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Studies on the Strength of Hollow Concrete Block Masonry Externally Bonded with Textile Reinforced Mortar Composites

Jeevitha B, Madhavi K*, S M Basutkar, M V Renukadevi

Department of Civil Engineering, RV College of Engineering, Bengaluru-59, India

**Corresponding Author:* kmadhavi.rvce@gmail.com

ABSTRACT: Textile reinforced mortar often referred as TRM in the literature combines open mesh configuration textiles with inorganic cement-based mortars. The aim of the present study is to determine the mechanical properties of hollow concrete block masonry externally bonded with coir and glass textile reinforced mortar composites. The properties of textile composites were determined by testing TRM Coupons. A total of 39 prisms were cast. The block masonry prisms were externally bonded with coir and glass textile fiber mesh with mortar. The elastic properties of block masonry, shear and flexural strength were determined for both unreinforced and strengthened specimens. The results showed that increasing the number of layers of textile fibers, enhanced the flexural capacity of TRM coupons. The provision of connectors also enhanced flexural strength. The stiffness of unreinforced masonry prisms was found to increase by strengthening with textile reinforcements even though the increase in compressive strength is marginal. There is a significant enhancement in flexural strength and shear bond strength of externally bonded specimens when compared to unreinforced masonry.

Keywords: Hollow concrete Block, textile reinforced mortar, composite

1. INTRODUCTION

Masonry walls are common elements of a load bearing masonry structures. Bricks are the traditional building material most commonly used for construction. Energy efficient building blocks such as stabilized mud blocks and hollow concrete blocks have been developed, and work has been carried out to use these blocks for load bearing masonry construction. The walls of masonry structure are susceptible to severe damage under out-of-plane loads of earthquakes due to poor flexural strength. Several techniques have been developed in the past to enhance the out- of-plane flexural strength and ductility of unreinforced masonry (URM) walls, including the use of ferro-cement and fiber reinforced polymer (FRP) composites. The disadvantages associated with FRP provided the opportunity to innovate novel inorganic mortar-based composites called textile reinforced mortar (TRM). Conventional methods that are in practice for retrofitting of masonry buildings are jacketing, injection as a restoration technique, external reinforcement and post-tensioning.

TRM entails the usage of textiles in the form of grids on the exterior surfaces bonded using mortars (Papanicolaou et al.2011). The tensile strength of TRM Coupons is usually governed by both the fiber grid and the mortar that is overlaying (Bernat et al.2015).

The qualities of the textile decide the properties such as ultimate strength, tensile modulus of elasticity in the fractured state, and failure mode. Despite this, the peak strain is generally lower than that of dry fabrics due to the stiffening action of the mortar (Santiset al.2015). The usage of textile reinforcement led to enhanced durability and is one of the alternatives to traditional steel reinforcement. TRM is an interesting retrofitting technique as it blends the outstanding properties of composite constituents with the required properties provided by mortars (Raoof et al.2016). The mechanical performance of TRM and its efficacy in reinforcing applications are extremely reliant on the mechanical properties of the fibers and the mortar, as well as fiber to mortar and mortar to substrate interface bonding behavior (De Felice et al.2014, De

Santiset et al.2015, Olivito et al.2016,.D'Ambrisi et al.2013). Traditional retrofitting techniques, similar to exterior reinforcement with steel plates, welded meshes of steel and surface coating of concrete, are known to be intricate, time consuming and add substantial mass to the structure which may surge the inertia forces prompted by an earthquake (Bernat et al.2013). Babaeidarabad et al.2014 reported that various retrofitting approaches have been presented and applied to improve the performance of masonry structures, such as post-tensioning, grouting, concrete jacketing, and fibre reinforced Polymer Composites. Due to the disadvantages, FRP composites are gradually being replaced by an advanced mineral-based composite material, fibre reinforced cementitious matrix (FRCM). These constituents are predominantly suited for the strengthening of masonry buildings due to their high compatibility with substrate and robustness against environmental means. Studies on textile reinforced mortar composites and their feasibility for structural strengthening have been reported by several authors (Carozzi et al.2014). Vasconcelos et al.2012 carried out a study on unreinforced masonry (URM) walls subjected to out-of-plane loading. It was observed that URM walls are lacking in flexural capacity due to out of plane loads caused by wind and earthquake. Strengthening of URM walls has been proven to improve the rigidity and absorption of energy. Marcari et al.2017 concluded that FRCM systems are a groundbreaking solution for the restoration and strengthening of structures that are extremely promising. These include high-strength textiles that are bound by mortar matrices to the surface of structural members. Depending on the textile geometry, FRCM compounds may be bonded to the all-inclusive face of the structure or in straight strips. Studies by Meriggi et al.2019 showed that TRM can aid in improving the seismic efficiency of structural elements of masonry. Precast textile reinforced concrete laminates to strengthen brick masonry walls were used by Gopinath et al.2020 and found to be adequate. A Comparative study on the performance of FRP and TRM composites for strengthening brick masonry was investigated by Salman Khaleel et al.2021.

Growing awareness of the environment demands study and research on new eco-friendly products. The necessity for green and sustainable supplies is certainly a growing interest in materials. Natural fiber composites are considered due to the problems faced by petroleum-based goods and the need to find sustainable alternatives. Comparatively lower cost, renewability and the need for eco-friendly goods are the key driving factors for new natural composite materials. Inorganic matrix-embedded natural fiber textiles could provide a reinforcing solution for URM structures. As the extent of studies on the mechanical characteristics of natural fiber composites is limited, the usage of natural fibers is still in the backlight. Compared to other natural fibers, coir is the toughest fiber because of its high content of lignin. Coir is obtained from the fibrous mesocarp of coconut fruits. It is cultivated extensively in tropical countries such as Thailand, India and Sri Lanka etc. (Saw et al.2019). The desire for bio composites in the automobile, packaging, electronics, health, and structural industries has increased the interest of researchers in using biofibers (Isiaka OluwoleOladele et al.2022). Coir fibers have been considered mainly for door mats and floor furnishing. However, due to the current research on natural fibers, coir fibers have found use as technical textile in different fields of applications. Recent past research has focused on coir to use it for various construction applications. Studies are ongoing to find the use of coir fiber as geotextiles for paved structure construction (Nitin Tiwari et al.2020).

The majority of earlier studies have focused on synthetic fiber composites such as glass and carbon. The extent of work on inorganic mortar-based textile composites with natural fibers is limited. Hence, the main objective of the current study is to investigate the effectiveness of coir and glass textile mortars on the strength of block masonry when externally bonded.

2. EXPERIMENTAL INVESTIGATION

Textile reinforced mortar (TRM) coupons were prepared and tested for flexural strength as they were externally bonded to the masonry to evaluate the mechanical properties of block masonry

2.1 Preparation of TRM specimen

The TRM overlay is made up of yarns placed in two orthogonal directions in a woven cloth. Coir mesh and glass fibre mesh are the two types of textile fiber grids employed in the current study as shown in Figure 1. Cement-sand mortar 1:3 and Talrak Microcrete, a general purpose non shrink free flow cementitious micro concrete, were used as matrices. The coir mesh used in the present study is procured from the coir board of India and the properties are listed in Table 1. The properties of the glass mesh as per the supplier are shown in Table 2. The compressive strength of the 1:3 cement mortar and commercially available microcrete used in this study are14.6MPa and 50MPa respectively.

(a)

(b)

Figure 1 a. Coir textile mesh b. Glass textile mesh

Table 1 Properties of Coir mesh

Parameter	Value
Density(kN/m^3)	11.5-14.0
Tenacity(g/tex)	10.0
Breaking elongation (%)	30.0
Specific gravity	1.15
Young's modulus (GN/m^2)	4.5

Table 2 Properties of Glass mesh

Parameter	Value
Area weight(g/m^2)	45±3
Mesh size (mm)	2.5 x 2.5
Weight of raw mesh (g/m^2)	45
Colour	White
Yarn Type(tex)	Warp yarns:66tex; weft roving:33tex
Breaking strength (per 50mm)	Warp≥600N; weft≥420N

Rectangular specimens of dimensions 350 X 50 X 15 mm were cast with a combination of two types of mortar and fibers. Similar sizes of specimens were used in their study by Felice et al. 2014 and Askouni et al.2017. Specimen moulds were created by cutting thermacol to the required dimensions as shown in Figure 2.a. The specimens were demoulded after 24 hours of casting. After demoulding the specimens, they were marked to identify the mortar substance and textile fiber grid combination and kept for curing. Tests were carried out after 28 day curing period. To determine the influence of the connectors, fibre and mortar were connected using a binding wire as shown in Figure 2.b. The coupons were tested with different configurations such as the number of layers embedded in the mortar and type of mortar, as indicated in Table 3. A Two-point loading test was performed to determine the flexural strength of the TRM specimen as shown in Figure 2.c. Flexural strength is critical for understanding matrix-to-textile bond characteristics, which influence cracking and, as a result, substrate adherence and durability.

(a)

(b)

(c)
Figure 2: a. TRM specimen b. Binding wires as connectors for fabric and mortar
c. Flexure test on TRM specimen

Table 3: TRM specimens with different configurations

Sl No.	Number of specimen	Mortar substrate	Textile fibre	Number of layers/ connectors
1	3	Cement sand (1:3)	Glass fiber	Single layer
2	3			Double layer
3	3	Microcrete	Glass fiber	Single layer
4	3			Double layer
5	3	Cement sand (1:3)	Coir fiber	Without connectors
6	3			With connectors
7	3	Microcrete	Coir fiber	Without connectors
8	3			With connectors

2.2 Tests on hollow concrete blocks

The compressive strength test was conducted as per the norms of IS 2185 Part-1 (2005) . Concrete blocks were tested on a 200 T compression testing machine. The block is kept on a level surface and steel plates are placed for uniform distribution of load. The loading rate was kept constant at 14 N/mm^2/min. Another crucial parameter to understand masonry behaviour is the modulus of elasticity of the block specimen. A demountable mechanical strain gauge with a gauge length of 150 mm is used to measure the strain. Water absorption and the initial rate of absorption were determined as per the standard codes of practice. The mean compressive strength of the 6 blocks and coefficient of variation is shown in Table 4.

Table 4 Physical properties of concrete blocks

Parameter	Result	Coefficient of variation (%)
Bulk density Kg/m^3	1570.55	2.01
Initial Rate of Absorption Kg/m^2/min	0.854	5.98
Water absorption %	1.89	11.52
Compressive strength (MPa)	5.37	4.93

2.3 Construction of hollow concrete block masonry prisms

Cellular hollow concrete block masonry prisms were cast using cement-sand mortar (1:6). The mortar thickness of 10mm was maintained throughout all the prisms. The masonry prisms were cured for a period of 28 days using wet burlap. Various tests such as compressive strength, shear bond test and flexure tests were conducted on prisms. The masonry prisms were cured prior to the application of the textile fibre grid. When the prism was approximately 80% saturated, a 6 mm thick layer of mortar was applied on all the sides of the prism. After that, the textile fiber was placed on the applied mortar and slightly pressed so that the mortar penetrates into the fiber mesh as shown in Figure 3. Then, a second layer of approximately 6 mm mortar is applied to the surface of the fiber to cover it completely. The application of the second layer of mortar is carefully done while the first layer is in its fresh state. For masonry triplets, the fiber was placed on two sides of the specimen. The process of curing was done for 28 days for all TRM masonry prisms and triplets by using wet burlap. While using Microcrete, a predefined amount of water to maintain a water-powder ratio 0.16 was calculated and added to the ready mix and mixed thoroughly. The application of the mortar and reinforcing method remains the same as that of the cement-sand mortar.

(a) (b) (c)

Figure 3. a. First layer of mortar application b. Application of coir fibre
c. Final layer of mortar application.

2.4 Compressive strength of masonry

The compressive strength of masonry prisms was carried out as per IS: 1905 (1987). According to the code, the height-to-thickness ratio for prisms should be between 2 and 5, with a minimum height of 400 mm. The height to thickness ratio in this study is 4.16. Steel plates were placed on top and bottom of the prisms for uniform loading. The applied load was recorded through a 1000 kN proving ring. The prisms were tested on a 2000kN loading frame, as shown in Figure 4. The deformations were recorded using 100mm demec gauge to compute the modulus of elasticity. The prisms were loaded and tested until failure.

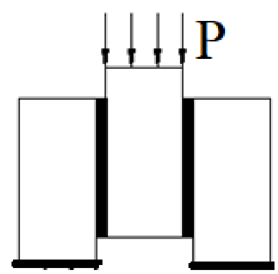
Figure 4 Compressive strength test

2.5 Shear bond test using the triplet test

The shear bond strength is determined using the triplet test in this study. A schematic diagram of the shear test is shown in Figure 5.a. The blocks at the ends are supported, while the block in the middle is sheared as indicated in Figure 5.b. The two end blocks of a triplet are restrained from moving. The load at which the specimen fails is recorded. The maximum force obtained during testing was used to assess the shear bond strength of the triplet. Shear strength is computed by dividing the failure load by the whole area under shear, which includes both joint faces of the triplet. In the triplet test it is assumed that two interfaces will fail at the same time. Hence, the load had to be divided by two times the corresponding shear area. The shear bond strength is calculated using the formula given below.

$$\tau = \frac{P}{2bd}$$

Where 'τ' is the shear bond strength, 'P' is the load at failure, 'b' is the width of the joint and 'd' is the length of the joint.



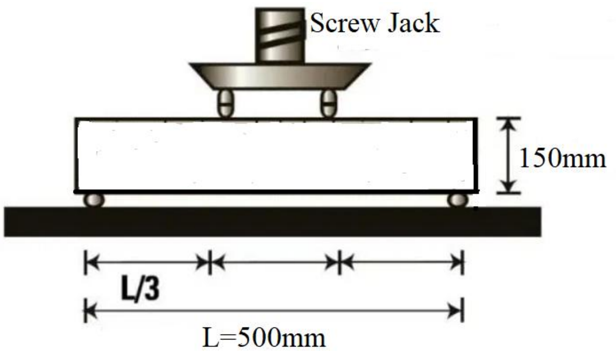
(a)

(b)

Figure 5 a. Schematic diagram for the shear bond test b. Experimental setup for shear Bond test

2.6 Flexural strength test

The flexural strength of both unreinforced and TRM bonded masonry prisms was determined by supporting it as a beam and tested under two-point loading. A schematic diagram of the flexure test is shown in Figure 6.a. The test was conducted as per IS 516. The centre to centre distance between the supports was kept at approximately 500 mm. Two point loads were applied at one third span, and a proving ring of 100 kN was used to measure the load applied by the screw jack as shown in Figure 6.b.



(a)

(b)

Figure 6 a. Schematic diagram for the flexure test and b. Flexure test Experimental setup

3. RESULTS AND DISCUSSION

3.1 Flexural strength of TRM specimen

The flexural strength of TRM Coupons of various configurations is shown in Table 5. The TRM specimen consisting of glass fiber experienced brittle failure. Fibers were cut exposing sharp cut edges of the glass fiber. However, TRM made of the Coir fiber specimen failed by developing cracks in the mortar but no failure of the fiber was observed.

Table 5: Flexural strength of TRM specimen

Sl No.	Mortar substrate	Textile fiber	Number of layers/ connectors	Average Flexure Strength (N/mm^2)
1	Cement sand (1:3)	Glass fiber	Single layer	27.93
2			Double layer	40.82
3	Microcrete	Glass fiber	Single layer	33.3
4			Double layer	57.48
5	Cement sand (1:3)	Coir fiber	Without connectors	17.48
6			With connectors	37.6
7	Microcrete	Coir fiber	Without connectors	33.3
8			With connectors	45.66

3.2 Compressive strength of masonry prisms

Unreinforced masonry prisms sustained an average maximum load of 269 kN beyond which the prism failed. Figure 7.a shows the front face of the prism with vertical splitting cracks. The crack was first initiated at the base of the prism which propagated vertically up. Modes of failure of the prisms were unique for all unreinforced masonry prism specimens. Prism specimen-2 failed due to a combination of vertical cracks, spalling and localized crushing of the block at the toe of the prism.

(a) (b)

Figure 7 a. Failure of unreinforced masonry Prism b. Failure of prism with TRM

3.3 Behavior of Masonry prisms bonded with TRM

Masonry prisms reinforced with Coir natural fibre mesh with cement-mortar (1:3) substrate failed at an average maximum load of 327 kN. The low strength cement mortar most likely also had a low bond strength, which might have caused the vertical cracks along the face of the prism. However, the low strength mortar was able to deform more axially along the bed delaying the propagation of the vertical cracks through the top and bottom units. There was also localised crushing of block and spalling. Vertical cracks typically initiated at the interface of the mortar and unit at the joint and propagated through the top and bottom units. There was debonding of the fiber composite from the substrate. Masonry prisms reinforced with Coir fiber and microcrete sustained an average maximum load of 329 kN. The failure of masonry prisms was mainly because of vertical spalling of the block. Development of cracks and propagation of cracks were not visible under the substrate material.

Glass fiber reinforced masonry prisms with cement-mortar (1:3) failed at an average maximum load of 326 kN. The failure of the masonry prism for specimen 1 was mainly because of vertical splitting of the masonry prism. This indicated strong masonry substrate bond. Failure occurred after the formation of vertical cracks on the surface of the masonry prism. Slowly the cracks propagated and there was debonding of externally bonded fiber composite from masonry at the top of the prism. Partial block failure was observed after failure of the prism. The crushing was noticed by the initiation of cracks in the mortar surface and by the detachment of external reinforced mortar in contact with the blocks and there was debonding of parts of its external surface. Failure occurred after the formation of vertical cracks in the blocks.

Glass fiber reinforced masonry prisms with microcrete failed at an average maximum load of 355 kN. The failure of masonry prisms was mainly because of vertical cracks at the edge of the masonry prism, as indicated in Figure 7.b. Specimen 2 failed due to shear failure of the upper most block in the prism, spalling of masonry and development and propagation of vertical cracks.Specimen 3 failed due to the development of vertical cracks at the toe of the prism, and then cracks propagated eventually leading to failure of the prism.

The average compressive strength and elastic modulus of unreinforced masonry prisms are listed in Table 6. Figure 8 and Figure 9 show the stress-strain curves of coir fiber reinforced and glass fiber reinforced prism specimens. Masonry prism bonded with coir and glass fiber reinforced cement mortar is indicated as CC and GC respectively. Whereas Prism bonded with coir and glass fiber reinforced microcrete is denoted as CM and GM .

Table 6: Compressive strength of unreinforced and reinforced masonry prisms.

Type of Prism	URM	CC	CM	GC	GM
Prism Size (L x B x T) mm	400 x 150 x 625	410 x 160 x 635	415 x 160 x 635	410 x 160 x 635	410 x 160 x 635
No. of Specimens	3	3	3	3	3
Height/Thickness Ratio	4.16	3.96	3.96	3.96	3.96
Maximum load kN	269	327	329	326	355
Compressive Strength N/mm²	4.48	4.98	4.95	4.97	5.42
Modulus of Elasticity (MPa)	5157	11114	15593	6195	9696

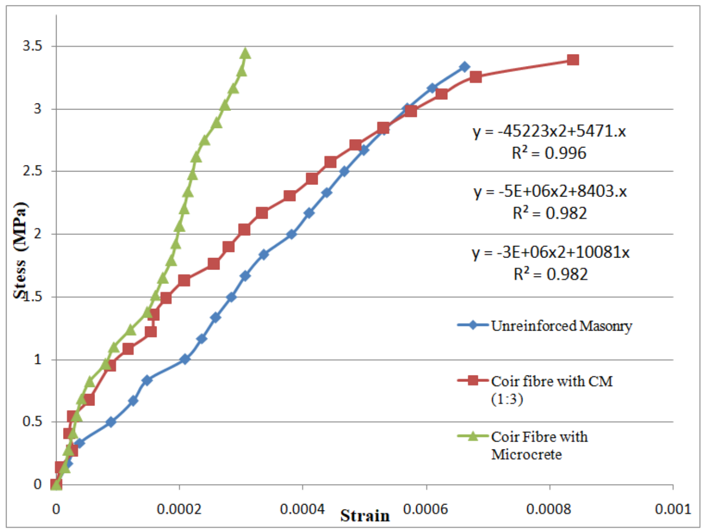


Figure 8: Stress-strain curve for coir fiber reinforced and unreinforced masonry prisms

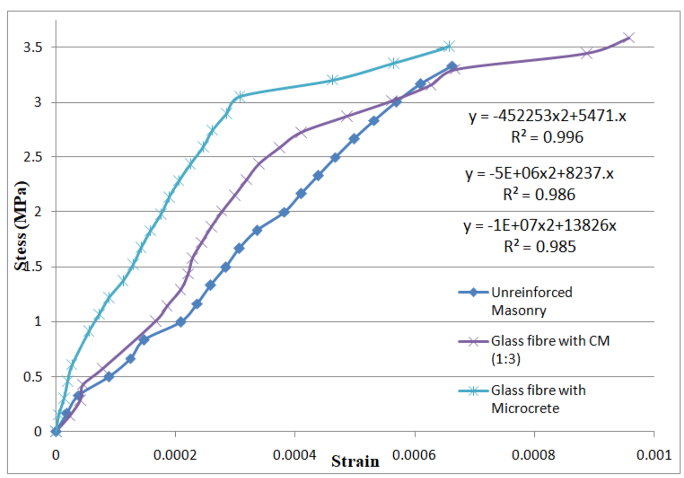


Figure 9: Stress-strain curve for glass fiber reinforced and unreinforced masonry prisms

3.4 Shear bond strength of Masonry

The unreinforced triplet carried a maximum average load of 56 kN. The splitting of the block was noticed in unreinforced triplets. Figure 10 shows the failure of the unreinforced triplet specimen. No interface failure was observed in any of the specimens. There was crushing and splitting failure in the units. For masonry prisms reinforced with Coir fibre and cement-mortar (1:3), cracks were noticed at the mortar bed joint which was then propagated to the centre of the middle block for the specimen. For masonry prisms reinforced with Coir fiber and microcrete, cracks were noticed in the intermediate block for all the specimens. For masonry prisms reinforced with glass fiber and cement mortar 1:3 cracks were developed at the mortar bed joint. For masonry prisms reinforced with Glass fibre and Microcrete, specimen 1 showed interface failure in one mortar bed joint, while the other two blocks were still intact. The remaining two specimens developed cracks in the intermediate block. Table 7 shows the average shear-bond strength of all types of reinforced masonry prisms and TRM bonded masonry prisms.

Figure 10 Failure of unreinforced triplet

Figure 11 Failure of block masonry in flexure

Table 7: Shear bond strength of unreinforced and reinforced masonry triplets

Type of Triple	Length of the Joint (mm)	Width of the Joint (mm)	Avg Max Load (KN)	Shear bond Strength (N/mm²)
URM	400	150	56.00	0.47
CC	400	150	69.00	0.58
CM	400	150	74.00	0.62
GC	400	150	76.33	0.64
GM	400	150	80.00	0.67

3.5 Flexural strength of Masonry prisms

A flexure test was conducted on 3 types of prisms URM, Coir with cement-mortar (1:3) and glass fiber with cement-mortar (1:3). Masonry prisms reinforced with glass fiber and cement mortar have experienced interface failure. However, the URM prism has witnessed complete failure, which is due to block failure. Prism with coir and cement-mortar failed partially, as indicated in Figure 11. Table 8 shows the average flexural strength of the three types of prism.

Table 8: Flexural strength of reinforced and unreinforced prisms.

Type of Prism	Prism Size (L x B x T) mm	Maximum load kN	Flexural Strength N/mm²
URM	400 x 150 x 625	2	0.833
CC	410 x 160 x 635	10	3.72
GC	410 x 160 x 635	5	1.86

4. CONCLUSIONS

1. Increasing the number of layers of textile fibers, increased the flexural capacity of TRM coupons. The provision of connectors also enhanced flexural strength.
2. The stiffness of unreinforced masonry prisms was found to increase by strengthening with textile reinforcements even though the increase in compressive strength is marginal.
3. The compressive strength of masonry prisms reinforced with glass fibre and coir fibre was almost the same and was 1.11 times that of unreinforced masonry prisms. For prims with Coir and Microcrete, it was 1.10 times the URM. Prisms externally reinforced using Microcrete and glass fiber yielded the maximum compressive strength. It was 1.21 times the URM. Among the different configurations adopted, glass fiber with microcrete showed the highest increase of 50% when compared to unreinforced masonry.
4. In the case of the flexure test, the average flexural strength of coir reinforced prisms is high. The increase in strength was 3.5 times when compared to unreinforced masonry prisms and 2 times with respect to glass fiber reinforced prisms. The shear bond strength of both coir and glass fibers with microcrete is comparable and enhanced when compared to unreinforced masonry.
5. The experimental results conclude that the improvement in the compressive strength of hollow concrete block prisms is not significant with either coir or glass textile reinforced mortar. However, TRM is effective in increasing the flexural strength of masonry.

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