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# EFFECT OF SURFACE ROUGHENING ON CONCRETE/TRM BOND

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Textile reinforced mortar (TRM) is applied on the concrete surface with the aim of strengthening reinforced concrete structures. The performance of the strengthened structural system is directly related to the bond between the existing concrete substrate and the freshly applied TRM layer. This paper presents the results of an experimental study carried out to investigate the significance of concrete surface preparation, performed prior to strengthening, on the bonding behavior of the TRM system. For this purpose, concrete slabs of size (500 mm × 500 mm × 100 mm) were prepared and strengthened using a 10-mm thick TRM layer. After that, the bond performance of the strengthening layer with the concrete slab was assessed using the pull-off test. Three different levels of surface roughening were considered before strengthening: (i) no roughening (regarded as the reference), (ii) low roughening level, and (iii) high roughening level. Two types of textile materials are used in strengthening systems: carbon and polyparaphenylene benzobisoxazole (PBO). A total number of 72 pull-off tests were performed, of which the results were analyzed to examine the significance of the test variables. Results revealed that as the concrete surface is more roughened before strengthening, the bond between concrete substrate and TRM layer becomes stronger. Moreover, the PBO-TRM systems exhibit more desirable bonding behavior compared to the carbon-TRM counterpart.

*Keywords*: Rehabilitation, Repair, Structures, Pull-off test, Level of roughening, Bond characteristics.

## 1 INTRODUCTION

Reinforced concrete structures are subjected to deterioration due to severe environmental exposure or unforeseen excessive loading (Aly *et al.* 2006, Ebead and Saeed 2014, Elghazy *et al.* 2016). Classically, several strengthening techniques have been proposed in the literature to address this issue and to extend the life of RC structures such as externally bonded fiber reinforced polymers (Baky *et al.* 2007, Ebead 2011, Ebead and Marzouk 2004, Elsayed *et al.* 2009, Kotynia *et al.* 2008) and ferro-cement (Ebead 2015). More recently, textile reinforced mortar (TRM) system has emerged as a promising alternative to these traditional strengthening solutions (Ebead *et al.* 2016b, Pino *et al.* 2016). Textile reinforced mortar is a composite material consisted of dry fibers cemented with an inorganic matrix, commonly used for strengthening vulnerable RC structures by being directly applied on the concrete surface (Ebead et al. 2016).

The performance of the TRM-strengthened structure is strongly dependent on the bond between the original concrete substrate and the overlying TRM layer. Understanding the bond characteristics plays an important role to achieve a valid prediction of the load carrying capacity as well as the mode of failure of the strengthened structure (Courard *et al.* 2014, Donnini *et al.* 2016, Lourenço 2013). In view of that, this paper is aimed to investigate the significance of surface preparation prior to strengthening on the bond behavior between concrete substrate and TRM system. Two types of commercially available TRM systems were implemented, and three different levels of surface roughening were considered prior to strengthening. The bond performance of the TRM strengthening layer with the concrete surface was assessed using the pull-off test.

## 2 EXPERIMENTAL PROGRAM

### 2.1 Materials

Concrete preparation for slab was done using ready-mixed concrete with a design compressive strength of 30 MPa. The 28-day cured average cylinder compressive strength was 29.65 MPa with the standard deviation of 1.2 MPa. Two commercially available TRM systems, namely PBO TRM (Ruredil 2016) (P-TRM) and carbon TRM (S&P 2016) (C-TRM) systems, were used in this study. Each TRM system has its associated mortar matrix for the particular fabric (PBO or carbon). Mortar mixes were prepared as per manufacturers' recommendations, 6.5 L of water per 25 kg of mortar for the PBO mortar matrix and 4 L of water per 25 kg of mortar for the carbon mortar matrix. The average 28–day compressive strength values of the mortar matrices were 20 MPa for carbon mortar and 29 MPa for PBO mortar. Table 1 lists the mechanical properties of each textile type, provided by the manufacturers.

Table 1. Properties of textile (in the warp direction) corresponding to the TRM systems.

| **Textile type** | **Area per unit width, $A_f$ ($mm^2$/mm)** | **Elastic modulus (GPa)** | **Tensile strength (GPa)** | **Ultimate strain (%)** |
|---|---|---|---|---|
| PBO | 0.045 | 270 | 5.80 | 2.15 |
| Carbon | 0.157 | 240 | 4.30 | 1.75 |

### 2.2 Specimen Preparation

Slabs of dimensions (500 × 500 × 100 mm) were prepared with a design concrete compressive strength of 30 MPa. Each TRM group involves three slabs. Figure 1 shows the details of the slab specimen used for the tests. A layer of steel mesh with 8 mm diameter bar is provided at the middle of the slab thickness. Each slab was cured for 28 days. After the curing period, the slabs were subjected to three different levels of surface roughening by water jetting (Figure 2a). Figure 3 shows the slabs with three different levels of roughening.

Three levels of surface roughening were utilized, namely, (i) Reference (R) – with no surface roughening (Figure 3a); (ii) Low level roughening (L) – 5 minutes of continuous water jetting at a pressure of 500 bars over the whole area of the slab. Low level roughening (L) represents the removal of a thin layer of mortar finishing from the top of the slab (Figure 3b); and (iii) High level roughening (H) – 10 minutes of continuous water jetting at a pressure of 500 bars over the whole area of the slab. High level roughening (H) represents exposure of aggregates in the slab (Figure 3c).

After the surface roughening, TRM layer with one layer of textile was placed on top of the slab, through the following steps: (i) the slab was water-saturated for 30 minutes prior to application of the mortar matrix; (ii) a layer of mortar, approximately 5 mm in thickness, was laid, followed by impregnating one layer of fabric into the mortar matrix with a slight pressing by hand; (iii) another layer of mortar matrix of 5 mm thickness was laid (Figure 2b).

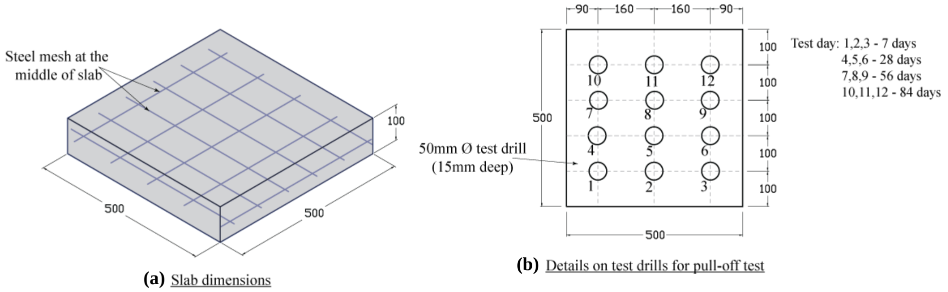
The slabs after applying TRM layer are shown in Figure 2c. Each slab was subjected to pull-off tests at 4 different ages, namely 7, 28, 56 and 84 days. Each testing age has three test data points illustrated by the drill holes in Figure 1b. The test matrix for the pull-off test is presented in Table 2.

Table 2. Test matrix and summary of pull-off test results.

| Specimen ID | Roughening level | TRM type | Mean pull-off strength (MPa) | Standard deviation (MPa) | Strength gain (%) |
|---|---|---|---|---|---|
| C-R-7d | N/A | Carbon | 0.74 | 0.26 | N/A |
| C-R-28d | N/A | Carbon | 0.58 | 0.05 | N/A |
| C-R-56d | N/A | Carbon | 0.79 | 0.12 | N/A |
| C-R-84d | N/A | Carbon | 0.99 | 0.26 | N/A |
| C-L-7d | Low | Carbon | 0.91 | 0.07 | 23.4 |
| C-L-28d | Low | Carbon | 0.76 | 0.27 | 29.5 |
| C-L-56d | Low | Carbon | 0.83 | 0.26 | 4.6 |
| C-L-84d | Low | Carbon | 1.37 | 0.14 | 37.8 |
| C-H-7d | High | Carbon | 1.20 | 0.19 | 61.7 |
| C-H-28d | High | Carbon | 1.12 | 0.04 | 90.9 |
| C-H-56d | High | Carbon | 1.16 | 0.47 | 45.6 |
| C-H-84d | High | Carbon | 1.50 | 0.25 | 50.1 |
| PBO-R-7d | N/A | PBO | 0.97 | 0.11 | N/A |
| PBO-R-28d | N/A | PBO | 0.87 | 0.15 | N/A |
| PBO-R-56d | N/A | PBO | 1.09 | 0.14 | N/A |
| PBO-R-84d | N/A | PBO | 1.07 | 0.15 | N/A |
| PBO-L-7d | Low | PBO | 0.75 | 0.13 | -22.4 |
| PBO-L-28d | Low | PBO | 0.87 | 0.46 | -0.4 |
| PBO-L-56d | Low | PBO | 1.28 | 0.15 | 17.7 |
| PBO-L-84d | Low | PBO | 1.14 | 0.15 | 6.5 |
| PBO-H-7d | High | PBO | 1.18 | 0.27 | 22.1 |
| PBO-H-28d | High | PBO | 1.52 | 0.25 | 73.7 |
| PBO-H-56d | High | PBO | 1.34 | 0.16 | 22.9 |
| PBO-H-84d | High | PBO | 1.56 | 0.23 | 46.1 |

## 2.3 Test Setup

The bond tests were performed according to ASTM C1583/C1583M (2013), where a circular cut was made on the cured TRM system using a core drill, to a depth of 0.5 in. (12.7mm) into the substrate. A cylindrical disc of steel was attached with the epoxy to the TRM surface in order to pull off the circular area. The adhesive was left to be cured for 24 hours before performing the pull-off test. The uniaxial tensile load was applied perpendicular to the test surface using the pull-off test machine, Proceq. The test was performed under load control at a constant rate so that the tensile stress increased at a rate of 0.035 MPa/sec.



**(a)** Slab dimensions

**(b)** Details on test drills for pull-off test

Figure 1. (a) Details of slab specimen; (b) Test drill locations for pull-off tests.

Figure 2. Specimen preparation details: (a) Surface roughening by water jetting; (b) TRM laying; (c) Six slabs after TRM laying under curing; (d) Core drilling Ø-50mm, Depth – 12.7 mm.

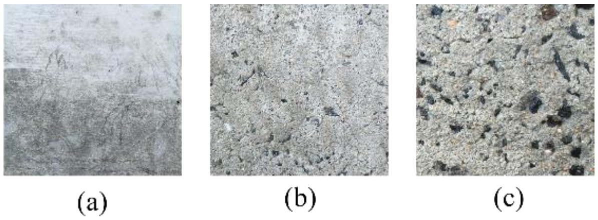


Figure 3. Pictures of the slab after surface roughening by water jetting: (a) Reference – R; (b) Low level roughening – L; (c) High level roughening – H.

## 3 RESULTS AND DISCUSSION

Table 2 shows the test results for mean pull-off bond strength for all tested samples. The primary failure mode of the pull-off tests occurred within the TRM composite system, at the interface between the TRM mortar and the fabric. For the Carbon-TRM, the average pull-off strength for all ages of reference specimen was 0.7 MPa, which is significantly lower compared to PBO-TRM reference specimen with an average value of 1.0 MPa. PBO-TRM, therefore, exhibited better results even for the reference specimens without roughening. With roughening the concrete substrate, there was a significant increment in the pull-off strength for Carbon-TRM, with a maximum increment of 37% in the pull-off strength compared to the reference specimen in the case of low level of roughening, and 91% for the high-level roughening. For the PBO TRM specimens, these increments were 18% for the low level of roughening and 74% for the high level of roughening. In addition, both TRM systems showed a significant improvement in the pull-off strength between 7-day and 28-day periods. The effect of test age on the improvement of pull-off strength was less significant after 28 days, as can be observed for the 56-day and 84-day test results (Figures 4-5).

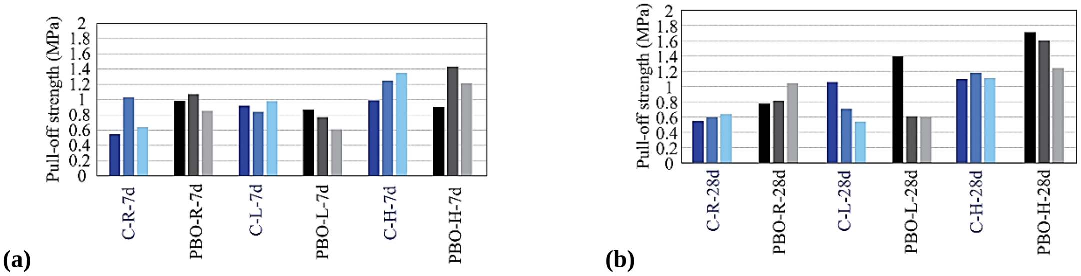


Figure 4. Pull-off test results for carbon and PBO TRM systems at different surface preparations: (a) 7 days, (b) 28 days.

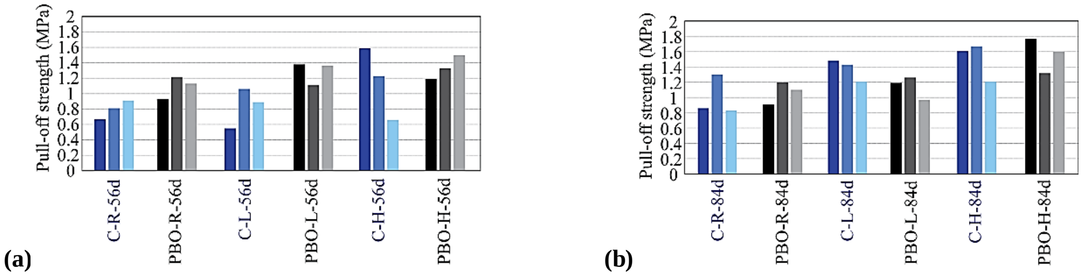


Figure 5. Pull-off test results for carbon and PBO TRM systems at different surface preparations: (a) 56 days and (b) 84 days.

## 4 CONCLUSION

The pull-off test was performed on RC slabs strengthened with two different types of TRM systems, namely: Carbon and PBO, in order to assess the effect of concrete substrate roughening level and aging. Three different types of concrete substrate roughening were incorporated with (a) the reference specimen (no roughening); (b) low level of roughening; and (c) high level of roughening. The effect of aging was studied at 7, 28, 56 and 84 days. A total of 72 pull-off tests were performed. The test results confirmed the noticeable effect of both the substrate roughening and the testing age on the pull-off strength for both TRM systems. The PBO-TRM system showed a higher pull-off strength compared to the Carbon counterpart. In general, there was a significant increment in pull-off strength for both TRM systems with concrete substrate roughening. The two levels of roughening adopted showed distinct results, where the higher level of roughening exhibited more enhanced strength. For the Carbon-TRM system, the mean pull-off strength of reference specimen of 0.7 MPa was improved up to 1.24 MPa with the high level of roughening. Similarly, for the PBO-TRM, the average strength of reference specimen was 1 MPa, which was improved up to 1.4 MPa with the high level of roughening. The effect of aging was significant up to 28 days, and then, there was no notable increment in the pull-off strength for 56- and 84-day test ages.

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## References

Aly, R., Benmokrane, B., and Ebead, U. A., “Tensile lap splicing of bundled CFRP reinforcing bars in concrete.” *Journal of Composites for Construction*, American Society of Civil Engineers, 10(4), 287–294, 2006.

*ASTM C1583 / C1583M-13, Standard test method for tensile strength of concrete surfaces and the bond strength or tensile strength of concrete repair or overlay materials by direct tension (pull-off method)*, West Conshohocken, PA, 2013.

Baky, H. A., Ebead, U. A., and Neale, K. W., “Flexural and interfacial behavior of FRP-strengthened reinforced concrete beams.” *Journal of Composites for Construction*, American Society of Civil Engineers, 11(6), 629–639, 2007.

Courard, L., Piotrowski, T., and Garbacz, A., “Near-to-surface properties affecting bond strength in concrete repair.” *Cement and Concrete Composites*, Elsevier Ltd, 46, 73–80, 2014.

Donnini, J., Corinaldesi, V., and Nanni, A., “Mechanical properties of FRCM using carbon fabrics with different coating treatments.” *Composites Part B: Engineering*, Elsevier Ltd, 88, 220–228, 2016.

Ebead, U., “Hybrid externally bonded/mechanically fastened fiber-reinforced polymer for RC beam strengthening.” *ACI Structural Journal*, American Concrete Institute, 108(6), 669, 2011.

Ebead, U., “Inexpensive Strengthening Technique for Partially Loaded Reinforced Concrete Beams: Experimental Study.” *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, 27(10), 4015002, 2015.

Ebead, U. A., Shrestha, K. C., Afzal, M. S., Refai, A. E., and Nanni, A., “Effectiveness of FRCM system in strengthening reinforced concrete beams.” *Proceedings of the 4th international conference in sustainable construction materials and technologies (SCMT4), University of Nevada, Las Vegas*, 2016.

Ebead, U., and Marzouk, H., “Fiber-reinforced polymer strengthening of two-way slabs.” *ACI Structural Journal*, 101(5), 650–659, 2004.

Ebead, U., and Saeed, H., “Flexural and interfacial behavior of externally bonded/mechanically fastened fiber-reinforced polymer-strengthened reinforced concrete beams.” *ACI Structural Journal*, American Concrete Institute, 111(4), 741, 2014.

Ebead, U., Shrestha, K. C., Afzal, M. S., El Refai, A., and Nanni, A., “Effectiveness of fabric-reinforced cementitious matrix in strengthening reinforced concrete beams.” *Journal of Composites for Construction*, American Society of Civil Engineers, 21(2), 4016084, 2017.

Elghazy, M., Refai, A. E., Ebead, U. A., and Nanni, A., “Performance of corrosion-aged reinforced concrete (RC) beams rehabilitated with fabric-reinforced cementitious matrix (FRCM).” *Proceedings of the 4th international conference in sustainable construction materials and technologies (SCMT4), University of Nevada, Las Vegas*, 2016.

Elsayed, W. E., Ebead, U. A., and Neale, K. W., “Mechanically fastened FRP-strengthened two-way concrete slabs with and without cutouts.” *Journal of Composites for Construction*, American Society of Civil Engineers, 13(3), 198–207, 2009.

Kotynia, R., Abdel Baky, H., Neale, K. W., and Ebead, U. A., “Flexural strengthening of RC beams with externally bonded CFRP systems: Test results and 3D nonlinear FE analysis.” *Journal of Composites for Construction*, American Society of Civil Engineers, 12(2), 190–201, 2008.

Lourenço, D. P. B., “Durability analysis of bond between composite materials and masonry substrates.” Universidade do Minho, 2013.

Pino, V., Hadad, H. A., De Caso, F., Nanni, A., Ebead, U. A., and El Refai, A., “Performance of FRCM strengthened RC beams subject to fatigue.” *Proceedings of the 4th international conference in sustainable construction materials and technologies (SCMT4), University of Nevada, Las Vegas*, Las Vegas, Nevada, USA, 2016.

Ruredil, *Technical datasheet, Ruredil X mesh gold data sheet*, 2016.

S&P, *Technical datasheet, S&P ARMO-mesh technical data sheet*, 2016