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TEXTILE REINFORCED MORTAR BASED FLEXURAL STRENGTHENING OF REINFORCED CONCRETE BEAMS

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Strengthening of reinforced concrete (RC) structures is often necessary due to the change of using or to enhance the strength of deteriorated existing RC structures attributed to aging and environmental effects. Interfacial bond between the existing RC member and the strengthening layer is known to be the main factor for any successful strengthening technique. This study investigates the efficiency of utilizing high strength cementitious connectors in preventing the debonding of textile reinforced mortar (TRM) strengthening layer from substrate concrete of RC beams. An experimental program is developed to investigate the effect of strength of mortars and the distribution of cementitious connectors on the behavior of the strengthened beams. TRM comprising eight and sixteen textile basalt fiber layers were utilized in these experiments. The results demonstrate the effectiveness of cementitious connectors on the failure mode of strengthened beams by means of controlling the debonding of TRM. The increase in cracking and ultimate loads is demonstrated due to the strengthening of RC beams using TRM.

Keywords: Basalt textile fibers, Strengthening of RC, Cementitious connectors, Bond of TRM.

1 INTRODUCTION

Increasing focus on the sustainability and hence reuse in the construction industry means that the change of use, increase in demand, or simply repairing of structures due to aging / deterioration is posing a significant challenge around the globe. Most of the existing RC structures do not conform to the ever-evolving latest safety and use standards. Various strengthening techniques have emerged to cater for this demand.

Fiber Reinforced Polymer composites are a widely used material for strengthening RC structures. The main advantages of this method include high strength to weight ratio and resistivity to future corrosion. The drawbacks are mainly attributed to the organic epoxy resins used to bind the fibers, such as poor fire resistance, applicability on wet surfaces or at low temperatures, and poor thermal compatibility with the base concrete e.g. SI Larbi, *et. al* (2010), and Elsanadedy (2013).

To overcome the above drawbacks, the use of inorganic binder (cementitious matrix) has been investigated in this study. Textile fibers cementitious technique has been investigated recently for the strengthening of masonry and RC structures. This technique uses textile polymer fibers bonded with the substrate concrete using a cementitious matrix (Ombres, 2011). Most previous studies on the use of textile reinforced mortars (TRM) exhibited debonding failure of the strengthening layer e.g. Bernat-Maso *et. al* (2014) and Contamine *et. al* (2013). The bond between the existing concrete and the strengthening cementitious layer depends primarily on the physical and chemical bonds of the interfacial zone between the two layers. Increasing the hydration product of the cement (C-S-H gel) increases the chemical bond strength at the interface (Espeche and Leon, 2011 and Eslanadedy, *et. al*, 2013). Furthermore, the cementitious matrix with high compressive strength exhibits higher bond strength with the substrate concrete (Julio *et. al*, 2006; Ray, *et. al*, 2005; Tayeh, *et. al*, 2013). The physical bond depends mainly on the mechanical interlocking between the substrate and cementitious matrix. The physical interlocking is effected by the surface preparation of the substrate concrete hence higher roughness led to the high bond strength as demonstrated by Julio *et. al* (2004), Santos *et. al* (2012), and Courard *et. al* (2014). Some investigations used anchors to improve the bond strength e.g. A.Di *et. al* (2008), Tetta (2015) and Bournas (2015) etc. These enhancements improved the bond but were insufficient to exhibit full flexural behavior.

This paper aims to improve the interfacial bond between the RC beams and the strengthening TRM layer by enhancing the physical and chemical bond of the interface. The chemical enhancement is investigated using a high strength mortar matrix, whereas high strength cementitious connectors are utilied to investigate the physical bond enhancement.

2 MATERIALS AND METHODOLOGY

2.1 Material Properties

Textile basalt fibers mesh with opening size 5 x 5 mm were used in this study, Table 1 presents the main properties of these fibers mesh. Three different mortar grades were used in this study as details in Table 2. High workability was required for mortar to provide full penetration of the mortar inside the holes drilled for the cementitious connectors. Flow table test as per BS-EN 1015-3:1999 revealed the mortar flow range between 225 and 300 mm. The mechanical properties and mix proportions of the mortars are listed in Table 2.

Table 1. Properties of textile basalt fibers.

Thickness (mm)	0.6 - 0.7
Type of Coating	Styrene-acrylic latex
Maximum Load (N/5cm)	1873.86 (wrap) ; 4416.29 (weft)
Elongation at break (%)	4.26 (wrap) ; 10.26 (weft)

Table 2. Mix proportions and mechanical properties of mortars.

Mix	**Cement (kg/m^3)**	**GGBS (kg/m^3)**	**Silica Fume (kg/m^3)**	**Silica Sand (kg/m^3)**	**Plasticiser (kg/m^3)**	**Water (kg/m^3)**	**f_{cm} (MPa)**
M35	500	--	--	1500	20	250	35.4
M70	750	--	--	1350	20	225	69.4
M135	770	153	117	1100	30	200	135.2

2.2 Methodology

16 beams (125 x 175 x 1400 mm) were cast with C30/37 concrete, reinforced with two 10mm diameter bars in the longitudinal direction and 8 mm diameter bars for shear reinforcement. The beams were moist cured (for 28 days) and the surface roughened uisng air needle hammer (to remove 2-3 mm from the surface) before the TRM strengthening layer was added and moist cured

for another 28 days. These were subjected to the four points flexural bending test as shown in Figure 1.

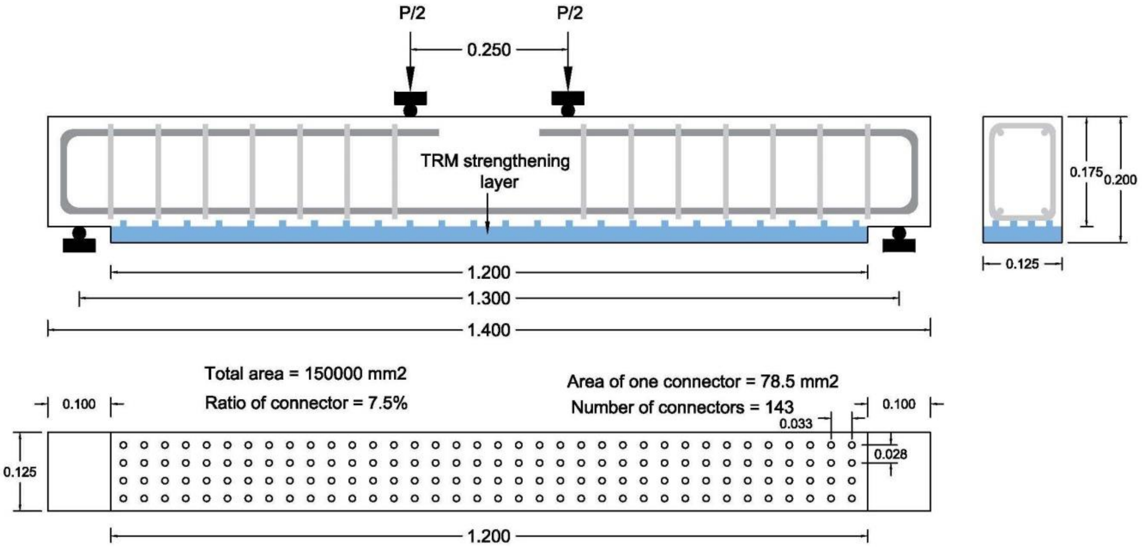

Figure 1. Details of RC beams and the 4 point bending set setup.

The cementitious connectors were employed to improve the mechanical bond between substrate concrete and TRM strengthening layer. This was achieved by drilling 10 mm diameter holes in the cover of the concrete beams before adding the strengthening layer. The connector ratio is determined as the ratio of the area of drilled holes to the total interface area between the substrate concrete and TRM mortar layer. The ratios investigated in this study are presented in Table 3.

Table 3. Details of the investigated RC beams.

Specimen designation	Mortar of TRM	No. of Basalt layers	Connector ratio (%)
CON-1 and 2	--	--	--
8B0-M35-1 & 2	M35	8	0
8B0-M70-1 & 2	M70	8	0
8B0-M135-1 & 2	M135	8	0
8B5-M135-1 & 2	M135	8	5
16B0-M135-1 & 2	M135	16	0
16B5-M135-1 & 2	M135	16	5
16B7.5-M135-1 & 2	M135	16	7.5

3 RESULTS AND DISCUSSION

A plot of vertical midspan deflection versus applied loads is shown in Figure 2. Control beams failed, as expected, in a typical flexural failure mode through yielding of longitudinal steel reinforcement followed by concrete crushing at the top mid-region of the beam. Despite the delamination of the TRM layer in some cases, a considerable enhancement can be observed in the stiffness and load carrying capacity of all the strengthened RC beams with respect to the control beam. In contrast to the control beams, all strengthened beams displayed a steep descending curve beyond the maximum load application. This may be attributed to the basalt fibers reaching ultimate capacity (since the fibers have a brittle tensile response) or slip between the TRM and substrate concrete beam. The beams strengthened with 16 basalt textile layers presented higher stiffness than eight layers counterparts reinforcing the above conclusion.

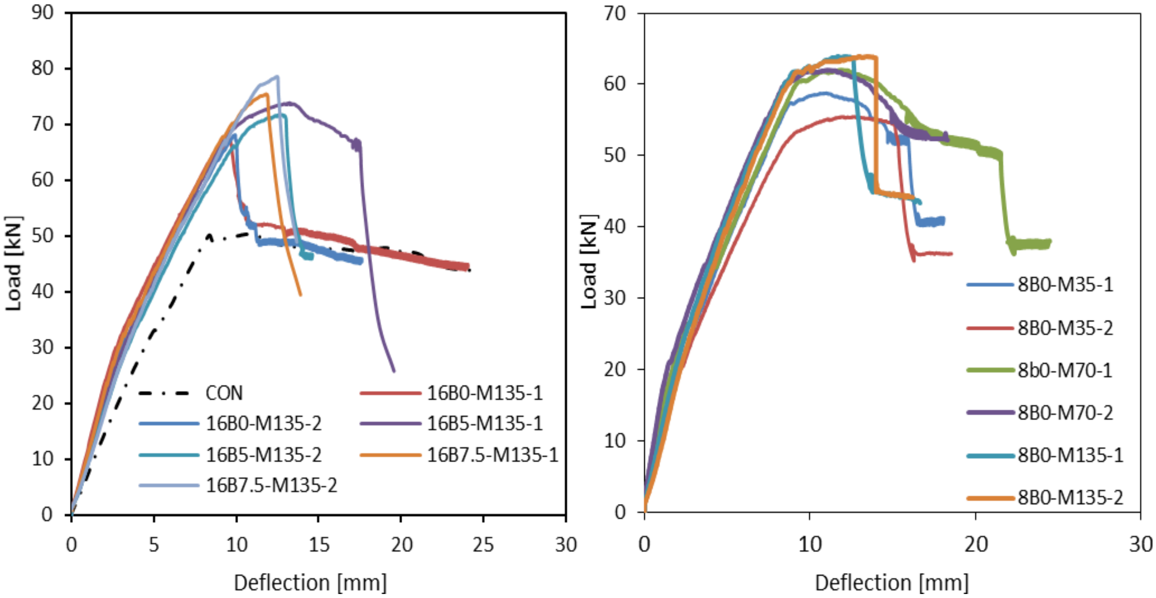

Figure 2. Load deflection curves of the control and strengthened RC beams.

Figure 3 depicts the loads pertinent to the first crack, yielding of steel, and ultimate loads for all the beams. The results of beams 8B0-M35, 8B0-M70 and 8B0-M135 are used to analyze the effect of the strength of TRM layer (without cementitious connectors) on the behavior of strengthened RC beams. An increase in the mortar strength increases the chemical adhesion part of the bond strength hence significantly improves the ultimate load capacity of the beams (Figure 3).

The application of cementitious connectors increased the contribution of TRM strengthening layer in resisting the applied load due to the improved interface bond strength. Three failure modes were observed; rupture of textile fibers followed by concrete crushing of beams strengthened with 8 layers of basalt fibers (Figure 4a), debonding of strengthening layer of beams strengthened with 16 layers of basalt fibers with cementitious ratio of 5% (Figure 4b), and substrate concrete cover separation of beams strengthened with 16 basalt layers and 7.5% connectors ratio (Figure 4c).

The effects of the number of layers of textile mesh on the behavior of strengthened beam can be evaluated by comparing the response of beams 8B0-M135 and 16B0-M135 (without cementitious connectors) and the beams 8B5-M135 and 16B5-M135 (with 5% connector ratio). The increase in the number of basalt layers increases the ultimate capacity of the strengthen beams, and the increase in ultimate load capacity was higher for beams with the cementitious connectors. The increase in capacity of the strengthened beams without connectors can be attributed to the improvement in bond, whereas the improved mechanical interlock due to the presence of cementitious connectors further enhances the load-carrying capacity of the beams with connectors.

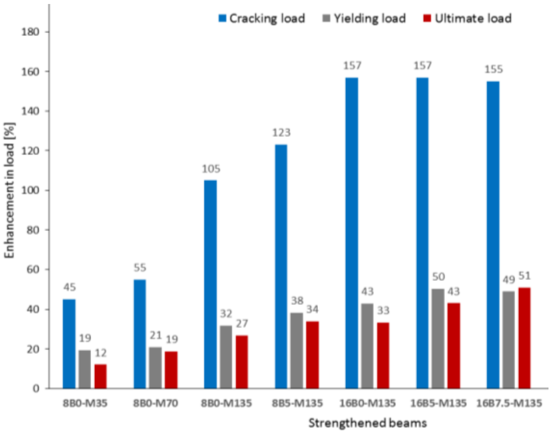

Figure 3. Enhancement in strength of RC beams strengthened with TRM.

Figure 4. Various failure modes observed in RC beams strengthened with TRM.

Beams with 16 basalt layers do not seem to increase the capacity of beams further and demonstrated the failure of substrate concrete cover at higher connector ratios (Figure 4c), meaning that the TRM strengthening of beams should be limited to the capacity of substrate cover concrete. This will become more relevant when the cover concrete is damaged e.g., by the corrosion deterioration of existing members.

4 CONCLUSIONS

The key conclusions drawn from this investigation are as follows:

- The application of cementitious connectors improved the bond strength. The increase in bond strength was sufficient to alter failure mode of the RC beams from bond to flexural failure.
- High strength mortar exhibits higher bond strength than its normal strength mortar counterparts.
- Cementitious connectors consisting of high strength mortar significantly improved the interfacial bond strength between the existing RC concrete member and textile reinforced mortar based strengthening layer. This improvement was sufficient to alter the failure mechanism from brittle failure (of beams without connectors) to the desired ductile flexural failure (of the strengthened RC beams). This improvement is a function of the properties and amount of textile fibers, which will be the subject of further investigation in the future.

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