TEXTILE REINFORCED MORTAR FOR STRENGTHENING REINFORCED CONCRETE BEAMS

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Abstract

The study included testing of six reinforced concrete beams (150 x 100 x 2700 mm): one control beam (without strengthening); one beam strengthened with one layer of textile bonded with epoxy to the tension side of the beam; while the remaining beams were strengthened with one layer, two layers and three layers of textile bonded with mortar. Additional U- shaped strips were used on some of the beams as anchorage to enhance the bond of the textile layers to the concrete surface. The test results indicated that epoxy bonded textile performed better in terms of strength enhancement as the bond was perfect compared to mortar bonded textile where the bond was the main cause of failure. However, the ductility or deformability was slightly better in beams strengthened with mortar bonded textiles. The test results also showed that as the number of layers increases, there is no significant increase in strength due to bond failure. When the U- shaped strips were used along with increasing number of textile fiber layers, the gain in flexure strength and gain in ductility was observed. From the results obtained in this study it is believed that TRMs is a potential solution for the structural upgrading of concrete structures provided the bond between the textile layer and the concrete surface is maintained.

1 Introduction

During the past three decades a great deal of research has been conducted in the area of strengthening and rehabilitation of existing concrete structures. The need for upgrading existing structures is mainly due to the deterioration of structural members especially in areas of aggressive environment (hot and humid) such as the Arabian Gulf region. Deterioration of concrete structures normally is one of two forms: deterioration due to the reinforcement corrosion or the deterioration of the concrete itself in the form of chloride contamination, sulfate attack, or carbonation of the concrete. Such deterioration results in loss of strength and stiffness of the concrete member. Various methods have been used to repair and strengthen reinforced concrete members. In recent years, fiber reinforced polymers (FRP) has gained increasing popularity in the civil engineering field due to the favorable properties possessed by these materials such as corrosion resistance, high strength-to-weight ratio, ease of application and flexibility to form to any desired shape. However the FRP strengthening technique has a few drawbacks, which are attributed to the organic resin used to impregnate and bond the fiber to the concrete surface. Some of these drawbacks may be summarized as follows: 1) poor performance of epoxy resins at high temperatures; 2) relatively high cost of epoxy resins; 3) it might be harmful to worker if not handled properly; and 4)incompatibility of epoxy resins with substrate materials. These problems could be solved if a cement-based matrix is used instead of epoxy matrix. In addition if a textile type of fiber is used instead of the continuous uni-directional fibers that will allow for a better bond with concrete.

Studies in the use of textiles in upgrading of concrete structures have been very limited. Kikukawa et al [2] investigated the effect of carbon fiber textile for flexural reinforcement to deteriorated reinforced concrete floor slab. The slabs were tested in laboratory by cutting out six specimens from existing structure aged more than 70 years. The repair method between concrete and carbon fiber textile was used as experimental parameter. From the test results, it was shown that strengthening with carbon fiber textile was effective. Using of textile reinforced concrete for strengthening in bending and shear was reported by Bruckner et al. [3]. Using test results it was demonstrated how thin layers of concrete with textile reinforcement can be used for strengthening of reinforced concrete (RC) members. The enhancement of bending capacity was illustrated with flexural strengthened RC-slabs. It was also established that the shear capacity may be increased through strengthening of RC-beams, and that properties of serviceability were improved, in particular the reduction of deflections and crack widths. Reinforced concrete beams are often strengthened by CFRP plates and the mode of failure of such beams is characterized by debonding of CFRP plates at their ends. The load-carrying capacity of these beams can be influenced by the strengthening of their ends, which controls the premature end failure occurring when the anchorage length of the plates or the shear span/depth ratio are low. The effect of end anchorage of CFRP plates using U-wrapping of shear spans with carbon fiber textile was reported by Buyle-Bodin, F and David, E. [5]. Lateral bonding of CFRP strips and U-wrapping using carbon fiber textile were found particularly efficient for the control of debonding cracks and delay the premature end failure of the beams. The load-carrying capacity is enhanced, and the ductility is increased.

In a recent study reported by Al-Salloum et al [5] the efficiency and effectiveness of textile-reinforced mortars (TRM) on upgrading the shear strength and ductility of a seismically deficient exterior beam-column joint has been studied. The results then were compared with that of carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP)-strengthened joint specimens. The test results demonstrated that TRM can effectively improve both the shear strength and deformation capacity of seismically deficient beam-column joints to an extent that is comparable to the strength and ductility achieved by well-established CFRP, and GFRP-strengthening of joints.

2 Experimental program

2.1 Specimen details

A total of 6 reinforced concrete beams were tested in this study as summarized in Table 1. Beam BC was a control beam without strengthening, while beam SILE was strengthened by bonding carbon fiber (CF) textile at the bottom of the beam using epoxy. On the other hand beam S1LM1 was strengthened by bonding CF textile at the bottom of the beam using readymade repair mortar that only required addition of water. One layer of mortar is first applied on the concrete surface with 2 mm thickness followed by placing the textile and then the second layer of the mortar is applied (see Figure 1). Beam S1LM1U is strengthened similar to S1LM1 with the addition of U-shaped CF textile strips applied on top of the CF textile around the cross-section (see Figure 2).

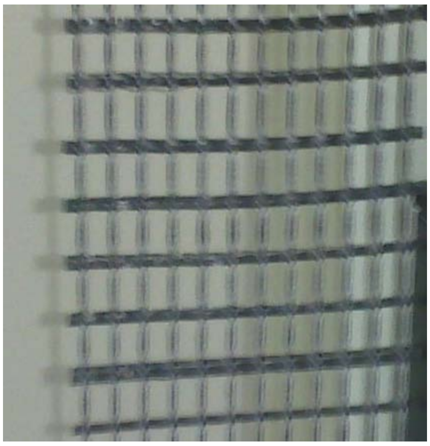
The specimens were 2.7 m long, 100 mm wide and 150mm high. All beams were reinforced with two 10 mm diameter bottom bars (tensile reinforcement) and two 8 mm top (compression) bars. The clear concrete cover was 20 mm on all sides of the specimen. For stirrups, 6 mm plain bars spaced at 290 mm were used in all specimens (see Figure 2).

Beam	**Description**
(CB)	Control beam
(S1LE)	Beam with 1 layer of textile bonded with epoxy
(S1LM1)	Beam with 1 layer of textile bonded with mortar, M1
(S2LM1)	Beam with 2 layer of textile bonded with mortar, M1
(S2LM1U)	Beam with 2 layer of textile bonded with mortar, M1, with U-shaped strips @ 500C/C as anchors
(S3LM1U)	Beam with 3 layer of textile bonded with mortar, M1, with U-shaped strips @ 500C/C as anchors

Table 1. Beam description

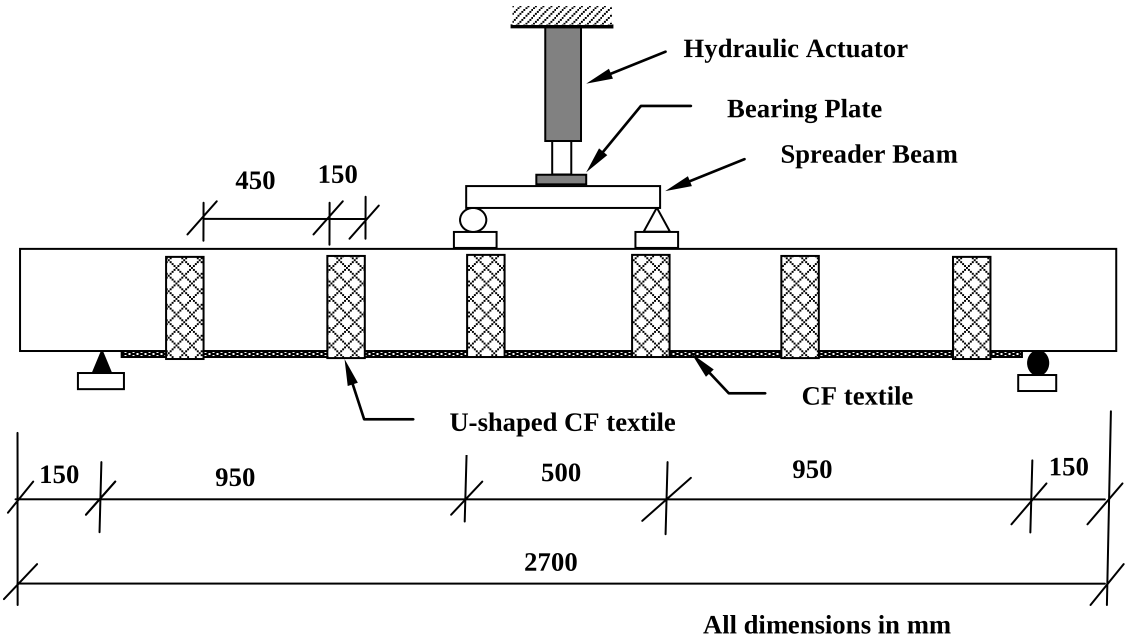
a) Application of first layer of mortar

b) Application of second layer of mortar

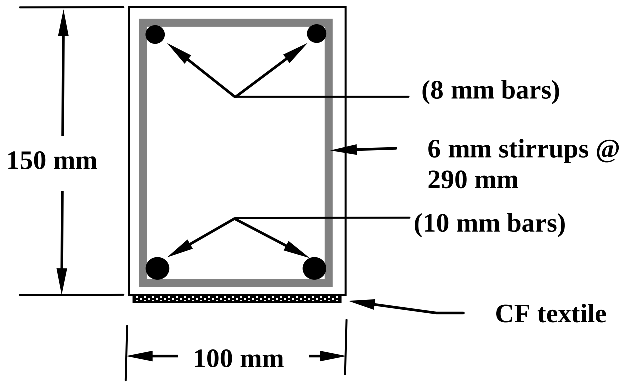


C) Carbon Fiber textile

Figure 1. Application of mortar and textile layers



a)



b)

Figure 2. a) Loading Set Up & b)Beam Cross-Section

2.2 Material properties

Carbon fiber textile fabric was consisting of fibers running in both directions (bi-directional) with opening of the grids of approximately of 5 mm. Width of each bundle of fibers is approximately 1.5 mm and the thickness of approximately of 0.5 mm (dry fibers), tensile strength of 320 MPa, modulus of elasticity of 8 GPa, and ultimate elongation of 4.0%. The mortar used to bond the textile to the concrete surface was a commercially available repair mortar that requires the addition of water to the mix with water to powder ratio of about 0.15. Compressive and tensile strengths of the mortar at 28 days were 55 MPa and 3.5 MPa, respectively. Ordinary portland cement was used for the concrete mix along with a maximum aggregate size of 10 mm. The concrete mix was proportioned by weight as follows, aggregate : sand : water : cement = 60 : 67 : 16: 25, with a water to cement ratio of 0.64. The concrete had a 28-day compressive strength on average of 35 ± 1.5 MPa and a tensile splitting strength of 3.0 MPa. The average yield strength of the 10mm diameter reinforcing bars was measured to be 660 MPa and modulus of elasticity was 200 GPa. The yield strength of the 6mm diameter plain reinforcing stirrups was 250 MPa.

2. *Test set up*

All specimens were loaded in four-point loading (see Fig. 2). The load was applied using a 250 KN hydraulic actuator through a spreader steel beam to the specimen. Four linear variable displacement transducers (LVDTs) with a range capacity of 100mm were used to measure the load-line and mid-span deflections of the beam during testing. All beams were tested to failure using load control with a rate of 0.05 KN/s for loading up to 20 KN (yielding load) and displacement (stroke) control with a rate of 0.05 mm/s was used to apply the loading from 20 KN to failure.

3. **Results and discussion**

Figure 3 presents the load-midspan-deflection curves for the beams that were strengthened with one layer of textile bonded with epoxy in one beam (S1LE) and with mortar in the other beam (S1LM1) and both were compared to the control beam (CB). The results showed that beam strengthened with epoxy bonded CF textile was slightly better in terms of load transfer between the CF textile and the beam concrete surface in comparison to beams strengthened with mortar bonded CF textile. The beam strengthened using epoxy bonded CF textile (beam S1LE) was able to resist a load of 24 kN at failure compared to a failure load of 23 kN in beam S1LM1. However, both beams resisted higher load than that of the control beam (CB) which failed at 21 kN. The failure of beam S1LE was due to rupture of the CF textile (Textile Rup.) and the other two beams failed by crushing of concrete (Con. Crush) as shown in Table 2 which summarizes the test results. Figure 4 shows the effect of adding more layers of mortar bonded textile. The beam that was strengthened with two layers (S2LM1) failed prematurely by bond failure of the textile layer without any gain in strength. To enhance the bond between the concrete beam and the textile layer, U-shaped strips were added to anchor the main textile layer in the remaining beams. This is observed in Figure 5 when comparing the behavior of beam S2LM1 and beam S2LM1U. The later included U-shaped strips and performed better in strength and deformation. This clearly indicates that adding U-shaped strips can enhance the bond that is required to transfer the load between the textile layer and the strengthened concrete beam. However, anchoring the textile layer cannot replace the bond strength provided by the mortar layer itself as can be observed when adding a third layer of textile such as in beam S3LM1U shown in Figure 6. It can be seen that adding a third layer resulted in minor gain in strength when comparing the failure loads of beams S2LM1U and S3LM1U in which beam S3LM1U failure was initiated by bond failure. This clearly indicates that the mortar was not able to provide the bond strength needed to utilize additional strength supported by a third layer of mortar. Table 2 summarizes all results with comparison in behavior between strengthened beams and the reference control beam.

4. **Conclusions**

This study presented test results of strengthened reinforced concrete beams using CF textile fabrics bonded with epoxy or mortar. Based on the test results it can be concluded that epoxy bonded CF sheet performed better than mortar bonded sheets. However, the ductility or deformability was slightly better in beams strengthened with mortar bonded textiles. Using U-shaped textile strips as anchorage improved the bond and as a result improved the strength and ductility of strengthened beams. Adding more layers of textile will not result in further gain in strength unless the bond properties of the mortar are also improved.

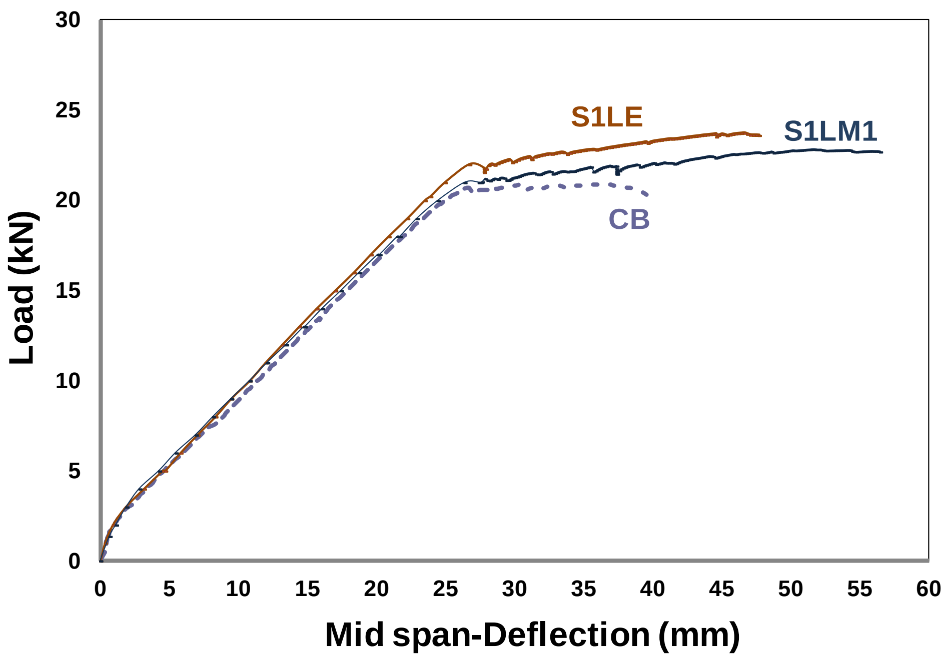


Figure 3. Load-deflection curves comparing epoxy vs mortar

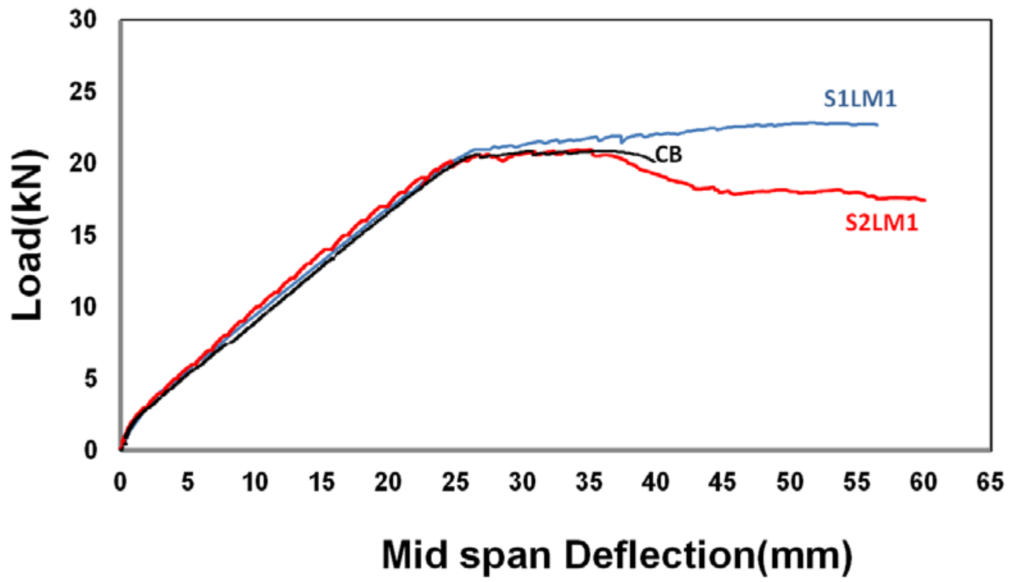


Figure 4. Load-deflection curves comparing effect of layers

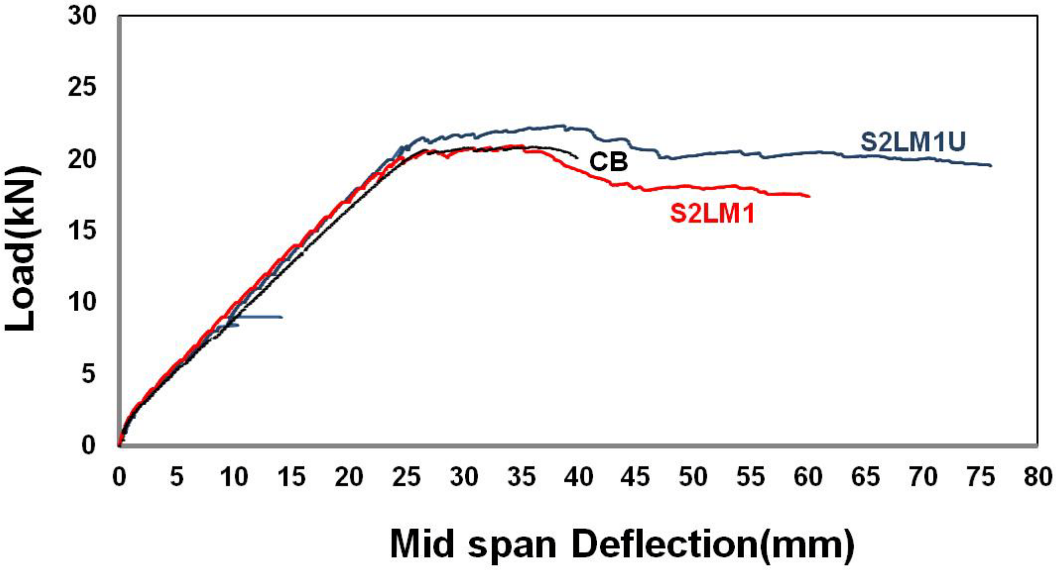


Figure 5. Load-deflection curves comparing effect of anchoring using u-shaped strips

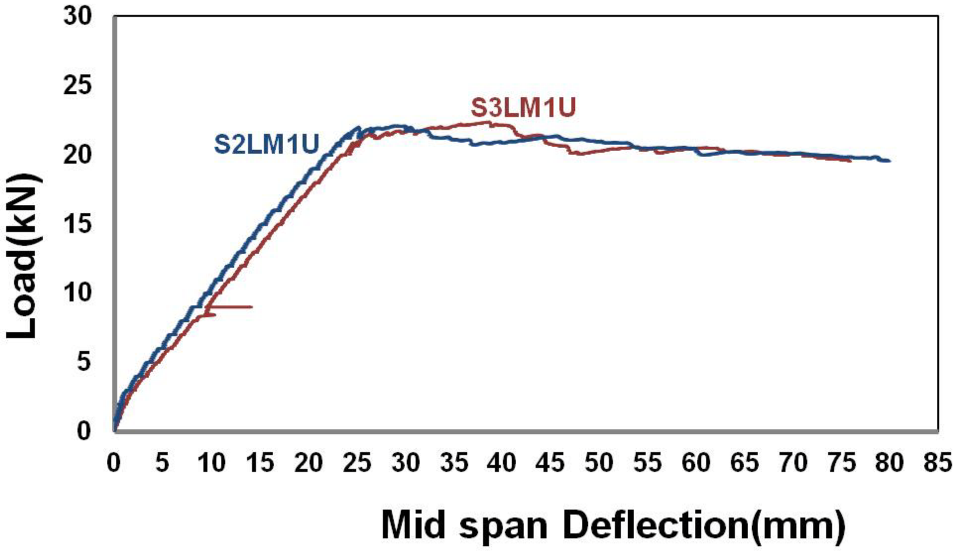


Figure 6. Load-deflection curves comparing effect of anchorage on additional textile layers

Beam	**Crack Load (kN)**	**Ultimate Load (kN), P_u**	**Yield Load (kN), P_y**	**Ultimate Deflection (mm), Δ_u**	**Yield Deflection (mm), Δ_y**	**Failure Mode**	**Stren. Effect * P_u/P_{CB}**	**Ductility ** Δ_u/Δ_y**
CB	2.0	21	20.5	40	26	C. Crush.	1.0	1.0
S1LE	3.0	24	22	47	26	Textile R	1.17	1.80
S1LM1	3.0	23	21	58	26	C. Crush	1.1	2.23
S2LM1	2.50	21	20	42	25	Textile Deb	1.0	1.68
S2LM1U	4.0	23	21	65	27	C. Crush.	1.12	2.40
S3LM1U	3.50	23.5	20	80	25	Textile Deb /C. Crush.	1.17	3.20

**Calculated as Ultimate load divided by Ultimate load of the control beam.*
***Calculated as Ultimate deflection divided by yield deflection of the respective beam.*

Table 2. Summary of test results.

References

[1] Kikukawa K., Mutoh K., Ohya H., Ohyama Y., Tanaka H., Watanabe K. Flexural reinforcement of concrete floor slabs by carbon fiber textiles. *Composite Interfaces*, **v 5**, n 5, pp. 469-478 (1998)

[2] Bruckner A., Otrlepp R., Curbach, M. Textile reinforced concrete for strengthening in bending and shear. *Materials and Structures*, **v 39**, n 292, pp. 741-748 (2006).

[3] Triantafillou T. C., Papanicolaou C. G. Shear strengthening of reinforced concrete members with textile reinforced mortar (TRM) jackets. *Materials and Structures*, **v 39**, n 285, pp. 93-103 (2006).

[4] Buyle-Bodin, F., David, E. Use of carbon fiber textile to control premature failure of reinforced concrete beams strengthened with bonded CFRP plates. *Journal of Industrial Textiles*, **v 33**, n 3, pp. 145-157 (2004).

[5] Al-Salloum, Y.A., Siddiqui, N.A., Elsanadedy, H.M., Abadel, A.A. And Aqel, M.A., 2011. Textile-reinforced mortar versus FRP as strengthening material for seismically deficient RC beam-column joints. *Journal of Composites for Construction*, **15**(6), pp. 920-933