Reinforced concrete beams strengthened with textile reinforced mortars

Pooja M S[1], Ajith A V[2]

[1]*M.Tech Student, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India*
[2]*Associate Professor, Dept. of Civil Engineering, Sree Narayana Gurukulam College of Engineering, Ernakulam, Kerala, India*

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Abstract - *In the context of renovation and repair work or when buildings are to be adaptively reused, it is necessarily required to strengthen the load-bearing structure. If such renovation work is aimed at adaptive reuse, this can often result in higher loads than permitted by the original design. The dominating technology to strengthen buildings is still steel reinforcement. But, this technology significantly increases the dimension of the structure as well as the load. Nowadays, instead of using ordinary steel reinforcement, researchers are introducing and trying out many methods. Recently, textile reinforcement has been introduction in the construction industry as a viable alternative strengthening material, to circumvent problems associated with FRP. The effectiveness of using textile-reinforced mortar as an innovative technique to improve the shear response of reinforced concrete beams has been investigated. The paper comprised of shear strengthening of shear deficient beams using Carbon and Basalt textile reinforced mortars. Test variables of this study were the matrix type namely cementitious mortar and pozzolanic mortar, wrapping configuration viz. U-wrap and Full-wrap and number of layers of textile reinforced mortar layers.*

***Key Words*: Textile reinforced mortars, Carbon fabric, Basalt fabric, Cementitious mortar, Pozzolanic mortar**

1. INTRODUCTION

Textile Reinforced Mortar (TRM) has recently been introduced in the construction industry as a viable alternative strengthening material, to circumvent problems associated with FRP. They are made of fabric grids and a cementitious agent which serves as a matrix and binder. The cementitious matrix used in TRC system has high thermal capacity and better compatibility with the concrete substrate compared to those of the epoxy resin used in FRP. The use of TRC composites for strengthening and repair of reinforced concrete structures, though relatively recent, is gradually gaining popularity as an alternative to FRP [9]. TRM is a composite material consisting of a matrix with a minimum aggregate size between 1 and 2mm. Textiles are fabric meshes made of long woven, knitted or even unwoven fibre rovings in at least two (typically orthogonal) directions. The quantity and the spacing of rovings in each direction can be controlled independently, thus affecting the mechanical characteristics of the textile and the degree of penetration of the mortar matrix through the mesh openings [14]. It is through this mechanical interlock that an effective composite action of the mortar-grid structure is achieved.

2. EXPERIMENTAL PROGRAMME

2.1 Concrete Mix Proportion

The concrete grade used in the experimental study is M25. The mix design is according to IS 456:2000. The materials used are 53 grade OPC (Ordinary Portland Cement), 20 mm size coarse aggregate and M-sand. Admixture used is Master Glenium Sky 8433. Table-1 shows the mix proportion used in the experimental study.

Table -1: Mix proportion for M25 grade concrete

Mix Proportion	1:1.8694:3.076
Water-cement ratio	0.40
Percentage of admixtures by weight of cement (%)	0.20
Mass of cement per m^3 of concrete (kg)	394.32
Mass of fine aggregate per m^3 of concrete (kg)	1212.97
Mass of coarse aggregate per m^3 of concrete (kg)	737.16
Slump (mm)	120

2.2 Mortar Mix Proportion

The mix proportion of cementitious mortar and pozzolanic mortar are 1:3. A 30% replacement of cement with fly ash is done in pozzolanic mortar.

2.3 Test Specimens and Configurations

A total of 9 shear deficient shear specimens are casted and tested, one among being the control specimen. Rest of the specimens are shear strengthened using Carbon and Basalt fabrics with U-wrap and Full-wrap configurations by varying the mortar used. The cross sectional dimensions of the specimens are 150mm x 200mm with a clear cover of 25mm on all sides of beam. The length of specimen considered is 1000 mm with an effective span of 880 mm.

The percentage of tension reinforcement provided is 2.094% which is a relatively higher value, taken so as to force the occurrence of shear failure in the strengthened beams so that we could study the shear strengthening effectiveness using

TRM. Two numbers of 20 mm diameter bars are provided at the bottom of the beam as tension reinforcement, and two numbers of 10 mm diameter bars are provided at the top of the beam as compression reinforcement. Stirrups of 8 mm diameter are provided at the two support points and at the loading point. The steel bars used are of the grade Fe 500. The detail of beam specimen is shown in Fig -1.

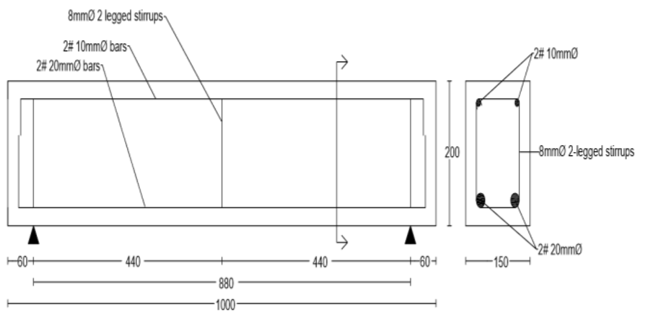

Fig -1: Longitudinal and cross section of beam specimen

The 8 specimens are strengthened using two layers of Carbon and Basalt fabrics by varying the mortar. The wrapping is done in shear region of the shear deficient beams. The shear region is found to be 260 mm which is 110 mm from either side of the beam specimen. Table -2 shows the specification of each of the specimen used in the experimental study. Fig -2 represents the typical longitudinal section of strengthened beam.

Table -2: Specification of Specimens

Specimen notation	Type of wrap	Type of mortar
UW-2C/M	U	Cementitious
FW-2C/M	Full	Cementitious
UW-2B/M	U	Cementitious
FW-2B/M	Full	Cementitious
UW-2C/P	U	Pozzolanic
FW-2C/P	Full	Pozzolanic
UW-2B/P	U	Pozzolanic
FW-2B/P	Full	Pozzolanic

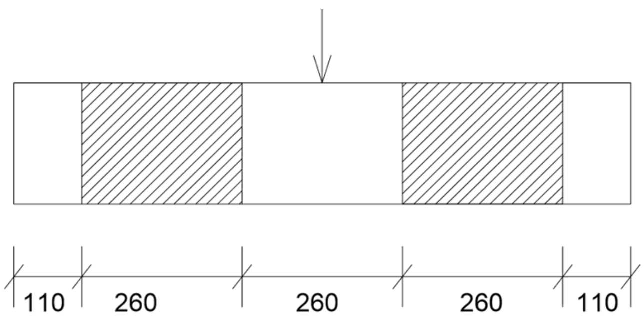

Fig -2: Longitudinal section of strengthened beams

2.4 Specimen Preparation

The beam specimens are casted in steel moulds of size 1000mm x 150mm x 200mm. Reinforcements are placed in the mould with a cover of 25 mm. The concrete is mixed in mechanical mixer and placed in the mould in layers and vibrated thoroughly. The top surface is leveled and finished. From the next day onwards curing was started. After 28 days curing, TRM application was started to all specimens except for the control specimen. Before the application of TRM, the surface was prepared by roughening using chisel. For eight specimens, all the four sides of shear span were roughed and for other eight specimens, three sides of shear span except the compression side were roughed. A layer of mortar of about 2 mm thickness was applied on the prepared surface using trowel. Cementations mortar and Pozzolanic mortar were used for each set of eight specimens. Then the textile was applied on the mortar surface in 0/90º until the mortar protruded out of the perforations between the rovings. The next layer of mortar was applied on the surface for covering the textile fabric. The specimens were wrapped in U-wrap and Full-wrap as per the specification given in Table -2. The procedure was repeated for all other beams. Each layer should be applied only after drying the previous one. Then 14 days curing was done before testing. Fig -3 shows the procedure of specimen preparation.

(a) Mould used for casting beams

(b) Casted concrete beams

(c) Surface preparation

(d) Wrapping of textile fabrics

(e) Application of mortars

Fig -3: Procedure of specimen preparation

2.5 Test Setup

The beam loading test under three-point loading were performed in a Universal Testing Machine (UTM) with 1000 kN capacity. The load was applied at midpoint of the beam specimen at a uniform rate till the ultimate failure. The specimens were arranged with simply supported conditions wih an effective span of 880 mm. Deflection of the beam was measured using a dial guage of least count 0.01 mm at centre of specimen. The experimental test setup is shown in Fig -4.

Fig -4: Experimental test setup

3. RESULTS AND DISCUSSION

The control beam and strengthened beams are tested under three point bending and the results are obtained in terms of the ultimate load and deflection at ultimate load. Also, the failure modes were noted. All the beams showed diagonal shear failure. The failure patterns of control beam, UW-2B/M and UW-2B/P are shown in Fig -5, Fig -6 and Fig -7 respectively. The other strengthened beams also followed a similar shear failure pattern.

Fig -5: Failure pattern of control beam

Fig -6: Failure pattern of UW-2B/M

Fig -7: Failure pattern of UW-2B/P

The summary of test results is tabulated in Table -3 as follows.

Table -3: Test results

Specimen notation	Ultimate load (kN)	Ultimate deflection (mm)
CB	98	3.75
UW-2C/M	122	5.00
FW-2C/M	142	6.00
UW-2B/M	154	5.25
FW-2B/M	162	5.85
UW-2C/P	142	5.50
FW-2C/P	132	4.00
UW-2B/P	140	4.50
FW-2B/P	154	5.50

3.1 Influence of TRM with cementitious mortar

In order to understand the influence of cement mortar on Carbon and Basalt textile fabrics this study is important. The corresponding strengthened beams are tested in UTM to obtain the ultimate load and deflection. Fig -8 shows the load-deflection graph of carbon and basalt strengthened specimens.

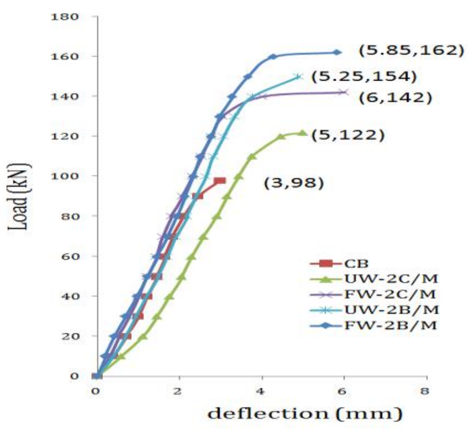

Fig -8: Load-deflection graph for cementitious mortar

All strengthened specimen obtained value greater than control beam. The percentage load carrying capacity for Carbon strengthened beams is up to 44%. But when compared to basalt fabrics, they showed increase up to 65%. As the configuration from U-wrap to Full-wrap the load carrying capacity is improved. Also, the percentage reduction in deformation with respect to control beam is found to be around 60% for both textile fabrics.

3.2 Influence of TRM with pozzolanic mortar

To note the behaviour of Carbon and Basalt textile with modified mortar, this study is conducted. Beams are tested and load-deflection graph is plotted as in Fig -9.

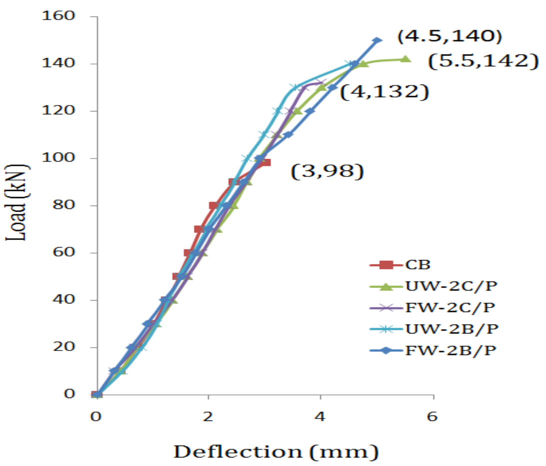

Fig -9: Load-deflection graph for pozzolanic mortar

In this case also, Basalt strengthened specimens obtained a greater value in load carrying capacity compared to carbon specimens. The increase is up to 57%. The ductile property of Basalt fabrics led to its increase in ultimate load. But pozzolanic mortar showed comparatively less improvement in load carrying capacity compared to cementitious mortar.

4. CONCLUSIONS

Major conclusions drawn from this study are as follows.

- Textile reinforced mortar is found to be a promising option for rehabilitating shear deficient members.
- Carbon fabric contributed about 20-50% increase in shear strength whereas, Basalt fabric contributed about 40-70% increase in shear strength when they were bonded to the shear region of shear deficient RC beams.
- Overall improvement of configuration from U-wrap to Full-wrap is between 10 -13%.
- The percentage reduction in deformation is up to 42% for Carbon fabric and up to 63% for Basalt fabric when compared to control specimen.
- All the specimens failed in shear and textile fabric have contributed in arresting the diagonal shear cracks up to a certain extend.

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REFERENCES

[1] A. Si Larbi, R. Contamine, E. Ferrier and P. Hamelin, "Shear strengthening of RC beams with textile reinforced concrete (TRC) plate", Journal of Construction and Building Materials, 24, 1928-1936, 2010.

[2] Blänksvard T., Täljsten B., and Carolin A., "Shear strengthening of concrete structures with the use of mineral based composites", Journal of Composites for Construction, 13, 25-34, 2009.

[3] Bruckner A., R. Ortlepp and M. Curbach, "Anchoring of strengthening for T-beams made of textile reinforced concrete (TRC)", Journal of Materials and Structures, 41,407-418, 2008.

[4] Christian Escrig, Lluis Gil, Ernest Bernat-Maso and Francesc Puigvert, "Experimental and analytical study of reinforced concrete beams shear strengthened with different types of textile-reinforced mortar", Journal of Construction and Building Materials, 83, 248-260, 2015.

[5] E. Tzoura and T. C. Triantafillou, "Shear strengthening of reinforced concrete T-beams under cyclic loading with TRM or FRP jackets", Journal of Materials and Structures,1-12, 2014.

[6] Hashemi, S. and Al-Mahaidi, R., "Investigation of bond strength and flexural behaviour of FRP strengthened RC beams using cement-based adhesives", Australian Journal of Structural Engineering, 11,129-139, 2010.

[7] Isabella Giorgia Colombo, Anna Magri, Giulio Zani, Matteo Colombo and Marco di Prisco, "Erratum to: Textile Reinforced Concrete: experimental investigation on design parameters", Journal of Materials and Structures, 46, 1953-1971, 2013.

[8] Natalie Williams Portal, Karin Lundgren, Holger Wallbaum and Katarina Malaga, "Sustainable Potential of Textile-Reinforced Concrete", Journal of Material in Civil Engineering, ASCE, 27, 1-12,2015.

[9] Oluwafunmilayo Awani, Tamer El-Maaddawy and Najif Ismail, "Fabric-reinforced cementitious matrix: A promising strengthening technique for concrete structures", Journal of Construction and Building Materials, 132, 91-111, 2017.

[10] Raphael Contamine, Angel Junes and Amir Si Larbi, "Tensile and in-plane shear behaviour of textile reinforced concrete: Analysis of new mutiscale reinforcement", Journal of Construction and Building Materials, 51,405-413, 2014.

[11] Rizwan Azam and Khaled Soudki, "FRCM Strengthening of Shear-Critical RC Beams", Journal for Composites for Construction, 18, 1-9, 2015.

[12] Thanasis C. Triantafillou and Catherine G. Papanicolao, "Shear strengthening of reinforced concrete members with textile reinforced mortar (TRM) jackets", Journal of Materials and Structures,39, 93-103,2006.

[13] Viktor Mechtcherine, "Novel cement-based composites for the strengthening and repair of concrete structures", Journal of Construction and Building Materials,41, 365-373, 2013.

[14] Yousef A. Al-Salloum, Hussein M. Elsanadedy, Saleh H. Alsayed and Rizwan A. Iqbal, "Experimental and Numerical Study for the Shear Strengthening of Reinforced Concrete Beams Using Textile-Reinforced Mortar", Journal for Composites for Construction,16,74-90,2014.

[15] Zoi C. Tetta, Lampros N. Koutas and Dionysios A. Bournas, "Textile-reinforced mortar (TRM) versus fiber-reinforced polymers (FRP) in shear strengthening of concrete beams", Journal of Composites, 77, 338-348,2015.

[16] C. Freeda Christy and D. Tensing , "Effect of class-F fly ash as partial replacement with cement and fine aggregate in mortar", Indian Journal of Engineering and Material Sciences, 17, 140 – 144,2010.

BIOGRAPHIES

Pooja M S is a final year student in Structural Engineering and Construction Management, SNGCE, Kochi, Kerala, India.

Ajith A V is currently an associate professor in Civil department, SNGCE, Kochi, Kerala, India.