Proc. 2021;45:2422-5.
166. Zhao M, Zhao M, Chen M, Li J, Law D. An experimental study on strength and toughness of steel fiber reinforced expanded-shale lightweight concrete. Constr Build Mater. 2018;183:493-501.
167. Zhou Y, Zheng S. Machine-learning based hybrid demand-side controller for high-rise office buildings with high energy flexibilities. Appl Energy. 2020;262:114416.
168. Zhou Y, Zheng S. A co-simulated material-component-system-district framework for climate-adaption and sustainability transition. Renew Sustain Energy Rev. 2024;192:114184.
169. Zhou Y, Zheng S, Liu Z, Wen T, Ding Z, Yan J, et al. Passive and active phase change materials integrated building energy systems with advanced machine-learning based climate-adaptive designs, intelligent operations, uncertainty-based analysis and optimisations: a state-of-the-art review. Renew Sustain Energy Rev. 2020;130:109889.
170. Sam-Daliri O, Ghabezi P, Steinbach J, Flanagan T, Finnegan W, Mitchell S, et al. Experimental study on mechanical properties of material extrusion additive manufactured parts from recycled glass fibre-reinforced polypropylene composite. Compos Sci Technol. 2023;241:110125.
171. Hidalgo Robayo N, Lantsoght EO, Batallas Tituaña J. Initial study on natural fibers for use in concrete mixes as a sustainable materials alternative. ACI Av Cienc Ing. 2024;16(1):e3159.
172. Naraganti SR, Pannem MR, Putta J. Impact resistance of hybrid fibre-reinforced concrete containing sisal fibres. Ain Shams Eng J. 2019;10(2):297-305.
173. Kanalli SA, Palankar R, Kumar B, Kumar P, Sk P. Comparative study of polymer fiber reinforced concrete with conventional concrete pavement. Int J Res Eng Technol. 2014;3(1):139-43.
174. Chia E, Nguyen HBK, Le KN, Bi K, Pham TM. Performance of hybrid basalt-recycled polypropylene fibre reinforced concrete. Structures. 2025;75:108711.
175. Bankir MB, Sevim UK. Performance optimization of hybrid fiber concrete according to mechanical properties. Constr Build Mater. 2020;261:119952.

176. Trindade AC, Silva FA, Alcamand HA, Borges PH. On the Durability Behavior of Natural Fiber Reinforced Geopolymers. Proceedings of the 41st International Conference on Advanced Ceramics and Composites: Ceramic Engineering and Science Proceedings; 2017 Jan 22–27; Daytona Beach, FL, US.
177. Li YF, Li JY, Syu JY, Yang TH, Chang SM, Shen MY. Mechanical behaviors of microwave-assisted pyrolysis recycled carbon fiber-reinforced concrete with early-strength cement. Materials. 2023;16(4):1507.
178. Li J, Chen J, Wan C, Niu J. Flexural toughness and evaluation method of steel fiber reinforced self-compacting lightweight aggregate concrete. Constr Build Mater. 2021;277:122297.
179. Davidovits J. Geopolymer chemistry and sustainable development. The poly (sialate) terminology: a very useful and simple model for the promotion and understanding of green chemistry. Proceedings of the 4th International Conference on Geopolymers (Geopolymer 2005); 2005 Jun 29-Jul 1; Saint-Quentin, France.
180. Talkeri A, Shankar AR. Alkali activated slag-fly ash concrete incorporating precious slag as fine aggregate for rigid pavements. J Traffic Transp Eng (Eng Ed). 2022;9(1):78-92.
181. Dewi ES, Ekaputri JJ. The influence of plain bar on bond strength of geopolymer concrete. Proceedings of the 3rd International Conference on Engineering, Technology, and Industrial Application (ICETIA 2016); 2016 Dec 7-8; Surakarta, Indonesia.
182. Abbass M, Singh G. Durability of rice husk ash and basalt fibre based sustainable geopolymer concrete in rigid pavements. Mater Today Proc. 2022;61:558-70.
183. Altoubat SA, Roesler JR, Lange DA, Rieder KA. Simplified method for concrete pavement design with discrete structural fibers. Constr Build Mater. 2008;22:384-93.
184. Crick CAT. Crack creep and joint performance behavior of fiber reinforced concrete [master's thesis]. Minneapolis (MN, US): University of Minnesota; 2020.
185. Liu X, Wang X, Chen Z, Jiang K, Xie Y, Hu Y, et al. Flexural behavior of concrete reinforced with micro basalt fibers and BFRP minibars. J Build Eng. 2024;97:110751.
186. Camille C, Hewage DK, Mirza O, Mashiri F, Kirkland B, Clarke T. Performance behaviour of macro-synthetic fibre reinforced concrete subjected to static and dynamic loadings for sleeper applications. Constr Build Mater. 2021;270:121469.
187. Mirjalili F, Moradian S, Ameri F. Enhancing the dyeability of polypropylene fibers by melt blending with polyethylene terephthalate. Sci World J. 2013;2013:468542.
188. Sivakumar A, Santhanam M. Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibers. Cem Concr Compos. 2007;29(8):603-8.

189. Roesler JR, Bordelon A, Ioannides A, Beyer M, Wang D. Design and concrete material requirements for ultra-thin whitetopping. Urbana (IL, US): Illinois Center for Transportation; 2008.
190. Yin S, Tuladhar R, Sheehan M, Combe M, Collister T. A life cycle assessment of recycled polypropylene fibre in concrete footpaths. Resour Conserv Recycl. 2016;108:105-14.
191. Ganguly S. Fundamentals of aging and degradation of polymer nanocomposites. In: Aging and Degradation of Polymer Nanocomposites. Amsterdam (The Netherlands): Elsevier; 2026.
192. Anil Kumar HM, Shoba MS. Durability and microstructure of fiber-reinforced geopolymer concrete with FA and GGBS. Structures. 2025;71:108096.
193. Liang N, You X, Yan R, Miao Q, Liu X. Experimental investigation on the mechanical properties of polypropylene hybrid fiber-reinforced roller-compacted concrete pavements. Int J Concr Struct Mater. 2022;16(1):3.
194. Zhou Y, Zheng S, Zhang G. A state-of-the-art-review on phase change materials integrated cooling systems for deterministic parametrical analysis, stochastic uncertainty-based design, single and multi-objective optimisations with machine learning applications. Energy Build. 2020;220:110013.
195. Zhou Y, Zheng S, Hensen JL. Machine learning-based digital district heating/cooling with renewable integrations and advanced low-carbon transition. Renew Sustain Energy Rev. 2024;199:114466.
196. Orouji M, Zahrai SM, Najaf E. Effect of glass powder & polypropylene fibers on compressive and flexural strengths, toughness and ductility of concrete: an environmental approach. Structures. 2021;33:2802-16.
197. Najaf E, Orouji M, Zahrai SM. Improving nonlinear behavior and tensile and compressive strengths of sustainable lightweight concrete using waste glass powder, nanosilica, and recycled polypropylene fiber. Nonlinear Eng. 2022;11(1):58-70.

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