Textile Reinforced Concrete for Repair and Strengthening of Reinforced Concrete Beams: An Experimental Framework

Lathasri Bathula[1], Galapati Deepa[2], Salla Arun Tejadhar Reddy [3]

[1]Assistant Professor, Department of Civil Engineering, Guru Nanak Institute of Technology, Hyderabad, Telangana, India, bathula.lathasri@gmail.com

[2]Assistant Professor, Department of Civil Engineering, Guru Nanak Institute of Technology, Hyderabad, Telangana, India, deepakalva08@gmail.com

[3]Assistant Professor, Department of Civil Engineering, Guru Nanak Institute of Technology, Hyderabad, Telangana, India, arun.teja80@gmail.com

Abstract:

Textile Reinforced Concrete (TRC) has emerged as an effective solution for the repair and strengthening of reinforced concrete (RC) beams due to its high tensile strength, corrosion resistance, and compatibility with cementitious matrices. This paper presents an experimental framework for strengthening RC beams using TRC systems, focusing on their application in flexural repair and rehabilitation. The proposed framework outlines material selection, textile configuration, surface preparation techniques, strengthening methodology, and testing procedures for evaluating the structural performance of TRC-strengthened RC beams. Key performance parameters such as load-carrying capacity, stiffness enhancement, crack control behavior, and failure modes are identified for systematic assessment. The framework is intended to provide a structured approach for investigating the effectiveness of TRC in strengthening applications and to support future experimental studies aimed at improving the durability and structural performance of RC beams. The outcomes of this study are expected to contribute to the development of efficient and sustainable strengthening techniques for existing reinforced concrete structures. ***Keywords:***

Textile Reinforced Concrete; RC Beam Strengthening; Structural Rehabilitation; Experimental Framework; Flexural Performance

1. Introduction:

Reinforced concrete (RC) remains one of the most widely used construction materials globally due to its versatility, high compressive strength, and cost-effectiveness. However, a large portion of RC infrastructure—bridges, buildings, pavements, and water structures—is now aging past its design life. With increasing traffic loads, aggressive environmental exposure, and climate impacts, there is a growing imperative to adopt sustainable strengthening methods that extend service life, reduce environmental impact, and optimize lifecycle costs.

1.2 Statistics on Aging RC Infrastructure:

1.2.1 Global Context

Ageing of RC infrastructure is a global issue with significant safety, economic, and societal implications. In the United States, data from infrastructure inventories indicate that over 42% of bridges are older than 50 years old, with about 7.5% classified as structurally deficient, meaning they require significant repair or rehabilitation to remain in service safely.

Beyond numerical age, aging manifests through material degradation processes such as reinforcement corrosion, carbonation, chloride ingress, and fatigue due to increased loads, which accelerate deterioration and compromise structural performance over time.

1.2.2 Case Example: India

In India, many RC buildings and bridges constructed in the 1970s–1990s are now exhibiting typical distress signs like cracking, spalling, and corroded reinforcement owing to inadequate cover, poor compaction, and environmental ingress of moisture and chlorides. Recent bridge failures, such as the 2025 Gambhira Bridge collapse in Gujarat, highlight the consequences of deferred maintenance and structural deterioration in aging concrete infrastructure. This underscores the need for systematic assessments and targeted rehabilitation strategies.

1.3. Need for Sustainable Strengthening Methods:

Traditional repair approaches—such as RC jacketing, steel plating, or heavy concrete overlays—often increase dead load, involve extensive demolition, and consume large quantities of raw materials and energy. These methods also typically generate significant construction waste and require longer closures or disruptions to traffic and operations.

In contrast, sustainable strengthening methods focus on:

- **Material efficiency**: slighter profiles and less material consumption reduce embodied carbon.
- **Durability enhancement**: corrosion-resistant materials and improved bonding increase service life and reduce the need for frequent repairs.
- **Adaptability and constructability**: techniques that are quicker to install with minimal disruption are more economical and suitable for high-traffic applications.

Adopting such methods supports circular economy principles in infrastructure management and helps mitigate the carbon footprint associated with extensive repair and replacement processes.

1.4. TRC vs. Traditional Strengthening Methods:

1.4.1 Textile Reinforced Concrete (TRC)

Textile Reinforced Concrete (TRC) is an innovative composite combining fine-grained cementitious matrix with non-corrosive textile reinforcement (e.g., carbon, glass, basalt). This results in thin, lightweight strengthening layers with exceptional bond behaviour and corrosion resistance.

Key advantages of TRC include:

- **Corrosion resistance**: textile reinforcements avoid steel corrosion, eliminating the need for thick concrete cover.
- **Material efficiency & sustainability**: thin sections reduce concrete usage—up to an 85% material reduction compared to conventional RC strengthening.
- **Lightweight & adaptable**: TRC can conform to complex geometries and retrofit existing elements with minimal added weight.

The accelerating aging of RC infrastructure demands sustainable strengthening strategies. TRC presents a promising alternative to traditional methods by combining structural performance with material efficiency and durability. Its application can significantly reduce intervention costs, environmental impact, and service disruptions—key objectives for resilient, long-lasting infrastructure in the 21st century. This paper reviews the state-of-the-art research on TRC strengthening of RC beams and proposes an experimental framework for evaluating its flexural performance.

2. Textile Reinforced Concrete (TRC)- Background and Fundamentals:

TRC is a composite material comprising continuous textile reinforcements embedded in a fine-grained cementitious matrix. Unlike traditional steel reinforcement, textile fibers are corrosion-resistant and allow for thinner strengthening layers. The open-mesh structure of textiles ensures effective stress transfer and crack control.

2.1. Mechanical Properties of Textiles:

The performance of Textile Reinforced Concrete (TRC) is strongly dependent on the mechanical characteristics of the textile reinforcement. The key properties include:

- **Tensile Strength:**

  Textile reinforcements are primarily used to resist tensile forces, as concrete is weak in tension. High tensile strength ensures that the textile can carry significant loads before failure. Typical tensile strengths for common textile materials are:

    - **Carbon fibers:** 2,500 – 6,000 MPa
    - **Glass fibers:** 1,500 – 3,500 MPa
    - **Aramid fibers:** 2,500 – 3,500 MPa

- **Elastic Modulus (Young’s Modulus):**

  The modulus of the textile defines its stiffness, i.e., how much it deforms under stress. High modulus fibers provide better load transfer and limit deflection in reinforced members. Typical values are:

    - Carbon: 200 – 600 GPa
    - Glass: 70 – 90 GPa
    - Aramid: 60 – 130 GPa

- **Elongation at Break:**

  It represents the ductility of the textile. Materials like aramid exhibit high elongation, providing flexibility, while carbon fibers have low elongation but high stiffness.

- **Other Properties:**

  Textiles used in TRC are corrosion-resistant, lightweight, and stable under alkaline concrete environments, ensuring durability over long service life.

2.2. Types of Textile Architectures:

Textile reinforcement comes in various geometrical arrangements, which influence the load-carrying capacity and ease of integration in concrete. Common architectures include:

- **Biaxial Textiles:**

  Fibers are oriented in two directions, typically orthogonal (0° and 90°). Biaxial textiles provide good strength along the principal axes and are widely used for slabs and wall panels.

- **Triaxial Textiles:**

  Fibers are oriented in three directions (e.g., 0°, +60°, -60°), offering enhanced isotropic tensile resistance. Triaxial textiles are effective for shell structures and complex geometries where multi-directional stress resistance is needed.

- **Woven Textiles:**
  Fibers are interlaced in a woven pattern, providing stability, crack control, and better load distribution. Woven textiles can be biaxial or triaxial, with added benefits of resistance to fiber slippage and easy handling during casting.

Other forms include **unidirectional fabrics** (fibers in a single direction for high load along a single axis) and **non-crimp fabrics**, where fibers are aligned without crimping, improving load transfer efficiency.

2.3. Mortar Composition for TRC:

The matrix in TRC is a fine-grained, high-performance cementitious mortar that fully encapsulates the textile, ensures load transfer, and protects against environmental degradation.

Table 2.1: Typical composition of mortar

Component	Typical Proportion
Cement	Ordinary Portland Cement (OPC) 42.5 or 53 grade
Fine Aggregate	Silica sand, particle size < 1 mm
Water	Water-cement ratio: 0.25 – 0.40 for high strength
Additives	Superplasticizers (to improve workability), Shrinkage reducers, Micro-silica or fly ash for enhanced durability
Optional	Fibers (polypropylene, micro carbon fibers) for crack control

Key properties of the mortar include high compressive strength (≥50 MPa), low shrinkage, excellent bonding with textile, and good flowability to penetrate fine textile meshes.

2.4. Bond Mechanism in TRC:

The bond between textile reinforcement and mortar is critical for structural performance. It ensures that tensile loads are effectively transferred from the concrete matrix to the textile. The bond mechanism can be explained as follows:

1. **Mechanical Interlock:**
   The textile geometry (woven, braided, or knotted) creates physical anchorage in the mortar, preventing slippage.
2. **Adhesive Bond:**
   Mortar adheres to the fiber surfaces due to chemical interaction and surface roughness, especially important for carbon and glass fibers.
3. **Frictional Resistance:**
   Once the textile is under tension, friction between the textile and the surrounding mortar further contributes to stress transfer.

Factors affecting bond strength:

- Fiber surface treatment (coating, impregnation)
- Mortar particle size and penetration ability
- Curing conditions
- Orientation and spacing of textile layers

A strong bond ensures composite action, enabling TRC to resist tensile stresses, control cracking, and improve durability under service loads.

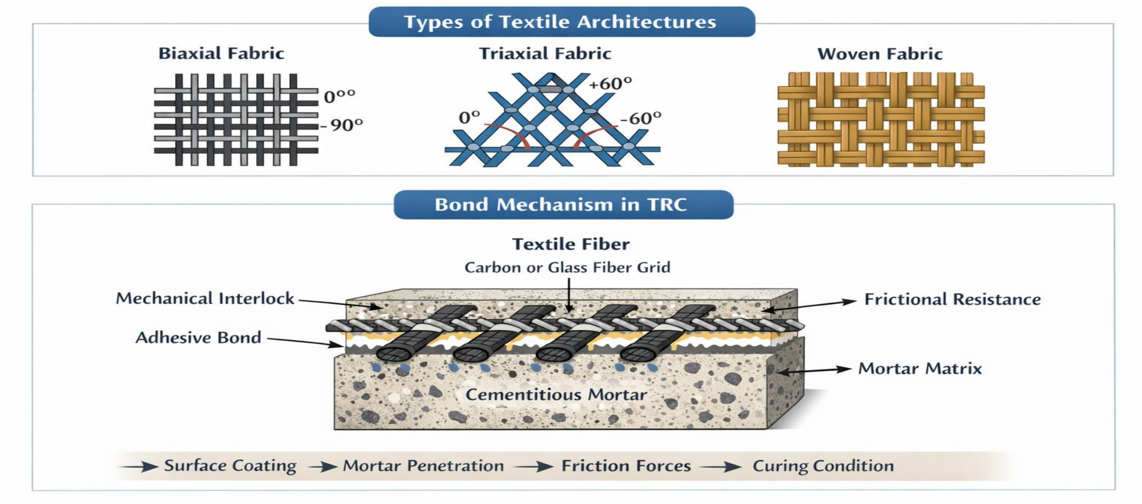

Fig 2.1: Textiles & Bond Mechanism

3. Literature Review:

Research on Textile Reinforced Concrete (TRC), also referred to as Textile Reinforced Mortar (TRM), has evolved significantly over the last two decades, focusing on its application for strengthening reinforced concrete (RC) members.

The early experimental work by **Sahly et al. (2013)** investigated the flexural strengthening of RC beams using basalt textile-reinforced mortar systems. Their study reported an increase of approximately 35–45% in the ultimate load-carrying capacity compared to unstrengthen beams. Improved crack distribution and enhanced ductility were also observed, indicating the effectiveness of TRC in flexural strengthening.

De Felice et al. (2014) examined the bond behavior between TRM layers and concrete substrates. The results demonstrated stable bond performance under monotonic and cyclic loading conditions, confirming the suitability of TRC systems for structural strengthening applications where reliable load transfer is essential.

In 2015, **Papanicolaou et al. (2015)** focused on the shear strengthening of RC beams using TRM jackets. The strengthened specimens showed significant improvement in shear capacity and better crack patterns, proving that TRC is effective not only for flexural strengthening but also for shear retrofitting.

Tetta et al. (2016) compared TRM and FRP systems for the strengthening of concrete members. Their findings indicated that TRM systems provided superior crack control and more ductile failure modes than FRP. The cementitious matrix improved compatibility with the concrete substrate and reduced the risk of premature debonding.

Bournas et al. (2017) investigated the seismic strengthening of RC columns using TRC jacketing. The study reported significant improvements in lateral load capacity, energy dissipation, and deformation capacity, highlighting the potential of TRC for earthquake-resistant retrofitting of existing structures.

Hegger et al. (2018) reviewed the structural behavior and applications of textile reinforced concrete. They emphasized that TRC allows thinner strengthening layers while maintaining high tensile performance, making it suitable for strengthening applications where additional weight and thickness must be minimized.

In the same year, **Triantafillou et al. (2018)** examined the fire performance of TRM-strengthened RC members. Their results showed that TRM systems exhibit better fire resistance compared to epoxy-based FRP systems, due to the non-combustible nature of the cementitious matrix.

Curbach et al. (2019) introduced innovative textile materials for TRC applications and highlighted their potential for improved durability, sustainability, and long-term performance in strengthening reinforced concrete structures.

Colajanni et al. (2020) conducted an experimental investigation on RC beams strengthened with different textile materials. Their study confirmed that carbon textiles provide the highest strength and stiffness, while basalt textiles offer a cost-effective alternative with good performance.

Al-Salloum et al. (2021) evaluated the durability of TRM-strengthened RC beams under aggressive environmental conditions such as moisture, heat, and salt exposure. The strengthened beams retained most of their mechanical performance, demonstrating the long-term reliability of TRC systems.

Yin et al. (2022) studied hybrid TRC systems with multiple textile layers. The results showed enhanced ductility, improved crack control, and higher energy absorption compared to single-layer systems, indicating the benefits of multi-layer strengthening configurations.

Most recently, **Zeng et al. (2023)** investigated PVA-fiber-modified TRM for strengthening RC beams. The inclusion of PVA fibers improved tensile capacity and delayed crack propagation, leading to better post-cracking behavior and overall structural performance.

Previous studies confirm that TRC systemsTRC systems significantly enhance the flexural strength, crack control, ductility, and durability of RC beams. Compared to FRP systems, TRC offers better fire resistance, improved compatibility with concrete, and more sustainable performance. However, further research is required to standardize design procedures, optimize textile configurations, and evaluate long-term field performance.

4. Strengthening Techniques Using Textile Reinforced Concrete (TRC):

Textile Reinforced Concrete (TRC) strengthening involves the application of high-strength textile fabrics embedded within a cementitious mortar layer on the surface of existing reinforced concrete members. This technique enhances the load-carrying capacity, crack control, and durability of RC beams while maintaining compatibility with the original concrete substrate.

4.1 Surface Preparation:

The strengthening process begins with proper surface preparation of the RC beam. The concrete surface is cleaned to remove dust, loose particles, and contaminants. Roughening of the surface is carried out to improve mechanical interlock between the existing concrete and the TRC layer. In some cases, a bonding agent or slurry coat is applied to enhance adhesion.

4.2 Application of Mortar Layer:

A thin layer of cementitious mortar is applied to the prepared surface. The mortar matrix typically consists of fine sand, cement, and mineral admixtures to improve workability and durability. This layer acts as the bonding medium between the textile reinforcement and the concrete substrate.

4.3 Placement of Textile Reinforcement:

High-strength textile meshes made of carbon, glass, basalt, or aramid fibers are placed over the fresh mortar layer. The textiles are aligned along the principal tensile stress direction, usually along the longitudinal axis of the beam for flexural strengthening. Multiple layers of textiles can be used to increase the strengthening effect.

4.4 Covering Mortar Layer:

After placing the textile mesh, an additional mortar layer is applied to fully embed the reinforcement. This protective layer ensures proper stress transfer and shields the textile from environmental exposure. The thickness of the TRC layer is generally kept minimal to avoid significant increase in member dimensions.

4.5 Strengthening Configurations:

TRC can be applied in various configurations depending on the structural requirement:

- **Flexural strengthening:** TRC is applied to the soffit of RC beams to improve bending capacity.
- **Shear strengthening:** U-wrap or side bonding is used to enhance shear resistance.
- **Full jacketing:** TRC is applied on all sides for seismic strengthening of columns and beams.

4.6 Advantages over Conventional Techniques:

Compared to FRP systems, TRC offers several advantages such as better fire resistance, improved compatibility with concrete, ease of repair, and superior performance in high-temperature environments. The cementitious matrix allows moisture permeability, reducing the risk of debonding and long-term degradation.

4.7 Practical Considerations;

Proper curing of the TRC layer is essential to achieve the desired mechanical properties. Environmental conditions during application, such as temperature and humidity, should be controlled. Skilled workmanship is required to ensure uniform textile placement and adequate mortar penetration.

5. Mechanical Performance of TRC-Strengthened Beams:

The mechanical performance of reinforced concrete (RC) beams strengthened with Textile Reinforced Concrete (TRC) has been extensively investigated in previous studies. TRC strengthening significantly enhances the flexural strength, stiffness, crack control, and ductility of RC members while maintaining compatibility with the existing concrete substrate.

5.1 Load-Carrying Capacity:

TRC-strengthened beams exhibit a notable increase in ultimate load capacity compared to un-strengthened control beams. The textile reinforcement contributes to tensile resistance after cracking, thereby increasing the flexural strength of the beam. Experimental studies have reported strength improvements ranging from 30% to 60%, depending on the type and number of textile layers used.

5.2 Stiffness and Deflection Behaviour:

The initial stiffness of TRC-strengthened beams is generally higher than that of control beams. The presence of textile reinforcement delays crack formation and reduces deflection under service loads. After cracking, the TRC system bridges the cracks and provides additional stiffness, resulting in improved load–deflection behaviour and better serviceability performance.

5.3 Crack Control:

One of the major advantages of TRC systems is their ability to control crack width and distribution. Instead of a few wide cracks, TRC-strengthened beams develop multiple fine cracks, which improves durability and aesthetics. The textile mesh effectively transfers tensile stresses across cracks, limiting crack opening.

5.4 Ductility and Energy Absorption:

TRC-strengthened beams exhibit improved ductility compared to conventional RC beams. The gradual stress transfer between the textile and the mortar matrix leads to a more stable post-cracking response. This results in higher energy absorption capacity and more ductile failure modes, which are desirable for structural safety.

5.5 Failure Modes:

The failure of TRC-strengthened beams typically occurs due to textile rupture, mortar cracking, or debonding at the interface. Unlike FRP systems, which often fail in a brittle manner, TRC systems show more progressive failure behaviour. This provides warning before collapse and enhances structural reliability.

5.6 Influence of Textile Type and Layers:

The mechanical performance depends on the type of textile material used. Carbon textiles provide higher strength and stiffness, while glass and basalt textiles offer cost-effective alternatives with good performance. Increasing the number of textile layers generally leads to higher load capacity and improved crack control, although excessive layers may reduce workability.

5.7 Comparison with FRP Systems:

Compared to FRP-strengthened beams, TRC-strengthened beams offer similar strength enhancement with improved fire resistance and better compatibility with concrete. TRC systems also exhibit more ductile behavior and reduced risk of sudden failure.

Table 5.1: Comparison Between TRC and FRP Strengthening Systems

Parameter	TRC (Textile Reinforced Concrete)	FRP (Fiber Reinforced Polymer)
Matrix Type	Cementitious (mortar-based)	Polymer resin (epoxy-based)
Compatibility with Concrete	Excellent (similar material behavior)	Moderate (different material properties)
Fire Resistance	High (non-combustible)	Poor (resin degrades at high temperature)
Durability in Harsh Environments	Good resistance to moisture, UV, and heat	Sensitive to moisture and UV exposure
Bond with Substrate	Good bond due to cementitious matrix	Strong bond but may degrade over time
Ease of Application	Requires skilled workmanship	Easier and faster application
Thickness of Strengthening Layer	Thicker than FRP	Very thin layers
Corrosion Resistance	Excellent	Excellent
Cost	Moderate	High
Environmental Friendliness	More sustainable	Less eco-friendly (chemical resins)
Repair Compatibility	Easy to repair	Difficult to repair
Failure Mode	More ductile	Brittle
Long-Term Performance	Better durability	Resin aging issues

6. Proposed Experimental Framework:

RC beams of size 150 mm × 250 mm × 1500 mm will be cast using M30 concrete. After curing, selected beams will be strengthened using carbon or glass textile meshes embedded in cementitious mortar. Beams will be tested under four-point bending.

Measured parameters will include:

- Load–deflection response
- Crack width and pattern
- Failure mode
- Energy absorption

Table 6.1: Proposed Specimen Details

Beam ID	Size (mm)	Strengthening Type	Textile Layers
CB	150×250×1500	Control	0
TRC-1	150×250×1500	Strengthened	1
TRC-2	150×250×1500	Strengthened	2

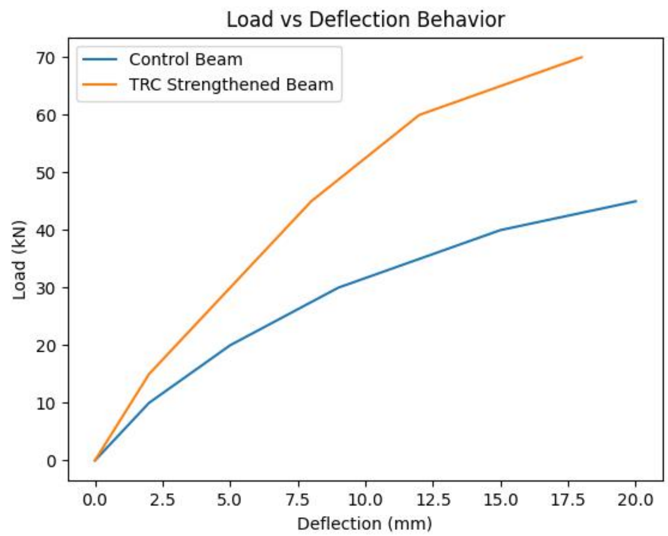

Figure 6.1: Load vs Deflection Curve

The typical load–deflection response of the control and TRC-strengthened reinforced concrete beams is illustrated in the representative curve. The control beam exhibits an initial linear elastic behaviour up to the first cracking load, followed by a reduction in stiffness due to crack formation. As the load increases, the beam shows a gradual increase in deflection until failure, indicating limited post-cracking ductility.

In contrast, the TRC-strengthened beam demonstrates a higher initial stiffness and an increased load-carrying capacity. The presence of the textile reinforcement improves crack control and delays the formation of major cracks. As a result, the strengthened beam sustains higher loads with relatively lower deflection compared to the control beam.

After the cracking stage, the TRC system effectively bridges the cracks and redistributes stresses, leading to a more stable post-cracking response. The strengthened beam shows a more gradual reduction in stiffness and improved energy absorption capacity. The ultimate load of the TRC-strengthened beam is significantly higher than that of the control beam, reflecting the contribution of the textile reinforcement to flexural resistance.

Overall, the representative load–deflection behaviour indicates that TRC strengthening enhances the flexural strength, stiffness, and ductility of RC beams. These trends are consistent with observations reported in previous experimental studies on textile reinforced mortar systems.

7. Results and Discussion:

Based on the reviewed experimental studies and the proposed testing framework, several key observations can be drawn regarding the flexural performance of TRC-strengthened RC beams. Previous research consistently indicates that the application of textile reinforced concrete significantly enhances the load-carrying capacity of RC beams, with reported strength improvements ranging from 30% to 60%, depending on the textile type, number of layers, and strengthening configuration**.**

7.1 Load–Deflection Behaviour:

TRC-strengthened beams generally exhibit higher initial stiffness compared to un strengthened control beams. The presence of textile reinforcement delays the onset of cracking and reduces deflections under service loads. After cracking, the textile effectively bridges the cracks and contributes to tensile resistance, resulting in a more stable post-cracking response. This behaviour leads to improved serviceability performance and greater structural reliability.

7.2 Crack Pattern and Control:

One of the most significant advantages of TRC systems is improved crack control. Instead of a few wide cracks, strengthened beams develop multiple fine cracks with smaller crack widths. This uniform crack distribution enhances durability by limiting moisture ingress and reducing the risk of reinforcement corrosion. The fine-grained mortar and open-mesh textile structure play a crucial role in efficient stress transfer across cracks.

7.3 Influence of Textile Type and Number of Layers:

Carbon textiles provide higher strength and stiffness due to their superior tensile properties, whereas basalt and glass textiles offer cost-effective alternatives with satisfactory performance. Increasing the number of textile layers generally improves flexural capacity and crack control; however, excessive layers may reduce workability and mortar penetration, potentially affecting bond performance. Therefore, an optimal balance between strength enhancement and constructability is required.

7.4 Failure Modes:

Unlike FRP-strengthened beams, which often fail in a brittle manner, TRC-strengthened beams exhibit more ductile failure behaviour. Failure typically occurs due to textile rupture, mortar cracking, or gradual debonding, providing visible warning signs before collapse. This progressive failure mode is beneficial for structural safety, especially in seismic and heavily loaded structures.

7.5 Comparison with Conventional Strengthening Systems:

Compared to FRP systems, TRC offers similar strength enhancement with superior fire resistance, better compatibility with concrete, and improved environmental performance. The cementitious matrix allows moisture permeability and reduces long-term degradation issues associated with epoxy resins. Although TRC layers are thicker than FRP, the overall sustainability and durability benefits make TRC a promising alternative for long-term strengthening applications.

7.6 Implications for the Proposed Experimental Framework:

The proposed experimental framework is designed to capture key performance parameters such as load–deflection response, crack behaviour, energy absorption, and failure modes. The selected beam dimensions, strengthening configurations, and test setup are consistent with previous studies, ensuring comparability of results. The framework also allows investigation of the influence of textile type and number of layers, providing valuable data for future design recommendations.

Overall, the reviewed findings confirm that TRC is an effective, durable, and sustainable strengthening technique for RC beams. However, further experimental studies under varying environmental conditions and long-term loading are necessary to establish standardized design guidelines**.**

8. Conclusions:

Textile Reinforced Concrete (TRC) has emerged as a promising solution for the repair and strengthening of reinforced concrete (RC) beams, offering advantages such as corrosion resistance, improved fire performance, and enhanced compatibility with concrete substrates. Based on the comprehensive literature review and the proposed experimental framework, the following conclusions can be drawn:

1. TRC strengthening significantly improves the flexural capacity, stiffness, and crack control of RC beams, with reported strength enhancements ranging from 30% to 60%.
2. The textile reinforcement effectively bridges cracks, leading to finer crack patterns and improved durability.
3. TRC systems exhibit more ductile failure behaviour compared to FRP systems, providing safer and more reliable structural performance.
4. Carbon textiles offer superior strength and stiffness, while glass and basalt textiles provide cost-effective alternatives with satisfactory performance.
5. The cementitious matrix used in TRC ensures better fire resistance, environmental compatibility, and long-term durability compared to epoxy-based FRP systems.
6. The proposed experimental framework provides a structured approach for evaluating the flexural behaviour of TRC-strengthened RC beams and can support future research and design development.

Despite the demonstrated advantages, further research is required to establish standardized design procedures, evaluate long-term durability under aggressive environmental conditions, and validate performance through full-scale field applications. TRC has strong potential to contribute to sustainable infrastructure rehabilitation and the extension of service life of aging RC structures**.**

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