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Review Paper

Composition and Mechanical Performance of Textile-Reinforced Concrete: A Comprehensive Review

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ABSTRACT

Textile-reinforced concrete (TRC) is gaining recognition as an advanced construction material due to its excellent load-bearing capacity, resistance to corrosion, and long-term durability. However, the influence of different textile types and design parameters on TRC's mechanical behavior remains not fully understood. This study aims to deepen the knowledge of TRC's mechanical performance and to identify potential avenues for future research. The compressive, tensile, and flexural behaviors of TRC are analyzed through a review of existing literature. Results show that TRC performance strongly depends on textile characteristics such as shape, geometry, weaving pattern, and yarn properties. Under tensile and flexural loading, TRC generally exhibits three stages: an initial elastic phase, a strain-hardening phase with multiple cracking, and a softening phase leading to failure. The bond between textile and cementitious matrix is also examined using pull-out test results. Textile geometry and surface properties significantly influence the interfacial bond strength. This review summarizes current knowledge on TRC behavior and highlights its potential applications in civil engineering.

1 Introduction

In recent decades, the construction sector has confronted increasing challenges related to structural durability material efficiency [1, 2], and environmental sustainability [3, 4]. Conventional reinforced concrete, although widely used, suffers from intrinsic limitations such as steel corrosion, significant cover thickness requirements, and high self-weight [5]. These drawbacks often result in increased maintenance costs and reduced service life, particularly in aggressive environments [5].

In this context, TRC has developed into a promising composite system for construction and structural use [6]. TRC consists of a fine-grained cementitious matrix combined with non-metallic textile reinforcements made of continuous fibers such as alkali-resistant glass, carbon, basalt, or aramid [7, 8]. Unlike traditional steel reinforcement, textile reinforcements are non-corrosive, enabling a notable decrease in the thickness of the concrete protection and enabling the production of lightweight and slender structural elements [9].

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Recent research on advanced cementitious materials and textile-reinforced concrete (TRC) highlights a clear shift toward more efficient and sustainable solutions. Significant improvements in mechanical performance and durability have been achieved through the optimization of matrix composition and textile architecture, alongside the use of innovative binders such as geopolymers or low-carbon cement systems [2, 3, 5, 6, 8]. Over the past two decades, extensive investigations have focused on the mechanical behavior of TRC under various loading conditions, with particular emphasis on tensile response, multi-cracking mechanisms, flexural performance, bond behavior, and long-term durability [8, 9]. The type, geometry, and orientation of textile reinforcement have been identified as key parameters governing structural response, while the textile–matrix interface plays a critical role in load transfer, crack distribution, stiffness evolution, and post-cracking behavior, especially under aggressive environmental conditions [4, 8, 10–12, 13]. In parallel, hybrid reinforcement strategies combining short fibers and continuous textiles have demonstrated enhanced toughness and improved post-cracking performance [14], while recent developments also explore multifunctional properties such as thermal efficiency and energy storage capacity [9, 15]. Despite these advances, the existing literature remains fragmented, with variations in testing methods, textile configurations, matrix formulations, and specimen geometries leading to significant discrepancies in reported results. Moreover, the influence of key parameters such as reinforcement ratio, textile impregnation, and matrix strength still requires further consolidation to establish consistent interpretations and reliable predictive models [11, 12].

Given these considerations, the objective of this review paper is to provide a structured and critical overview of the current state of knowledge on Textile Reinforced Concrete. The review focuses on constituent materials, bond mechanisms, tensile and flexural behavior, influencing parameters, and modeling approaches. Particular emphasis is placed on identifying convergences and discrepancies in experimental findings and highlighting research gaps that require further investigation.

2 Constituents of Textile Reinforced Concrete

The behavior of Textile Reinforced Concrete (TRC) strongly depends on the properties and interaction of its constituent materials. TRC is a composite system composed of a fine-grained cementitious matrix and textile reinforcements. The mechanical behavior, cracking response, durability, and structural efficiency of TRC are governed by the characteristics of both components and their interface [6].

2.1 Cementitious Matrix

Unlike conventional concrete, TRC uses a fine-grained mortar without coarse aggregates to ensure proper impregnation and bonding with the textile reinforcement. The matrix typically consists of cement, fine sand (maximum particle size generally below 1 mm), mineral additions, water, and chemical admixtures [7, 8]. High-performance matrices are often preferred to enhance tensile strength, reduce porosity, and enhance durability. Incorporating supplementary cementitious materials like silica fume, fly ash, or slag helps densify the microstructure and enhances the interface between the textile and the cement matrix [9]. In recent years, ultra-high-performance mortar (UHPM) and low-clinker binders have also been investigated to optimize both mechanical performance and environmental impact [8, 10].

The matrix tensile strength and fracture energy play a key role in the multi-cracking behavior of TRC. A sufficiently strong and ductile matrix promotes crack distribution and improves stress transfer to the textile reinforcement. Conversely, a weak matrix may lead to premature crack localization and inefficient reinforcement utilization [11]. Current challenges involve replacing 70% to 80% of Ordinary Portland Cement (OPC) with substitutes such as Fly Ash (FA), Silica Fume (SF), and Limestone Powder (LS) [12].

2.2 Textile Reinforcements

The reinforcement in TRC consists of continuous fiber textiles arranged in unidirectional, bidirectional, or multi-axial configurations. The most commonly used fibers include [1, 16, 17]:

- Carbon fibers are noted for their superior tensile strength, elevated elastic modulus, and outstanding stability in alkaline media.
- Alkali-resistant (AR) glass fibers, offering a cost-effective solution with good mechanical performance.
- Basalt fibers, providing a balance between mechanical properties and economic considerations.
- Aramid fibers, known for their high toughness and impact resistance.

Textile reinforcements are typically manufactured in the form of grids or fabrics with defined mesh sizes and yarn cross-sections as shown in Figure 1. The mechanical response of TRC is strongly influenced by textile parameters such as fiber type, yarn linear density, spacing between yarns, textile orientation, and number of layers. Table 1 gives different characteristics of most used fibers in textile reinforced concrete [18]. In addition to conventional synthetic fibers, recent research has explored the use of natural fibers in TRC, including jute, flax, bamboo, cotton, sisal, and coir. These plant-based fibers offer potential benefits in terms of sustainability, low cost, and reduced environmental impact. Studies have investigated their mechanical performance, durability, and compatibility with cementitious matrices, highlighting both opportunities and challenges for their integration in structural elements. While natural fibers generally exhibit lower tensile strength and variability compared to synthetic fibers, their use in TRC is being optimized through treatments, hybridization with synthetic fibers, and careful matrix design to achieve acceptable mechanical and durability performance [19].

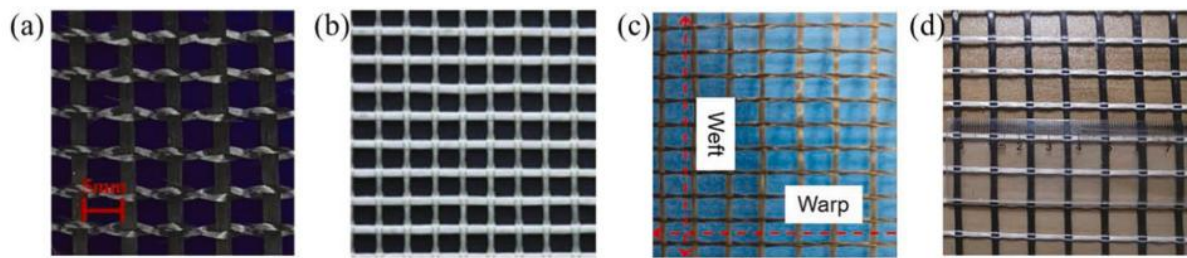


Fig. 1- Textile reinforcement (a) Carbon [9], (b) AR-glass [8], (c) basalt [10], and (d) hybrid [11].

Table 1. Fiber classifications and their key mechanical characteristics [20]

Fiber Type	Material	Density (g/cm ³)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Strain Capacity (%)
Natural fibers	Jute	1.23	187–773	13–31	2.5
	Flax	1.38	343–1035	27–6	1.2–3.3
	Bamboo	0.6–1.1	140–230	11–17	3.8–5.8
	Cotton	1.6	220–840	4.5–12.6	2–10
	Sisal	1.5	80–855	9–38	9–38
	Coir	1.2	160–250	3–6	30
Manmade fibers	Carbon	1.4	1100–4000	150–235	1.4–1.8
	Glass	2.6	120–790	30–40	2.5
	Boron	2.48–2.82	500–2100	450	3.7
	Ceramic	2.7–3.88	1967–2930	150–373	-
	Aramid	1.44	1412–2097	98–102.2	-

2.3 Textile–Matrix Interface

The textile–matrix interface is a critical component governing stress transfer mechanisms. Unlike ribbed steel bars, textile reinforcements rely primarily on friction, mechanical interlocking, and chemical adhesion for load transfer [15, 20]. Bond performance depends on several parameters, including matrix strength, textile geometry, and curing conditions. Insufficient bonding may result in yarn pull-out failure, whereas optimal bonding promotes distributed cracking and improved post-cracking stiffness [21]. The complexity of the textile–matrix interaction makes it one of the most investigated aspects in TRC research (Fig. 2). Understanding and optimizing this interface remains essential for developing reliable design models and improving structural performance [22–24].

Further predictions of the interfacial behavior should account for the average bond and shear strength per unit length. Considering the various failure mechanisms of TRC (Fig. 2a), analytical fiber pullout models are employed to estimate performance, either based on yarn asperities and geometry or on the mechanical characteristics of warp and weft intersections

(Fig. 2b). As illustrated in Figure 2c, the interfacial shear stress varies along the yarn with slip; thus, the shear stress can be expressed as $\tau(x) = \tau[s(x)]$, where τ and s represent the shear stress and slip, respectively [16].

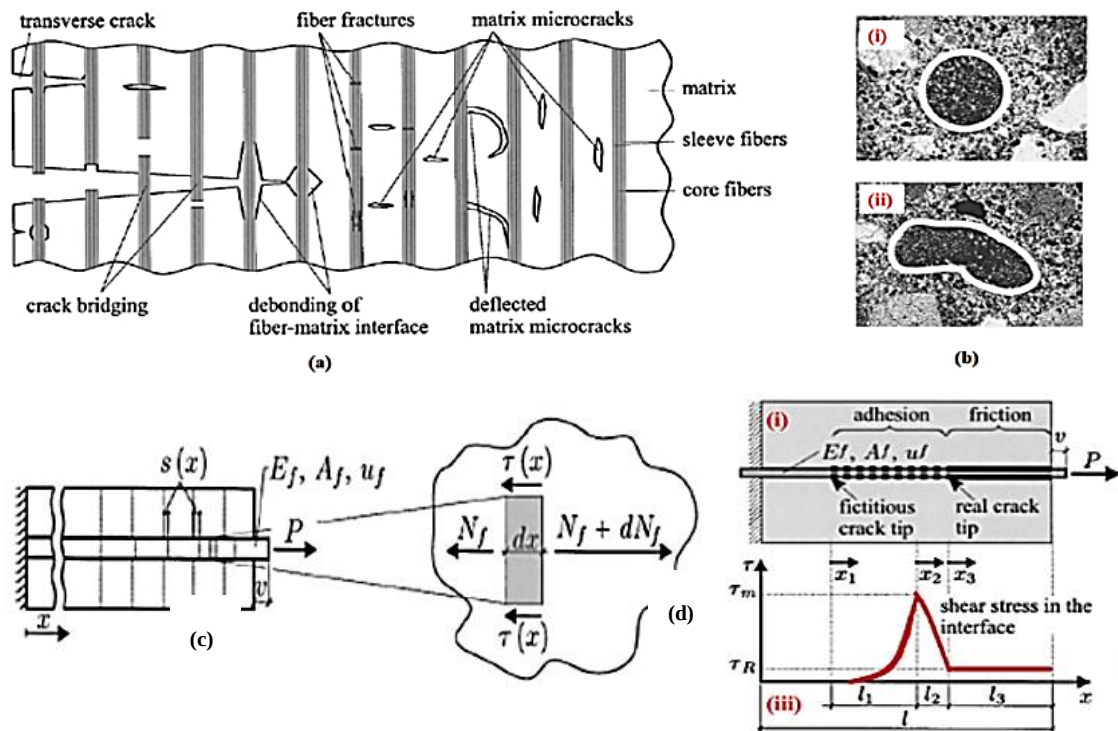


Fig. 2- (a) Typical damage mechanisms in TRC under partial failure, including transverse cracking, fiber breakage, matrix microcracks, crack bridging, and debonding at the fiber-matrix interface. (b) Cross-sectional view of highlighted roving boundaries: (i) ideal circular interface, (ii) distorted boundaries resulting from non-uniformity. (c) Mechanical pull-out schematic for a TRC yarn. (d) Tri-linear shear stress-slip relationship for analytical purposes: (i) mechanical model, (iii) corresponding interfacial shear stress distribution [16].

3 Mechanical Test Procedures

The mechanical assessment of Textile Reinforced Concrete (TRC) relies primarily on tensile, flexural, and pull-out tests (Fig. 3), which together provide a comprehensive understanding of its structural behavior.

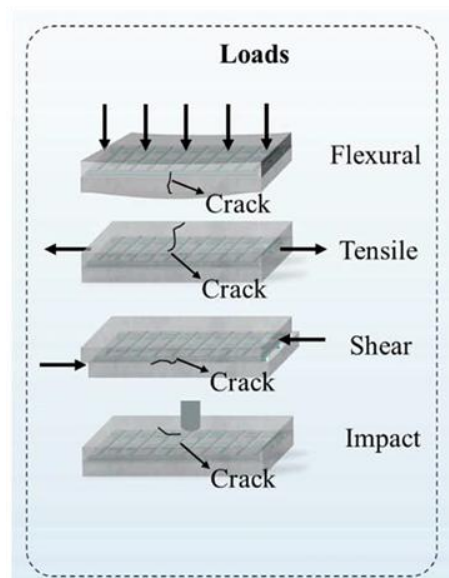


Fig. 3- Key effects of applied loads on TRC in service [5]

Direct tensile tests are used to evaluate cracking response, strain-hardening behavior and ultimate tensile load-bearing capacity, reflecting the effectiveness of load transfer between the textile reinforcement and the cement matrix [25, 26]. Flexural tests simulate bending conditions commonly encountered in structural elements and allow assessment of stiffness, crack distribution, and post-cracking performance. Pull-out tests, on the other hand, specifically investigate the interfacial bond between the textile rovings and the surrounding matrix, which governs load transfer mechanisms and long-term durability. Combined, these experimental approaches form the basis for evaluating the mechanical performance and reliability of TRC systems [8].

3.1 Uniaxial tensile experiment

Tensile tests under uniaxial loading are essential for determining the tensile strength, ductility, and cracking behavior of TRC composites. Specimens are typically prepared as thin rectangular plates.

3.1.1 Mechanical Response

The tensile stress-strain curve of high-performance TRC generally exhibits trilinear behavior (Fig. 4):

- Stage I (Linear Elastic Stage): The composite behaves in a monolithic manner. The applied load is primarily carried by the uncracked cementitious matrix, resulting in a linear stress–strain response governed by the matrix stiffness.
- Stage II (Multiple Cracking Stage): Once the matrix attains its tensile strength, multiple fine and nearly parallel cracks develop throughout the specimen. In this stage, a significant reduction in stiffness occurs, and a plateau region typically appears in the stress–strain curve, reflecting the progressive redistribution of stresses from the matrix to the textile reinforcement.
- Stage III (Stabilized Cracking): At this stage, the matrix is fully cracked, and the tensile load is entirely transmitted to the textile reinforcement. The mechanical response is then governed by the elastic modulus and tensile capacity of the textile until ultimate failure occurs, either by textile rupture or pull-out (slip).

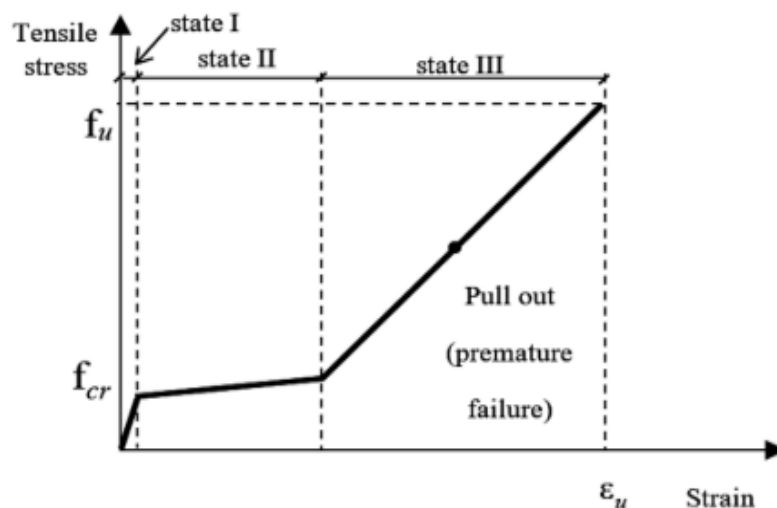


Fig. 4- Typical stress-strain relationship of TRC [27]

3.1.2 Influencing Factors

Tensile performance is highly dependent on the textile laying direction, with the warp direction typically providing superior load-bearing capacity compared to the weft. Furthermore, adding more textile layers significantly enhances the ultimate stress and energy absorption capacity.

3.2 Flexural Performance

Flexural testing is critical for evaluating TRC in structural applications such as façade panels and thin shells. Tests are predominantly conducted using four-point bending setups, which create a constant moment zone allowing for a detailed analysis of crack kinematics.

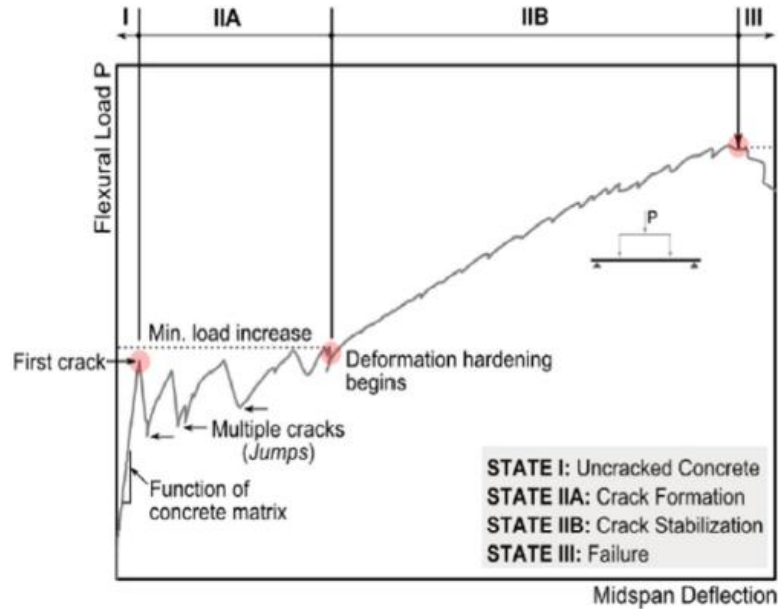


Fig. 5-Representative load-midspan deflection curve for a TRC specimen under four-point bending, showing the different stages [13]

- **Failure Modes:** TRC elements in bending typically fail through textile tensile rupture, matrix crushing, or delamination (interfacial debonding).
- **Short Fiber Synergy:** The incorporation of short, dispersed fibers (e.g., steel, PVA, or glass) into the cementitious matrix significantly improves the first-crack strength and control of crack widths, leading to a more robust deflection-hardening response [14].

3.3 Interfacial Bond and Pull-out Behavior

The bond behavior at the textile-matrix interface is the primary factor governing the global structural efficiency of TRC [28]. Bond strength is based on direct pull-out testing of individual yarns, double-sided symmetric/unsymmetric pull-out tests, or single-lap shear tests to simulate the stress state of externally bonded reinforcement [28].

3.3.1 Tri-linear bond law

The relationship between shear stress and slip consists of an initial elastic adhesion phase, followed by a debonding (softening) phase, and finally a constant friction phase after the chemical bond has been broken. Carozzi proposed a tri-linear bond-slip relationship, as illustrated in Figure 5:

- Stage I: at the initial stage, the yarn is fully attached to the surrounding matrix. As the yarn begins to move, the interfacial shear stress rises with the increase in yarn displacement until the maximum slip u_{max} is reached. Once the peak shear stress is achieved, the interface starts to soften.
- Stage II: with further displacement of the yarn, the interfacial shear stress progressively declines until the slip reaches the value u_0 (Figure 6).
- Stage III: beyond this point, the shear stress no longer changes with displacement and remains constant, corresponding to the frictional stress τ_0 .

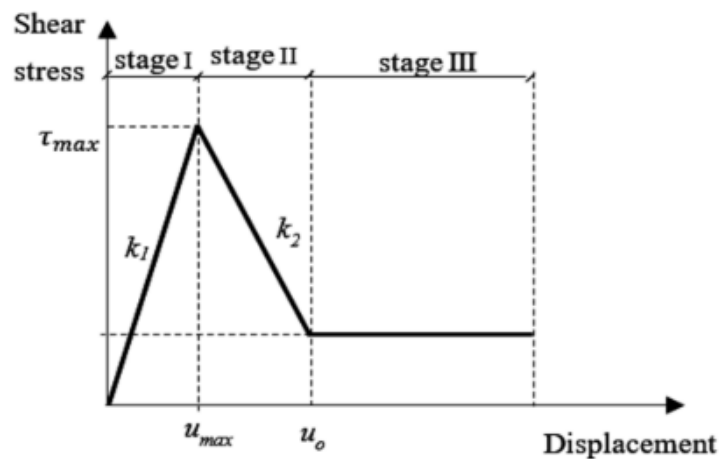


Fig .6- Shear stress–displacement behavior at the textile-matrix interface [2]

3.3.2 Telescopic effect:

Since the textile is composed of multifilament yarns, the matrix often penetrates only the outer filaments (sheath). The inner filaments (core) tend to slide relative to the outer ones, a phenomenon known as the telescopic effect, which influences the ductility of failure

4 Flexural Performance Analysis

Table 2 provides a summary of selected research studies on Textile Reinforced Concrete (TRC), organized to highlight key experimental parameters and findings. It includes the year of publication, authors, type of mechanical test performed, textile type, matrix type, and the essential results reported. This compilation allows for a quick comparison of different TRC systems and helps identify trends in mechanical behavior, materials selection, and testing methodologies

Table. 2 -Summary of Research Studies on TRC

Year	Authors	Type of Test	Type of Textile	Type of Matrix	Essential Results
2025	X. Zhang et al. [16]	Interfacial bond stress testing (single-shear)	Carbon fiber textile	Fine-grained mortar	Predictive curves for damage factors showed good agreement with test data.
2025	T. Zhang et al. [29]	Uniaxial tensile tests on thin plates	Basalt fiber leno textile	Fine-grained mortar	Textile layer number and spacing significantly affected tensile properties; an optimized model accurately reflected tensile response.
2025	M. Alma'aitah et al. [9]	Flexural response and pull-out tests	AR-glass textile	Ultra low-carbon concrete using composite cements	High cement replacement levels improved sustainability; yarn slip was identified as the predominant failure mode.
2025	L. Jing et al. [21]	Uniaxial tensile tests	TRC (implied carbon/glass)	Fine-grained concrete containing Phase Change Materials (FPCC)	Evaluated mechanical performance after multiple thermal cycles (up to 600 cycles).
2025	I. Sharifi et al. [28]	Uniaxial tensile performance	Carbon textile	Two different matrices (soft Mix A and strong Mix B)	Load capacity was higher along the warp direction relative to the weft; telescopic pull-out phenomenon was observed

Year	Authors	Type of Test	Type of Textile	Type of Matrix	Essential Results
2024	M. Alma'aitah et al. [30]	Pull-out and four-point flexural tests	Bidirectional AR-glass textile	Sustainable composite cements with hybrid short fibers	Replacing ARG fibers with PVA/PP reduced cracking strength but increased ultimate flexural deflection.
2022	M. Lee et al. [13]	Four-point flexural tests	Weft-knitted textiles (Aramid, Carbon, Glass)	Fiber Reinforced Concrete (FRC)	Use of tall shear connectors doubled bearing capacity compared to flat reinforcement; short fibers improved crack width limitation.
2014	N.W. Portal et al. [31]	Pull-out tests	Basalt and Carbon meshes	Fine-grained concrete	Extracted local-bond behavior used for FE modeling; 3D models effectively validated assumptions for simplified 1D models.

5 Textile reinforced concrete durability

Research on the durability of textile-reinforced concrete (TRC) focuses on its resilience to thermal cycles, chemical aggression, and long-term cyclic loading, leveraging the inherent corrosion resistance of non-metallic reinforcement [32]. Exposure to high temperatures is critical as it degrades polymer fiber coatings; however, uncoated carbon fibers maintain excellent residual performance above 500 °C, while innovative matrices incorporating fly-ash phase change cenospheres (FPCC) demonstrate robust mechanical stability after 600 thermal cycles [6]. Simultaneously, immersion in saline solutions or alkaline environments can alter the bond at the textile-matrix interface due to increased microscopic porosity, a challenge addressed through the development of ultra low-carbon matrices that limit pore solution alkalinity [8]. Finally, service life durability is influenced by repeated loading, which causes bond creep and increased crack opening in tests simulating 100 years of service life, necessitating the incorporation of short dispersed fibers (PE, PVA) to provide effective microcrack bridging and protect the primary reinforcement [33].

6 Conclusion

Textile Reinforced Concrete (TRC) is emerging as an advanced technology that meets contemporary requirements for lightweight construction, durability, and reduced environmental impact in the field of civil engineering. Its main advantage lies in the use of non-corrosive textile reinforcements (carbon, glass, basalt), which eliminate the need for the thick concrete covers required for conventional steel reinforcement, thereby enabling the design of thin and materially optimized structural elements.

One of the major challenges concerns long-term behavior under repeated loading or fatigue. The stress transfer mechanism strongly depends on interfacial bonding and on the anchorage of rovings within the fine-grained matrix. Progressive slip at the fiber–matrix interface, especially under severe cyclic loading, represents a critical factor limiting mechanical durability. Therefore, a deeper multi-scale understanding of damage mechanisms (microcracking, interfacial debonding, filament rupture) is essential.

Future research should focus on:

- Physico-chemical optimization of the fiber–matrix interface to enhance anchorage and slip resistance;
- Development of low-clinker matrices incorporating reactive mineral additions to reduce carbon footprint without compromising mechanical performance.
- Investigation of coupled thermo-mechanical behavior under fire exposure.
- Integration of predictive numerical models capable of simulating in-service and long-term behavior.

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