Compression behaviour of brick masonry strengthened with Textile Reinforced Concrete (TRC) – A preliminary study

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Abstract: Masonry is one of the most widely used conventional materials throughout the world but its failure mainly occurs due to low tensile resistance. The main objective of this study is to observe the effectiveness of the relatively new construction material Textile Reinforced Concrete (TRC), in strengthening the brick masonry prism. In the present work TRC consisting of an overnight cementitious curing mortar (OCCM) along with alkali resistant glass textile which can resist high tensile stress is used for strengthening of unreinforced brick masonry. The technique adopted in this work is not time consuming and is also practically feasible. Tests were carried out to study the axial compressive behaviour of prisms strengthened with cast-in-place TRC overlays and pre-cast TRC laminae with varying reinforcement ratios. Detailed investigations were carried out to observe failure patterns and ultimate failure load. From observations, 4 ply TRC overlays were found to be more effective. Among all strengthening methods mortar bonded TRC laminae exhibited enhancement in terms of compressive strength. It is concluded that this technique may benefit many applications in the area of masonry retrofit.

1. Introduction

Even though concrete usage is prevalent in present age, masonry is still widely adopted in construction field. It is mostly used in low rise buildings because of its ease of construction and economy. However, past earthquake studies have indicated that unreinforced masonry (URM) structures are prone to extensive damage. In short, masonry is subjected to in-plane and out of plane failures where shear stresses come into action, which cannot be resisted by URM walls. It is observed that failure of brick masonry is brittle in nature. To overcome all these drawbacks strengthening of masonry is recommended. Many retrofitting techniques are adopted namely repointing [1], Near Surface Mounted reinforcement Technique [2], Shotcreting [3] and Fiber Reinforced Polymer (FRP) [4]. Among all FRP is mostly chosen because of its application feasibility and lightweight benefits. Disadvantages of FRP linked with using epoxy as bonding agent were low resistance to fire and glass transition temperature and difficulty in application on wet surfaces [5]. Other general methods for ductile strengthening adopt materials like Engineering Cementitious Composites (ECC) [6]. Eco-friendly Ductile Cementitious Composite (EDCC) [7]. Textile Reinforced Concrete (TRC) is an innovative composite material developed alternatively for FRP.TRC consist of fine grained concrete with alkali resistant textile embedded in it which can resist high tensile stress. Similar to organic binders, cementitious binders can also be used as retrofitting material [8] which is reflected in TRC. The reinforcing textile can be of alkali
resistant glass, carbon, Aramid, poliparafenilen benzobisoxazole (PBO) etc. Nevertheless, compared to other materials peculiarity of TRC is the strain hardening behaviour with multiple crack formation, which is more suitable for seismic retrofitting. Low self-weight of textile allows production of lightweight and thin-walled elements.

Applications of TRC in concrete is becoming popular for flexural [9] and shear strengthening [10]. TRC exhibits enhanced performance and efficiency which may benefit applications in masonry retrofit (in terms of stiffness, tensile and compressive strength). It has been proved that as a retrofitting material the overall cost of TRC is much lower compared to Ferro cement and FRP [11]. TRC applications adopt not only the single layer of textile but also multiple layers of textile layers. It was observed that walls strengthened with 4 plies showed 3 times increase in tensile and shear strength compared to walls strengthened with 1 ply of Fiber Reinforced Cementitious Matrix (FRCM), indicating that increase in the number of layers of FRCM increases tensile and shear strength [12]. However, there is a limit for increasing number of textile layers. An increased textile layer in the middle plane reduces the bond between textiles so that premature slippage occurred before reaching the tensile strength [13]. However to enhance the performance of TRC another method is developed by stretching textile [14]. During stretching of textile, the layers of textile will be stiffened so that finer particles of matrix impregnate into yarns which enhance bonding of matrix and textile leading to an increase in tensile strength. Literature shows that the most common failure of brick masonry panels strengthened with Textile Reinforced Mortar (TRM) under loading is debonding at the binder-textile interface [15].

Above studies indicate that TRC strengthening is a suitable technique for retrofitting. With advantages of freedom from corrosion, high tensile strength, flexibility, and ease of application on any surface TRC made its entry into construction field. Limited studies are reported on compression behaviour of masonry prism. Increase in load bearing capacity is observed for masonry prism strengthened with FRP [16]. An enhancement in shear and compressive strength is observed for Glass Fiber Reinforced Polymer (GFRP) composites [17].

2. Objectives and scope
Although few studies were done in the strengthening of the prism using FRP, studies are lacking in prism strengthening with TRC. A preliminary study is carried out to observe the effectiveness of TRC strengthening by varying reinforcement ratio and methods of strengthening. The objectives of the investigation are

- To find an optimum number of textile layers with respect to prism compressive strength.
- To compare the efficiency of strengthening between bonded TRC laminae and Cast-in-place TRC.

The scope of the work was restricted to axial compression test on masonry prism with an aspect ratio of 4 and with 4 and 5 number of textile layers as reinforcement for TRC. The cast-in-place TRC was tried in both stretched and un-stretched modes.

3. Experimental Programme

3.1 Material details

3.1.1 Brick: In this study Solid clay bricks with dimension 220mm×110mm×70mm procured from the Local manufacturer, Chennai was used. The compressive strength and water absorption were determined in accordance with [18] as 5MPa and 18% respectively.

3.1.2 SRG-45: SRG-45 (bidirectional glass textile) product of Saint Gobain Technical Fibers shown in Figure 1 was used in this study. Table 1 shows the properties of SRG-45 given by the manufacturer. The textile was tested by following the specified code guidelines [19] and the ultimate tensile strength of textile was 40kN/m.
3.1.3 Mortar: In order to resolve the problem of time constraint special kind of mortar - Overnight Cementitious Curing Mortar (OCCM) - was used. Curing period of this mortar is only 24 hours and 27MPa strength can be obtained in 24 hours. This mortar was used to strengthen prism along with glass textile with 0.18 w/b ratio. For brick masonry prism construction, 1:4 mortar with OPC 53 grade and the fine aggregate of 1.18mm was used with 0.67 w/c ratio. The 28 day compressive strength of the mortar of this mortar was 16MPa.

3.1.4 Textile Reinforced Concrete: The uniaxial Tensile strength of TRC was performed to know the composite behaviour of the matrix along with the textile as an integrated system and also to determine the influence of the number of textile layers. Coupons for both stretched and unstretched cases with 3, 4, 5 textile layers were cast. The dimension of the coupons was 500mm×6mm×12mm as per [20]. The tensile strength of TRC coupons with different textile ratios is shown in figure 2. Prominent enhancement in tensile strength was found in coupons with reinforcement. Unreinforced coupons indicated brittle failure after peak load. For TRC coupons failure is ductile and also strain hardening behaviour is observed. On observation, it is clear that no two TRC characteristics are alike.

Figure 2. Uniaxial tensile strength of coupons

Table 1. Properties of SRG-45

| Property          | Value          |
|-------------------|----------------|
| Weight            | 225 Kg/m²      |
| Mesh Size         | 25×25mm        |
| Area              | 33.58 mm²/m    |
| Tensile strength  | 45kN/m         |
| Elongation Ability| < 2%           |
3.2. Construction of Unstrengthened masonry prism
The stacked masonry prism was constructed by taking 5 bricks having dimension 220mm×110mm×77mm with mortar thickness of 10mm as shown in Figure 3. The dimensions of prisms were kept as 410mm×220mm×105mm to meet code provisions of IS:1905 [21] (recommends prism dimension of at least 40 cm high and height/thickness ratio between 2 and 5). The joint mortar with cement to sand ratio 1:4 and water-cement ratio 0.67 was used for constructing the prisms.

![Figure 3. Stacked prism](image)

3.3 Strengthening of the prism
Four different types of strengthening methods were used for comparative study. Total 26 prisms were constructed and the number of specimens for each technique is mentioned in table 2. For each technique, 2 number of specimens were strengthened with 3 layers, 4 layers and 5 layers of textile.

| Type of strengthening                  | No. of specimens |
|---------------------------------------|------------------|
| Unstrengthened prism                  | 2                |
| Mortar bonded Laminae                 | 6                |
| Epoxy bonded Laminae                  | 6                |
| Cast-in-place unstretched TRC         | 6                |
| Cast-in-place stretched TRC           | 6                |

3.3.1. Casting of TRC laminae: Laminae of dimension 400mm×220mm×12mm were cast for strengthening the prisms. As the laminae were bonded to full face of the prism, they were cast to the same dimension of the prism with 12mm thickness. OCCM was used for casting laminae with water cement ratio of 0.18. For single laminae, 2.34kg of overnight curing cementitious mortar was required. SRG textiles were trimmed in such a way that textile would fit into laminae frame without any projections outside. Laminae with 3, 4 and 5 layers of textile were cast. To cast TRC laminae, at first binder of 6mm thickness was placed followed by placement of textile layers. Then textiles were pressed into the 1st layer of the binder as shown in Figure 4(a). Textile layers were not put together; instead alternative layers of textile and mortar was placed. After placing the number of layers of textile, the binder was applied again till an overall thickness of 12mm was achieved for TRC coupon as shown in figure 4(b). After 24 hours, laminae were water cured before bonding to the prism.
3.3.2 Prism strengthened with TRC laminae: Laminae were bonded using both OCCM and epoxy on a single side of the prism. 6 prisms were strengthened with mortar bonded laminae and other 6 with epoxy bonded laminae. Strengthening with laminae bonding was done after 14 days of prism construction. Each lamina with a thickness of 12mm weighed about 2 to 2.5kg. Prism was placed horizontally on a level floor and OCCM of 10mm thickness was applied over the surface as shown in Figure 5(a). Laminae were placed over 10mm OCCM and pressed well. Level of laminae was ensured with the help of the spirit level before the mortar in the middle started setting as shown in figure 5(b). The strengthened prisms were cured for 24hrs before testing under compression. Figure 5(c) shows prism bonded with TRC laminae using OCCM.

4kg of epoxy adhesive mixed with 2kg hardener component shown in Figure 6(a) was used to bond the laminae on the surface of the prism. The thickness of the epoxy layer was maintained 6mm throughout the surface of the prism to bond TRC laminae as shown in figure 6(b). TRC laminae were bonded over prism as shown in figure 6(c). The setting of epoxy occurred within 6 hours.
3.3.3 Prism strengthened with cast-in-place TRC: Twelve prisms were strengthened with cast-in-place TRC. OCCM was used for strengthening of the prism. For strengthening of each prism, overnight mortar 2.34kg was mixed at the water-cement ratio of 0.18 in a mortar mixer of 15 kg capacity. The mixed mortar was placed over the prism for about 6mm thickness using a trowel and then textile layers were pressed over the mortar as shown in Figure 7(a). Textile layers were laid in such a way that alternate layers of textile and matrix were seen. The thickness of the strengthening was maintained 12mm. After these processes, the surface was finished within the setting time as shown in figure 7(b). Strengthening was done with 3, 4 and 5 number of textile layers on 2 prisms each.

![Figure 7. (a) Placing of textile (b) Cast-in-place unstretched TRC](image)

In case of cast-in-place stretched TRC, a frame was fabricated for stretching. Length of the textile was kept more than the frame length in order to clamp textile. Textile layers were clamped together into the frame with the help of the wooden frame at the stiffening ends in order to prevent slipping of textile in the steel frame. After fixing of textile layers, stretching of textile was done manually by fixing at one end and tightening the bolts at the other end. The textile needed to be stiff enough while strengthening onto the prism surface. Prism surface was made wet and first layer of mortar applied for 6mm. Next frame with stretched textile layers was placed over the prism and mortar was applied as shown in Figure 8(a). The mortar was finished to an overall thickness of 12mm as shown in figure 8(b). The extra length of textile was trimmed after 24 hours of strengthening and then prism was water cured.

![Figure 8. (a) Placing of stretched textile on prism (b) Cast-in-place stretched TRC](image)

3.4 Experimental setup
Axial compression test on stack bonded brick prism was done as per [19]. In order to distribute the load uniformly and to make the top surface level, capping of masonry was done using overnight mortar on both the top and bottom surfaces. The capped surfaces were cured for 24hrs. Axial Compression test was performed on 3000kN capacity displacement controlled compression testing machine at the rate of loading 0.8mm/min. In order to maintain the surface level and for uniform distribution of load, the surface of prisms was given Plaster of Paris capping and plywood of 3mm thickness was placed during
loading. Parameters recorded from the experiment were Load at first crack, peak loads and displacements, crack pattern.

4. Results and Discussions
Uniaxial compression results for the tested specimens are discussed below. After casting ID’s were given for each specimen and are mentioned as follows: UP-Unstrengthened prism, MB4L-Mortar Bonded 4 layer textile, EB4L-Epoxy bonded 4 Layer, U4L-Unstretched 4 Layer textile, S4L-Stretched 4 Layer textile.

4.1 Unstrengthened prism
The unstrengthened prism (UP) under uniaxial compression failed through vertical cracking as shown in Figure 10. The cracks initiated at the top and propagated to the bottom of the prism. Spalling of brick was also observed. Prism failed at 52kN of compressive load.

![Figure 10. Unstrengthened prism failure](image)

4.2 Prism strengthened with TRC laminae
Two methods were used to bond laminae to prism - one mortar bonded and the other epoxy bonded. All the specimens were tested 14 days after strengthening. For all the specimens crack initiated from the top and propagated to the bottom of the prism at the interface of bonding. Figure 11(a) and 11(b) show the typical failure of mortar and epoxy bonded laminae respectively. It was observed that on the face of laminae multiple cracks were observed which revealed that textile behaviour was attained and debonding of laminae was main failure mode for both epoxy and mortar bonded laminae.

![Figure 11. Failure pattern of (a) mortar bonded laminae (b) epoxy bonded laminae](image)

Figure 12 shows the comparison of peak load under compression between mortar and epoxy bonded laminae. It is observed that mortar bonded laminae showed enhanced compressive strength than epoxy
bonded laminae. Among the different reinforcement ratios used 4 ply TRC is observed effective in terms of compressive strength for both mortar and epoxy bonded laminae. Compared with UP, strength enhancement of 22% is observed for 3 layers, 38% for 4 layers and 20% for 5 layers in case of mortar bonded laminae and an increase of 8.5% for 3 layers, 34.6% for 4 layers and 4.1% for 5 layer textile for epoxy bonded laminae. It is noticed that the load carrying capacity is decreased from 4 layers to 5 layers even though the number of layers is increased. This is due to delamination of textile layers. The reason for the low compressive strength of epoxy bonded laminae than mortar bonded might be improper interface bonding. This can be overcome by adopting some surface preparation on laminae before it is pasted on the surface of the prism.

![Figure 12. Comparison of mortar and epoxy bonded laminae](image)

**4.3 Prism strengthened with cast-in-place TRC**

Two methods were used to strengthen prism with cast-in-place TRC - one using unstretched textile and other using stretched textile. Figure 13(a) shows cracking pattern of unstretched cast-in-place TRC and Figure 13(b) of stretched TRC. Failure is due to debonding of cast-in-place TRC from the prism. Multiple cracking behaviour was observed in both cases. First, multiple cracking was formed on the strengthened face. When textile exceeded its capacity, strengthened TRC debonded from the prism and ultimately failure happened.

![Figure 13. Failure pattern (a) Unstretched TRC (b) Stretched TRC](image)

Not only the volume fraction of textile and type of matrix used but also interface bond between the prism and cast-in-place TRC plays a vital role in the development of strength. Figure 14 shows peak loads of cast-in-place strengthened prisms. It is observed that there is an increase of 84.42% for U4L and 17.2% for U5L in compressive strength for unstretched TRC compared to case UP. In the case of cast-in-place
TRC with stretched textile, an increase of 30% for S4L and 54.3% for S5L with respect to case UP is observed. Stretching effect should be more robust so that enhancement in strength can be achieved. Further investigation can be done in case of prisms to know more about stretching effect and also factors affecting it.

**Figure 14.** Comparison of stretched and unstretched cast-in-place TRC

In all the methods investigated, enhancement in compressive strength is more for 4 layer textile. Figure 15 shows peak load under compression for the different methods attempted.

**Figure 15.** Comparison of strengthening methods with 4 layer TRC

Between the mortar and epoxy bonded TRC laminae cases, mortar bonded can be preferred, whereas with respect to in-situ methods unstretched is preferred over stretched strengthening. Generally, mortar bonded laminae exhibited more load carrying capacity. More investigations are needed on prisms, to understand the behaviour under eccentric compression. Bond shear and pull out test may help to understand the parameters influencing interface bonding.

5. Conclusion:
The behaviour of masonry prism strengthened with TRC has been investigated under axial compression. The conclusions drawn from the investigation are as follows:

1. The optimal number of layers to be used in prism strengthening was observed as 4.
2. Among the different options, TRC laminae with mortar bonding are the better choice for strengthening compared to cast-in-place strengthening.
3. Strengthening by TRC laminae bonding using Epoxy needs surface preparation.
4. Further investigations need to be performed on stretched and unstretched case to draw perfect conclusion of compressive strength variation.
6. References

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