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Textile Reinforced Mortars Retrofitting Methods of Structural Members: A Review

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Abstract

Textile Reinforced Mortars (TRM) materials have been carefully investigated as an effective and innovative way of retrofitting structural strength. This study provides a concise summary of the structural behavior of TRM-reinforced structures. The article is broken into five sections. The first branch consists of examinations of the TRM's long-term viability. In contrast, the TRM's behavior under tension levels is described in the second branch. At the same time, the flexural strengthening and bonding features of TRM are discussed in the third and fourth branches, respectively. A comprehensive review of the seismic upgrading technique and its application is provided in the fifth branch, which includes the efficiency of TRM jackets in seismic retrofitting of reinforced concrete (RC). Overall, based on all the research and conclusions that were considered, where the TRM system demonstrated adequate effectiveness in the service load, yield stages, and the confinement of reinforced concrete, vastly improves strengths and deformability, increases ductility, and changes the mode of failure by flexural instead of shearing. With enhancements to energy dissipation and a secure bonding capacity at elevated temperatures, it was characterized by its great durability in a chemically hostile environment Compared to its epoxy-resin equivalents. Therefore, (TRM) is an appropriate replacement for (FRP) in some significant applications.

Keywords: Durability; Fabric-Reinforced Cementitious Matrix; Flexural strengthening; Textile Reinforced Concrete

1. Introduction

Compared to the conventional Fiber Reinforced Polymers (FRP) technique, Textile-Reinforces Mortars (TRM) have attracted more attention from researchers for externally bound structural reinforcing [1]. Utilizing TRM in structural reinforcement provides numerous advantages and benefits, such as boosting the structure's serviceability and utility by increasing its load-bearing capacity [1],[2]. Moreover, TRM consists of continuous fabrics (one-dimensional, two-dimensional, and three-dimensional textile-fiber fabrics made of carbon, steel, basalt, glass, etc.) [3]. Concrete reinforced with non-metallic textiles is the composite material composed of the concrete matrix tailored to the specific needs of a reinforcement. Up to thousands of filaments within the reinforcing grid are saturated for mortar [4]. For nearly three decades, the material behaviors of carbon-reinforced concrete have been studied [5]. The FRP strengthening approach has a few disadvantages, the majority of which are related to the use of organic resins to bind or saturate the fibers. These disadvantages may be summed up as follows: 1) Epoxy resins exhibit poor behavior at temperatures above the glass transition temperature; 2) FRP cannot be applied at low temperatures conditions or on wet surfaces ; 3) the inability to vapor; 4) the relatively high cost of epoxy resins; 5) the difficulty of conducting a post-earthquake assessment of the damage suffered by reinforced concrete behind (undamaged) FRP jackets; 6) the incompatibility of epoxy resins and substrate The replacement of organic binders with inorganic binders, such as cement-based mortars [6], is, therefore, a potential solution to the issues above.

For externally strengthening structures, TRM, also known as textile-reinforced mortar, is recommended [7]. It is a high-strength carbon, basalt, or glass fiber composite embedded in inorganic materials such as cement-based mortars, as in "Fig. 1"[8].

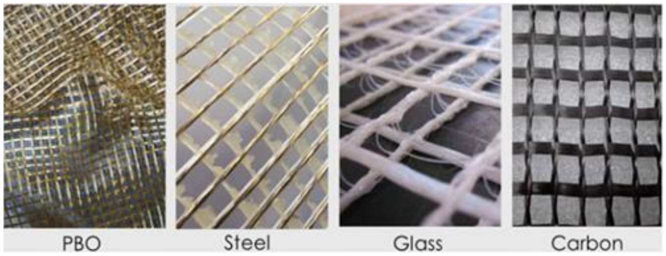


Figure 1. Textile fiber types: (a) polyphenylene bezobisoxazole (PBO); (b) steel fiber textile; (c) glass fiber textile; and (d) carbon fiber textile [8]

The fiber rovings are typically woven or stitched in at least two orthogonal orientations, resulting in an open-mesh shape. The TRM composite is also known by the acronyms TRC (Textile Reinforced Concrete) [9] and FRCM (fabric-reinforced cementation matrix) systems [10]. Cement-based mortars have several advantages for TRM, including 1) resistance to high temperatures [11],[12]; 2) compatibility with concrete substrates; 3) the ability to be applied in a cold environment or on a wet surface; 4) vapor permeability; and 5) cheap cost. Applying TRM to the tension zones of reinforced concrete elements, such as beams or slabs, can enhance their flexural strength. The increased rigidity restricts deflections at the level of service load. This technology is also classified as an emerging technology with a promising future [13],[14]. Textile-reinforced mortars (TRM) can be used as an alternative to fiber-reinforced polymers (FRP) to increase the axial capacity of concrete by confinement, overcoming several concerns with the usage of FRP without considerably decreasing performance [13].

The U-shaped covers are useful in terms of durability. For these reasons, TRM is becoming increasingly desirable as an alternative to the commonly utilized FRP for reinforcing existing structures [13]. TRM jacketing could effectively contain reinforced concrete in seismic zones, where structures constructed by earlier seismic codes must meet the performance requirements set out by more recent seismic designs. Jackets, which aim to strengthen the confinement action in the potential plastic hinge regions or over the entire member, are one of the most popular upgrading procedures for reinforced concrete buildings [13]. Because textile-based composite materials could be used to create brand-new prefabricated structural components or enhance current structures, they have been the subject of substantial research [15]. The replacement of damaged boards with textile-reinforced slabs only necessitates a slight increase in dead weight due to the minimal deadweight of the textile reinforcement and the reduced concrete overlay. By employing lightweight aggregate concrete rather than heavier-weight concrete, the slab's self-weight can also be decreased [16].

Coated textiles, such as steel fabrics (Fig. 1b), are more rigid and cannot readily be applied to complex geometries due to their stiffness. They are composed of entangled steel fibers with a single orientation. Lastly, a mortar-coated connection between the fibers and the matrix is essential [8].

When using TRM jacketing, the procedure begins with surface preparation, followed by applying the initial coat of mortar to wet concrete, applying the mortar-coated fabric layers, and putting the final mortar layer over the fabrics. When cementation cement, silica fume, fly ash, powdered quartz, quartz sand, and water are combined to form the matrix of a composite cement-based textile mesh, the finest overall performance is attained. In addition, concrete and masonry structures can be repaired and reinforced utilizing externally bonded textile-based technologies such as American Concrete Institute (ACI) 549.4R (2013) [17]. When textiles are the primary reinforcing components of TRC, their design specifications depend [18],[19].

The following are the primary assumptions of design: 1) Cross-sections are predominantly flat. 2) It is assumed that reinforcing steel and concrete are compatible with respect to strain. (3) Steel, concrete, and textile reinforcement are believed to be firmly bonded [10].

2. Cement Matrix

The TRM/TRC cement matrix comprises binders, fine-grained aggregates, silica fume, fly ash, and a low water-to-binder ratio. The matrix must be physically and chemically compatible with the textile reinforcement. When selecting a binding material, its high strength, depending on the application, a sufficient bond between the reinforcement and cement matrix, workability during fabrication and setting, geometrical stability, the production process, and low shrinkage and creep are the most important considerations. Different cement-based matrix compositions enhance the rheological properties of reinforced concrete with textiles. The required compressive strength determines the proportions of the components used in the cement matrix. According to the literature, the usual compressive strength of the cement matrix utilized for structural purposes is 50–60 MPa [20],[21]. The most common water-to-binder ratio runs between 0.29 and 0.40. Increased binder content enhances mortar's bonding to reinforcement [22]. Therefore, the matrix is either cementitious or lime-based (Suitable for weak and old constructions are hydraulic- limes, mixed cement-lime mortars, pozzolanic-lime mortars, lime mortars coupled with short fibers, etc.) [23].

Recently, geopolymer was used as an alternative binder. Compared to other forms of concrete matrices, geopolymer-based matrices are chemically very resistant, particularly to acidic conditions, which are quite hostile. Thus, geopolymer-based TRC could be utilized for repairs or as protective coatings as an alternative to polymeric resins [21]. The size of fine-grained aggregates ranges from 1 to 2 mm, depending on the reinforcement's mesh size [22]. In addition, mineral admixtures such as fly ash and micro-silica were primarily intended to improve the workability of fresh concrete, minimize the amount of cement, and reinforce the interfacial interaction between the fabric and the aggregate [24].

3. Durability

Developing a multiscale testing and modeling framework is necessary to comprehend the durability of TRM composites. These systems' stability and deterioration mechanisms must be assessed at the structural or system level, overall, and at all levels individually (a matrix, a textile, a textile to the mortar bond, and a TRM to the substrate bond). Exposure levels guarantee a rate of decline at every level. Investigating the combined exposure's long-term behavior is crucial in addition to loads that cause stress in the reinforcement.

In light of this, long-term durability is the capacity to apply ongoing stress to the textile's reinforcement while subject to the influences of external elements throughout a building structure's service life without the reinforcement failing [25].

3.1. Long-Term Durability of Polymer Reinforcement

Temperature, humidity, stress, and alkalinity are environmental factors that affect long-term durability [26]. Due to the difficulties of conducting long-term testing for a service life of up to one hundred years, these parameters are employed for fake aging. Therefore, it is necessary to extrapolate the trend line derived from the test results to demonstrate the residual fiber's tensile strength in rebar-constructed buildings throughout their service life [26],[27].

3.1.1. Ambient air temperature

The ambient air temperature represents the energy level. When the temperature increases between 20 and 80 degrees Celsius, energy levels increase, and chemical reactions speed up [28]. The TRM binding is strong at high temperatures, whereas the FRP bonding capability is reduced significantly after exposure to high temperatures. Also, FRP specimens demonstrated cohesive failure at 50 °C, whereas adhesive failure was only found at 75 °C at the concrete–resin interface [11].

3.1.2. Elevated temperature effect

Studies on the role of elevated temperatures, which are limited and primarily focused on cement-based mortars, can be categorized as follows: 1) studies of understanding the residual mechanical properties after exposure to high temperatures is of concern; and 2) studies of understanding the mechanical performance of TRC composites at different temperatures is the objective. Typically, the first type of research is conducted by exposing materials to various temperatures and exposure periods. The specimens are subsequently mechanically evaluated after being cooled to room temperature. In the second research category, specimens are tested at a specified temperature. Typically, after these experiments, samples are exposed to the required temperature, and mechanical loads are applied while the temperature is maintained. Again, tensile tests are the most widely used approach for post-aging characterization [29],[30].

High temperatures cause TRC composites to degrade, but in some circumstances, tensile and bond strength have been found to rise at 150–200 °C [31],[32]. After this point and a temperature increase to 600 °C, the TRC/TRM degradation indicators became visible [32] because of the coating's thermal disintegration and the matrix's dryness. These include a change in failure mode, fabric deterioration, and textile-to-mortar contact degradation [33].

Donniniet et al. [34] studied the mechanical behavior values of FRCM systems in high-temperature environments. Their research indicated that depending on the type of fabric reinforcement employed, FRCM systems could provide high-temperature compatibility while maintaining mechanical performance when exposed to 120 °C. It has been demonstrated that when exposed to high temperatures, FRCM performs better than FRP. Spelter et al. [25] also conducted a study on long and short-term tests. The developed testing concept aims to conduct long-term tests lasting 200, 1000, and 5000 hours. Loading and long-term durability tests were done with simultaneous temperature, stress, alkalinity, and humility. According to the conclusion, the capacity test increases the ultimate failures of stress. Al-Lami et al. [35] conducted a research program that describes the behavior of the repercussions for the long-term durability of the FRCM composites. According to the findings, the matrix and fiber utilized substantially affected the composite's durability. Donnini et al. [36] conducted an experimental program to describe the behavioral effects of diverse environmental exposures on the mechanical properties of an FRCM system. They concluded that none of the simulated aging conditions substantially affected the FRCM composite's mechanical properties. Regarding environmental resistance, FRCM composite specimens outperformed glass yarns due to the presence of the inorganic matrix.

3.1.3. Moisture

Due to exposure to high humidity, nearly every component of a structure is in contact with moisture in some way. Moisture levels are significant in outside construction facade panels, bridges, and other structures. Moisture can activate various chemical reactions in concrete when alkali is carried from the surrounding environment via the concrete to the reinforcement. When the exterior fiber surfaces of unimpregnated AR-Glass reinforcement reach a specified moisture content, they lose elasticity. OH-ions pass through, depending on the permeability and diffusion coefficient of the concrete-impregnating agent for textile reinforcement [37],[38].

3.1.4. Tensile stress

Depending on the stress level, a load causes the stress to rupture fibers after a certain period [38]. The fiber tension causes the polymeric matrix to have tiny fractures, allowing it to be subjected to a chemical attack [27]. Additionally, the matrix can absorb more stress from the fibers than the fibers could absorb from the matrix at the micro-fracture zone. The fibers are not perfectly aligned during the manufacturing procedure, resulting in an unequal load [38]. On the other hand, internal composite stresses are anticipated to cause the covering material to creep. Thus, the symmetry of the fiber placements is improved. Microcracks may accumulate over time, leading to fiber rupture when the maximum tension or strain is reached. As a result, the non-cracked fibers must take on the stress, resulting in additional fiber ruptures and, finally, the collapse of the fabric [38].

3.1.5. Chemical reaction

The majority of the current literature focuses on the effects of alkaline, saline, and acid solutions on the mechanical properties of TRC composites [25]. Due to the absence of established standard operating procedures, samples have been submerged in solutions at varying temperatures or concentrations or undergone wet-dry cycles. The majority of studies that have considered the function of an alkaline environment [38],[39] have utilized tensile tests to examine changes in mechanical performance following exposure. The least frequent tests are flexural and fiber-to-matrix bond tests [40].

3.1.5.1. Durability of Composite Matrix

In most cases, FRCM composites use an inorganic matrix composed of lime or cement [22],[23]. This section primarily concerns the strength of mortars built from cement and lime. Aluminum oxide (Al_2O_3) and calcium hydroxide ($Ca(OH)_2$) are two matrix components that can interact with chlorides and sulfates, hence diminishing the matrix's durability [36]. Machoveca et al. [41] experimented to investigate the resilience of the TRC in a tough environment using durability-accelerated testing on high-performance concrete concerning the cementitious matrix (HPC). Due to the high density of the concrete and the generally modest penetrability of the media employed, the exposed specimens to the chemically hostile environment deteriorated predominantly at the surface. The investigated TRC is more resistant to the harsh environment. Yin et al. [40] conducted 12 h of wetting in a saline solution (5 wt% NaCl) followed by 12 h drying at room temperature on TRC coupons with a cement-based matrix.

The results revealed that the matrix flexural strength gradually dropped as the number of cycles increased. Donnini (2019) [42] demonstrated similar residual flexural strengths for specimens in the lime mortar, exhibiting a percentage loss of roughly 10% for specimens subjected to repeated wet-dry cycles and prolonged immersion. The alkali-aggregate chemical interaction, which is present in some types of aggregate, may affect the glass microfibers dispersed in the mortar [43],[44]. The data collected suggests that when subjected to certain extreme climatic conditions, the FRCM may form microcracks, reducing the composite's stiffness and breaking strength.

3.1.5.2. The capacity of the matrix-fiber interface is durable

The stress transmission between the reinforcements' individual parts and between the substrate and the reinforcements affects how effectively they perform when externally connected. Externally bonded FRCM composites with a single fiber layer have two primary interfaces: the matrix-fiber interface and the matrix-substrate or composite-substrate interface [36].

In certain studies, the interface matrix fibers were subjected to combined uniaxial-tensile testing on coupons to collect data [44]. It was investigated using scanning electron microscopy (SEM) [45], and the variations in load response for the matrix-fiber bond behavior helped explain the differences between control and conditioned specimens [37]. According to some authors, high porosity and low-strength matrices exhibit more evidence of the Characteristics deteriorating because of salt assault and freeze-thaw cycles [46],[47]. The internal reinforcement made of glass or basalt fibers may be exposed to a less hostile environment because lime-based matrices have a lower pH than cementitious ones.

According to Nobili's research on lime-based FRCM systems reinforced with glass fabrics, which were tested in alkaline and saline environments before and after [37], the tensile strength of the FRCM composite is between 10% and 15% lower than that of reference specimens. Additionally, the flexural strength of the mortars is reduced by more than 50%.

Colombo et al. [47] used uniaxial tensile stress to investigate freeze-thaw cycles' effect on uncracked and cracked specimens of 20% greater compared to the cracking load. However, broken specimens had inconsistent findings, and no discernible pattern could be observed. Tests for durability, such as (ACI 549.4R-13) [17], measure the residual mechanical properties of FRCM systems after exposure to various environmental conditions. These tests include aging in water vapor, immersion in salty and alkaline solutions at 22 °C for up to 3000 hours, freezing-thawing cycles, resistance to fuel, and thermal tests. These recommendations stipulate the mechanical testing of FRCM samples, which consist of a fabric reinforcement and an inorganic matrix.

As the hydration process proceeds, the matrix adjacent to the multifilament yarn may become denser as hydration products leak into the crevices between the filaments, potentially diminishing the matrix-fiber binding characteristics [36].

3.1.5.3. The composite-substrate bond's durability

According to the studies, only a few studies address the durability of composite-substrate bonds. A sulfate assault can degrade the connection between the substrate and composite, reducing the contact between the two [48],[49]. In addition, salt precipitation at the interface can weaken the bond and cause the composite-substrate interface to fail as opposed to the matrix-fabric interface [41, 48]. As part of an experimental program, Donnini [42] Conducted ten wet-dry cycles in a saline solution of sodium chloride (3.5 wt% of NaCl) at 60 °C on FRCM-masonry joints with an AR-glass textile and a lime-based matrix. After conditioning, the composite-substrate interface of the specimens deteriorated, reducing their load-bearing capacity. Franzoni et al. [49] examined a steel-reinforced grout (SRG) composite made of steel wires that are externally fastened to masonry blocks and a matrix made of lime. They found that four wet-dry cycles in a saline solution comprising 8% sodium sulfate dehydrate ($Na_2SO_410H_2O$), followed by drying at 60 degrees Celsius, had no significant influence on load-carrying capacity. All of the specimens also experienced interlinear failure, characterized by fiber slippage from the interior layer of the matrix while the matrix itself is still connected to the substrate. The analysis showed that significant salt buildup and crystallization at the contact area reduce the bonding capacity and shift the failure mode to the interface between the composite and substrate. These needs could be affected by the matrix's porosity and the pore's radius. Therefore, the impact of saline attacks and sulfate on the interface may not be as great as the impact on the matrix and fibers [49].

4. Methods of Standard materials testing

At the microscale, a mix of traditional techniques for testing materials (to describe the thermal and mechanical characteristics of fiber, mortar, and fabric), as well as fabric/yarn pull-out tests (to assess the textile-to-mortar bond and yarn-to-mortar behavior). Our comprehension of the bonding mechanism in the TRM system is improved when these test methods are used in conjunction with microstructural chemical and physical test methods [23].

Tensile, flexural, and shear tests are critical at the composite (TRM) level to determine the nonlinear reaction and break the composites' behavior under different loading conditions.

The TRM-to-substrate bond must also be tested to ascertain the dominant mode of failure, the bond strength of the complete reinforced system, and the TRM's ability to fully transmit loads from the substrate to the strengthening system. Standard static or dynamic testing on structural components or structures can be used to assess the effectiveness of this strengthening technique on a structural scale in increasing the capacity and nonlinear response of structural components [23].

5. Mechanical Performance for TRM Composites

5.1. Strengthening of flexural behavior

Flexural strength can be increased by applying TRM to the tension zones of reinforced concrete elements such as beams or slabs.

Fig. 2 depicts a load versus vertical displacement curve to demonstrate the effect of strengthening on two-way slabs for the load-displacement relationship diagram for RC members with flexure reinforcement [3]. The flexure behavior of unreinforced components can be split into three stages: (a) uncracked until the first concrete cracking point, (b) cracked until the point of steel yielding, and (c) complete textile activation up to the maximum load for reinforced components [3].

Fig. 2 depicts the fibers being activated prior to the concrete cracking. Repeated concrete fractures also activate the strengthening layers in the second stage, resulting in stiffer behavior for an unreinforced component and an increase in yield load. TRM's contribution to flexural resistance becomes significant after a brief period of yielding to steel. Until the TRM layers begin to fail, approximately all of the additional load is carried by the TRM layers [3].

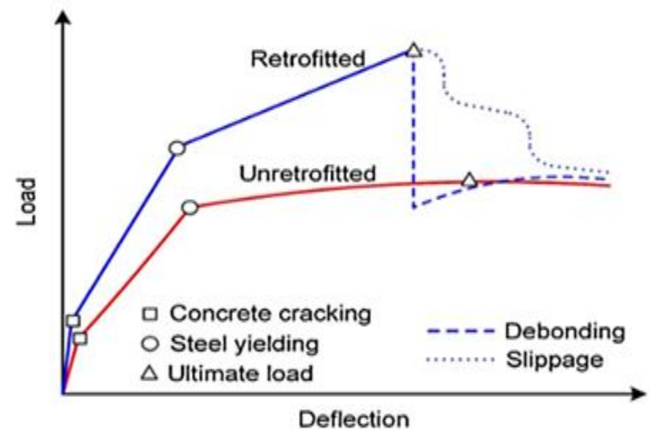


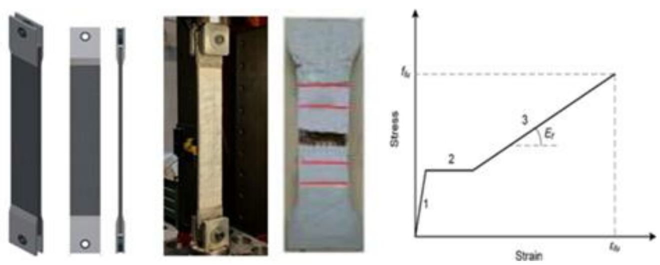
Figure 2. Strengthening effect of RC members in flexure [3]

The efficiency of TRM against FRP as externally applied flexural strengthening reinforcement of RC beams was investigated by Raoof et al. [50]. The objective of an experimental program was to compare the flexural performance of reinforced concrete (RC) beams strengthened with textile-reinforced mortar (TRM) and fiber-reinforced polymers (FRP) by tripling the number of TRM layers. The effectiveness ratio of TRM in comparison to FRP nearly doubled. Adding a coating to the dry textile increased the TRM effectiveness and varied the failure mode; different textile materials with about the same axial stiffness resulted in varying flexural capacity improvements.

According to the findings of this investigation, the service load and yield phases of TRM beams were adequately efficient. Additionally, many experimental and research programs have been done on this topic. Flexural fortification of (e.g., one-way [51] and two-way [18]) RC slabs According to [50], research has been conducted on the flexural performance of RC beams reinforced with TRM. The primary findings of these experiments were as follows: (a) Adding TRM to RC beams increased their flexural capacity significantly [50]; (b) increasing the number of TRM layers had a dual effect: it increased flexural capacity while also changing the failure mode [52].

A woven concrete layer in the bending area of a structural component could boost the bearing capacity of TRM layers in the tension side of the old concrete part, resulting in an increase in load-bearing capacity and a delay in the formation of cracks in the bending zone. The concrete foundation body incorporates the failure pattern generated by the transmission of forces from one reinforcing layer to another. 1) Fibers slipping out of TRM's connection with the concrete; 2) TRM's debonding (at the interface of concrete-mortar), and 3) Laceration of TRM's connection with the concrete (fibers slipping within the mortar)

[53]. The inner bond of the fibers predominantly determines the final two failure mechanisms. The link between the margins of textile threads and the surrounding concrete matrix [53] Consequently, TRM tensile tests are used to determine the maximum strain, stress, and modulus of elasticity of fibers. The effect of the pace of mechanical stress features on several TRM vouchers necessitates dynamic elasticity testing [54]. For the most often used laboratory models of TRM of the plate type (Fig. 3.a-c) and specimens in the form of bones or dumbbells [55]. Fig. 3c demonstrates that coupons can fail in the center [54],[55]. Fig. 3 shows how the usual TRM modeling responds to the tensile test result. Especially in the grip of the clevis method, the fiber layer slips through the mortar before a laceration. Nonetheless, this issue was overcome by applying a clamping hold (producing enough gripping pressure) [54]. According to [54] and [55], a strong link existed between how TRM laboratory models broke and how they were held.



(a) (b) (c)

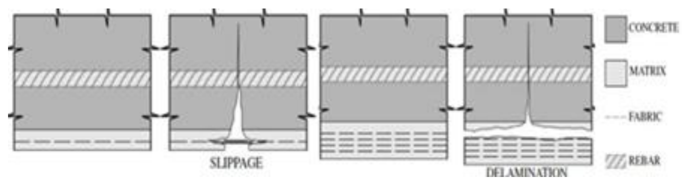
Figure 3. (a) Dumbbell TRM voucher; (b) rupture of the fibers; (c) the relationship of stress and strain vs for TRM specimens subjected to monotonic tensile [54].

It's all about how well the textile reinforcement is coupled to the mortar in quantity and type and the extent of mortar penetration within the textile holes. In terms of crack spacing and width [56]. The coating's uniform distribution of load significantly improves the Mechanical properties of the textiles [55],[57].

5.2. TRM's Bonding Features

The binding strength between the TRM and concrete substrate is directly related to the effectiveness of TRM jacketing as a reinforcing material. Regarding resistance to the connection between the concrete surface and TRM, the condition of the fiber rovings, the quantity of mortar impregnation, and important variables are the quality of concrete surface preparation. However, studies on the relationship between the TRM (steel or glass) and the surface of the concrete are uncommon [58],[59]. Several studies, including [59] and [60], examined the bonded length of a few specimens with ruptured TRM strips. This research discovered a nonlinear relationship between bond length, ultimate load, and bond capacity. Multiple studies have evaluated the width of PBO fabric TRM strips and concluded that it has no effect [61],[62].

According to analyses [60],[63], there was also a non-proportional rise in bond capacity and the number of TRM strata overall. In addition, as the number of TRM strata increased, the failure mechanism shifted from fiber slippage using a section of concrete-embedded mortar until the TRM layers began to separate [60],[64], as did several layers of PBO fabric TRM (Fig. 4), which depicts the failure mode of beams with 1-ply and 4-ply FRCM [65]. Due to the failure induced by fiber unbinding through mortar [60], surface preparation has a minimal effect on the performance of TRM.



(a) 1-ply FRCM (b) 4-ply FRCM

Figure 4. Schematic of the 1-ply and 4-ply FRCM-reinforced RC-beam failure mode [65]

After coating the textile material, the failure mechanism shifted from fiber to debonding of TRM at the interface between textile and mortar [63]. Additionally, more experimental research on this topic is needed. The link between TRM and the concrete substructure has been examined. e.g. [66]-[68].

6. Retrofitting for Seismicity

Resolving the problem of seismic upgrading of existing RC buildings for earthquake-prone structures has attracted considerable academic and professional interest. Local upgrading approaches involve applying measures to particular structural components of a structure. Utilizing textile materials (carbon, glass, basalt, etc.) encased in cementitious mortars as opposed to fabrics saturated with epoxy resins is a potential solution to the aforementioned problem. Fig. 5 demonstrates the use of the TRM in beams and RC columns [69].

(a) (b)

Figure 5. TRM as jacketing applications in a) columns and b) beams [69].

Triantafillou et al. [70] were the first to examine the relative merits of TRM and FRP systems as shear-strengthening materials for reinforced concrete buildings, which include seismic retrofitting. The experimental studies offered better knowledge of the advantages of TRM jackets over FRP in 1) improving the strength of flexural parts subject to shear in reinforced concrete and 2) The increased axial capacity of concrete through confinement. Triantafillou et al. [13] explored whether TRMs could improve the shear strength of concrete structures. According to scientists, the TRM strengthening approach was around 55% successful. Bournas et al. [7] show that TRM coverings successfully enhance cyclic deform capacities and RC column energy dissipation via delayed bar buckling. Three concrete columns were exposed to counteract cyclic loading by applying steady axial stress. Fig. 6 depicts load versus drift ratio curves for these samples. Due to bar buckling at the base of the column, the control specimen failed, which restricted its deformation capacity (Fig. 6.a).

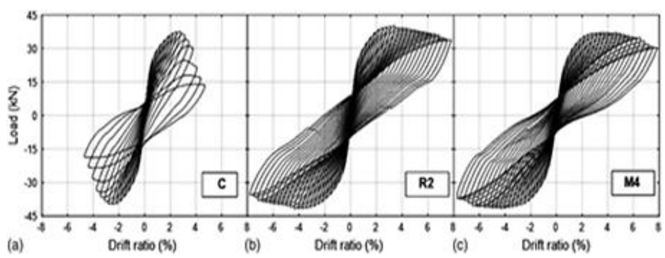


Figure 6. Curves relating load to the percentage of drift for a) the normative sample, b) The FRP-restricted specimen, and c) The specimen restricted by TRM [7].

The behaviors of two modified columns were Greater than a twofold increase in deformation capability. Local stress resistance of TRM jackets contributed to the superior performance of TRM jackets over FRP jackets during bar buckling. This proves the fact that TRM jackets are capable of deforming outward without fiber breakage. This phenomenon was ascribed to the gradual fracturing of individual fiber bundles. Therefore, TRM jacketing is as effective as comparable stiffness and durability FRP jackets. Bournes et al. [71] evaluated the efficacy of concrete columns with limited capacity caused by bar buckling or bond failure at lap splice points and the use of TRM jackets in those columns. They concluded that TRM jackets were a highly suitable method for enhancing the cyclic deformation capacity of RC columns by delaying bar buckling and preventing splitting bond failures in columns with lap-spliced bars relative to their FRP counterparts.

In addition, more experimental studies have been undertaken, and research projects employing TRM/TRC have been for strengthening static or seismic stresses, as in References [21],[72].

7. TRM application scope

Several commercial projects in Europe, the United States, Asia, and Latin America have proven the immense potential of TRM as a strengthening material for both masonry structures and concrete. TRM/TRC has already been utilized globally in the construction industry. The selected structural retrofitting projects comprised. e.g. (1) stadium improvements [72], (2) public buildings [16], the renovation of a commercial and residential building in Prague [53], and the refurbishment of a hyper shell in Magdeburg (also in Germany) [53]; (3) commercial buildings (Supermarket, The Netherlands, 2013); (4) transportation infrastructure (RC bridge piers, Russia 2007); Highway RC tunnel lining, Greece (2008) [16].

8. Conclusions

This article is based on a comprehensive literature review on the structural elements strengthened by textile-reinforced concrete and mortars (referred to as TRC, TRM, or FRCM) under long-term durability, the behavior of TRM at tension grades, the flexural behavior, and methods for increasing the load carrying capacity. TRM offers various advantages to structural elements in terms of their mechanical properties. Nevertheless, the following is a summary of the article's key points:

1. Due to the increased tensile strength of the fiber roving in the TRM material, concrete members containing TRM strata could bear greater tensile loads than those without TRM layers.
2. Due to the geometry of the mesh arrangement of the TRM layer (grid holes and spacing between these holes), a strong bind and interlock are produced between the matrix and TRM, where the strength of the fiber-reinforced element is determined by the quantity of mortar impregnation between the holes of the textile. Consequently, there are growing structural and non-structural aspects.
3. High temperatures do not affect TRM's binding capacity, but FRP's bond strength diminishes substantially when exposed to them.
4. Studies have shown inconsistent findings about endurance when exposed to salty surroundings of FRCM lime-based matrices. Variations in pore size and porosity and the effect of wet-dry cycles on the durability of inorganic-matrix composites were attributed to the disparity in the results.
5. When the flexural reinforcement technique of the RC beams is utilized by TRM composites, the cracks are controlled, and the ultimate load capacity increases. For some specimens with ruptured TRM strips, there is a nonlinear relationship between bonded length, ultimate load, and bond capacity.
6. The number of strengthening layers has a significant effect on the increasing peak load and ductility resulting from the use of TRM.

7. TRM jacketing substantially increased the material's strength and deformability. Compared to their epoxy-resin counterparts (FRP), TRM may be more effective in terms of strength and deformability in general.
8. The number of TRP layers significantly influences the component's ultimate load capacity. At the interface between mortar and fabric, the failure mechanism changes from fiber slippage to TRM debonding.

Nonetheless, this study provides the path for further research on themes such as the impact of using numerous types and configurations of TRC composites under dynamic and thermal loads. Understanding the long-term behavior of externally bonded inorganic-matrix composites requires extensive research on the effects of freeze-thaw and wet-dry cycles on sulfate attack. In addition, it is suggested that future research be conducted on the combined effect of each fiber with TRC on a structural element's mechanical properties.

Conflict of interest

The authors declare that they have no conflicts of interest

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Author contribution statement

Alaa. A. Muneam did all the necessary research and presented the results; all authors reviewed the study, checked the results, and contributed to the final manuscript.

Layth A. Al-Jaberi and Hesham A. Numan proposed the topic and methodology of the research, as did the author.

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