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Experimental Investigation on Two Way RC Slabs with Textile Reinforced Mortar

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Abstract:

Textile-reinforced mortar (TRM) is a cement-based composite material that consists of high-strength fibers in the form of textiles combined with inorganic matrices, such as cement-based mortars. The application of textile-reinforced mortar (TRM) as a means of increasing the flexural capacity of two-way reinforced concrete (RC) slabs is experimentally investigated in this study. In this paper, the effectiveness of textile-reinforced mortars (TRMs), the strengthening configuration on the basis of different orientation and the role of initial cracking in the slab is to be investigated experimentally. Here, a new type of textile (nylon-based textile) is used as strengthening material. Also Polymer-modified cementitious mortars were used as binding material for the textile sheets. For this purpose three large scale RC slabs were casted and tested under point loading in loading frame equipment. It is concluded that TRM increases the cracking load and hence the flexural capacity of two-way RC slabs, also the strengthening configuration plays an important role in the effectiveness of the technique.

Keywords — ***Textile-reinforced mortar (TRM), Nylon textile, Ultimate load, Initial cracking***

I. INTRODUCTION AND BACKGROUND

Reinforced concrete structures are largely employed in engineering practice in a variety of situations and applications. The main objective of strengthening methods is to achieve sustainability and cost-effectiveness. Using FRP as strengthening material there are some drawback, that is due to the use of epoxy resins. Because it has high cost, inability to apply on wet surfaces, low permeability to water vapour and poor behaviour at high temperatures etc. To overcome these drawbacks, the textile-reinforced mortar (TRM) is used. Textile Reinforced Mortar (TRM) composites are an innovative and particularly promising solution for the repair and strengthening of structures. They comprise high strength textile that is applied to the outer surface of the structural members by a mortar matrix. Textiles are made of either continuous fibres of carbon, glass, basalt and nylon arranged in the form of open meshes. The main characteristics of TRM are low cost, resistance at high temperatures, compatibility with concrete and masonry substrates, ability to apply on wet surfaces, and low temperatures and air permeability. TRM has high strength-to-weight ratio, offer relatively fast and easy installation. The mortars serving as binders and it may (or may not) contain polymeric additives used to improved the strength properties. The effectiveness of TRM reinforcements depends on the accuracy of the installation and on the curing conditions of the mortars. In recent years it is reported that the TRM is an alternative solution to the FRP retrofitting techniques. Also it has been used for strengthening of RC members and seismic retrofitting of masonry-infilled RC frames

A significant research effort has been made in the last few years toward the exploitation of the TRM strengthening technique in several cases of structural retrofitting. Experimental and Numerical Study for the Shear Strengthening of Reinforced Concrete Beams Using Textile-Reinforced Mortar [6] have shown very promising result with textile orientation.

In the last decade, investigate the effect of Textile-reinforced mortar (TRM) versus fibre reinforced polymers (FRP) in flexural strengthening of RC beams [4]. The investigated parameters are the strengthening material, that is TRM and FRP, the number of TRM/FRP layers, the textile surface condition, the textile fibre material (carbon, coated basalt and glass fibres), and the end-anchorage system of the external reinforcement. From this study concluded that TRM was generally inferior to FRP in enhancing the flexural capacity of RC beams with the effectiveness ratio between the two systems varying from 0.46 to 0.80 depending on the parameters examined. The study on use of TRM to strengthen a three-story reinforced concrete frame wall that was filled with masonry [3] showed that the lateral bearing capacity of the frame structure strengthened with TRM increased by approximately 56% and that the deformation at the top of the structure improved by 52% when the ultimate bearing

capacity was reached. Based on the above reviews it is concluded that more research have been done to study the effectiveness of the TRM.
In this paper, three slabs are casted and tested to examine the effectiveness of externally bonded nylon textile-reinforced mortars (TRMs), the strengthening configuration on the basis of different orientation and the role of initial cracking in the slab is to be investigated experimentally.

II. EXPERIMENTAL PROGRAMS

A. Test Specimens and Investigated Parameter

The objective of the present study was to evaluate the performance of TRM in increasing the flexural capacity of two way RC slabs. For this purpose, three RC slabs with a length of 1000 mm and a slab thickness of 100 mm (Fig.1) are fabricated and tested under single point loading in the loading frame equipment. The specimen is square in plan whereas the effective flexural span is 980 mm. The slab is reinforced with deformed steel bars. The deformed steel bars with 8 mm diameter and a spacing of 200 mm is placed in both directions. A clear cover of 20 mm is provided. Alternate main bars are cranked at a distance of 250 mm from the edge. Extra piece reinforcement (consisting of 8-mm-diameter deformed bars) was also placed.

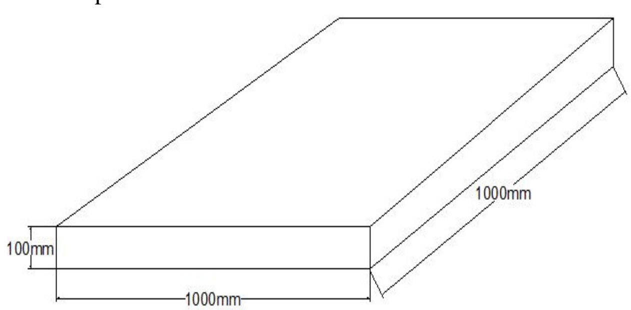


Fig. 1 Geometry of two way slab

The parameter examined is, the strengthening configuration (full coverage versus partial coverage). The description of the specimens as follows:

- CON: Unstrengthened slab which served as control specimen
- C1: Slab strengthened with nylon TRM layer (applied over the full tensile face)
- C2: Slab strengthened with nylon TRM layer (applied in a cross configuration)

All the strengthening schemes were applied on the tensile face region of the slab

B. Material Properties

Various materials are used and its material property test are carried out as per IS specification. The materials that are used in the study are Portland Pozzolana Cement, manufactured sand (M-Sand) of size less than 4.75mm is used as fine aggregate, and the coarse aggregate of size 20mm was used. The average compressive strength is measured on cubes with dimensions of 150 × 150 × 150 mm (average values from three specimens) for the maturity age of 7 days and 28 days are 15.96 N/mm^2 and 24.76 N/mm^2 respectively. The deformed steel bars with 8 mm diameter and Fe 550 grade is used. For casting two way slabs, reinforcement with cranking in both directions is preferred.
Nylon textile (Fig.2) was used as external reinforcement in slabs and it is a uncoated (dry) nylon- fiber rovings in two orthogonal directions and an equal amount of fibers in each one. The Properties of Nylon textile are shown in Table I.
The polymer-modified mortar used as a binding material between the textile and the concrete substrate, resulting in a good workability and plastic consistency. The high polymer contents in mortars reduced the compressive modulus. And also reducing stress on the bond between mortar and weaker substrates. The mortar compressive strength at 28 days is 45N/mm^2 and tensile strength at 7days is 2N/mm^2 respectively.

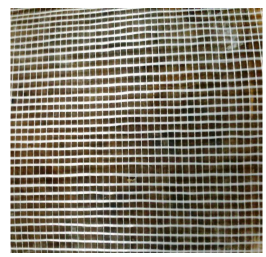


Fig.2 Nylon textile

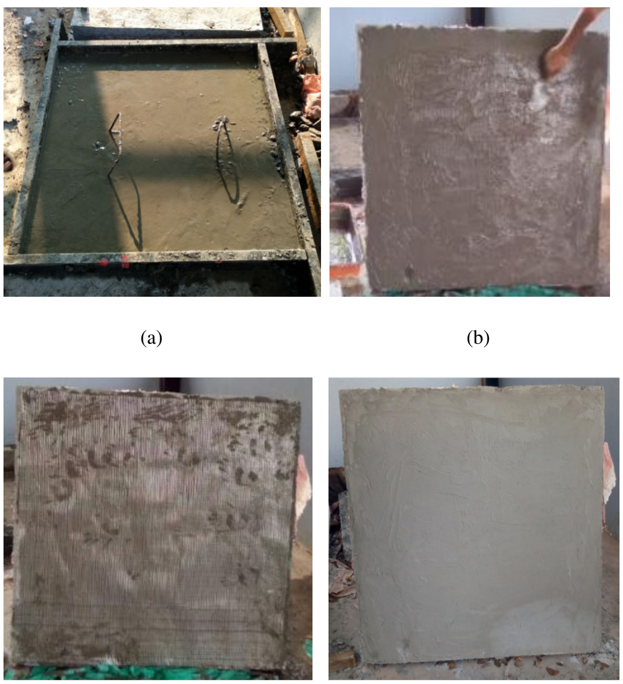
Table I
Properties of Nylon textile

Sl. No	Property	Value
1	Modulus of elasticity (GPa)	2.5
2	Specific gravity	1.14
3	Tensile strength (MPa)	850
4	Tenacity (g/den)	4-6

C. Casting of Specimens and Strengthening Procedure

Steel moulds are used for casting the slabs and reinforcements were tied as per design and placed in the mould. Concrete was mixed and placed in the mould in layers and compacted thoroughly. The top surface was levelled and finished and the same procedure is continued for other slabs also. From the next day onwards curing was started. The remaining two slabs consist of nylon textile fiber provided as external reinforcement arranged in different configurations. Specimen C1 was strengthened with one layer of Nylon textile that is applied over the full tensile face. In specimen C2 consist of two strips of nylon textile is applied on the tensile face of slab in a cross configuration (plus shape). Each strip had a width equal to half of the effective span, resulting in half the amount of fibers per direction of application when compared to specimen C1.So each strip has a width of 490 mm(980/2).The specimen is cured for 28 days and after 28 days of curing strengthening procedure is started.

The strengthening procedure included the following steps: Before the application of TRM the surface is prepared. The surface is roughed by using chisel to receive strengthening. A layer of mortar of about 2 mm thickness is applied on the prepared surface using trowel (Fig.3b). Then the textile was applied on the mortar surface and second layer of mortar was applied on the surface for covering the textile fabric (Fig 3c,3d). Then 14 days curing was done before testing.



(a) (b)

(c) (d)

Fig.3 TRM strengthening application steps of specimen C1: (a) Specimen C1 casted(b) first mortar layer application (c) nylon textile application (d) final finished surface

D. Experimental Setup and Procedure

All specimens were subjected to point loading and were tested as simply supported at their center. The test specimen was laid on rigid steel frame and the effective flexural span in both directions was 980 mm. The load was applied at a displacement rate of 1 mm/ min by using a 200 kN capacity hydraulic jack. For the better observation of the development of cracks all the specimen was white washed. The Linear variable differential transducers (LVDT) were placed at the bottom of the slab to measure the displacement of the test

Fig 4 Test setup of specimen

specimen. The measured displacement will be displayed in the digital indicator and further it is connected to Data Acquisition system. After connecting this, the load is applied and continued until failure. A compression type load cell was used. The Fig.4 shows the test setup of specimen.

E. Experimental Results

The specimen is tested by using loading frame equipment. The responses of the slab is tested and presented in the form of load versus central deflection curves, first crack load and the final crack pattern of slab is also illustrated. Table II also summarizes the main test results: the ultimate load, the mid span deflection corresponding to ultimate load, the observed failure mode and the flexural capacity increase from strengthening.

1) Load – deflection behaviour: The recorded values of load and deflection are used to draw the load Vs deflection curves and the deformation corresponding to each increment of load is noted. The load-deflection curves of all tested slabs are presented in Fig.5 When the load attains maximum, the specimen got crushed due to the load applied by the load cell. The downward movement of the piston type arrangement of the LVDT gives the deflection directly to the system provided along with the loading frame. After attaining maximum load, the valve of the loading frame machine is released and as a result, the load value found decreasing. The changes in the load can be seen in the load Vs deflection graph.

The control slab reached a maximum load of 61.9kN with central deflection of 7.63 mm. The first flexural cracks appeared at a load level of 31.9 kN.

Slab C1, which was strengthened with Nylon TRM layer, failed in a similar way but at a higher load, equal to 70.7 kN, owing to the contribution of the TRM to the flexural resistance. This slab exhibited a stiffer behavior with respect to the control slab and as indicated by the change in the slope of the load-displacement curve in Fig.5. Beyond cracking, a rapid change in the slope of the load deflection curve was observed. The first cracking load was also increased, reaching 46.9kN. The Table II shows the summary of experimental results.

Table II
Summary of experimental results

SI NO	Specimen	Ultimate load Pmax (kN)	Mid span deflection at Pmax (mm)	Failure Mode	Capacity increase (%)	First crack load (kN)
1	CON	61.9	7.63	A	-	31.9
2	C1	70.7	13.02	B	14.2	46.9
3	C2	67.2	17.68	B	8.56	32.7

Note: A- flexural failure; B- slippage and partial rupture of the textile fibers through the mortar followed by flexural failure

Slab C2 which was strengthened with same as that of slab C1 but in a cross configuration and is failed at maximum load of 67.2 kN and the corresponding central deflection obtained is 17.68mm

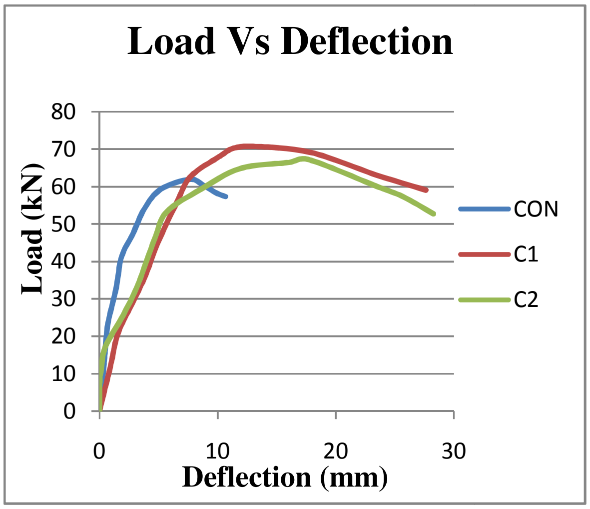


Fig.5 Load Vs Deflection graph

From the above graph, it is clear that for control specimen, the strength is less compared to Specimen C1and C2. The ultimate load and deflection of entire specimen is plotted using a bar chart as shown in Fig.6 and Fig.7

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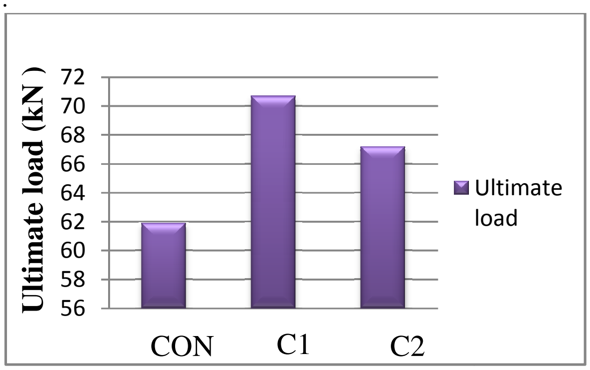


Fig.6 Ultimate load of all specimens

While comparing specimen C1 and C2 the strength of specimen C1 (TRM applied over the full tensile face) was improved and the deflection at maximum load has got reduced (see Fig.6 and Fig.7). Compared to the specimen C2 specimen C1 has a load increment of 5.2%. This means that covering the full face of the slab with a textile layer is more effective than applying two strips in a cross configuration. From Table II it is clear that the load at first crack of slabs strengthened with TRM applied over the full tensile face (C1) and applied in a cross configuration (C2) is higher as compared to load at first crack of control specimen.

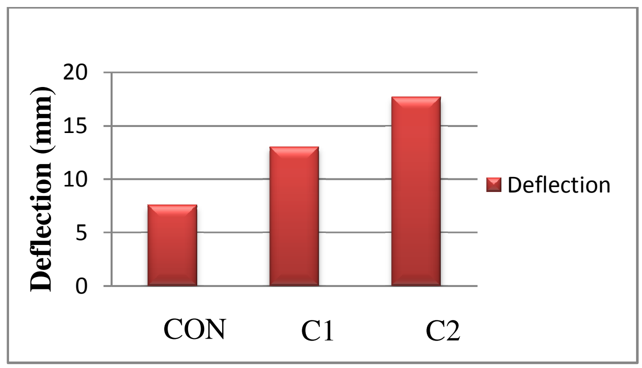
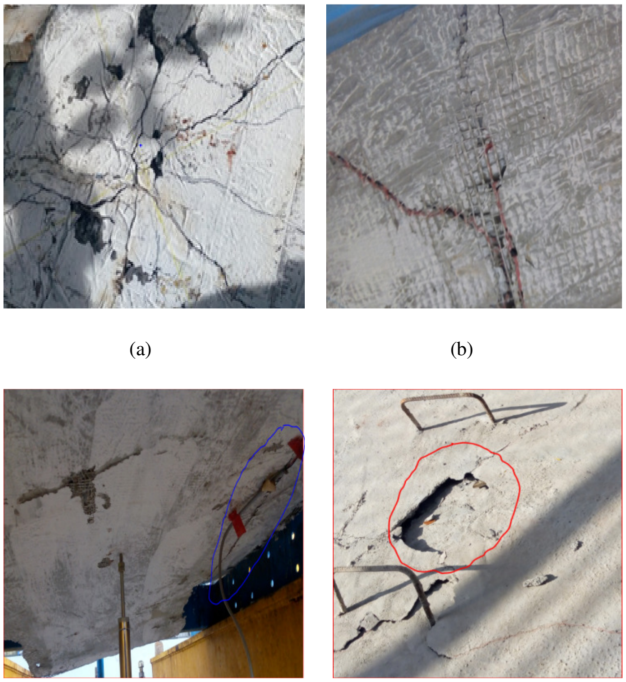


Fig.7 Central deflection of all specimens

*2) **Crack pattern**:* The control slab (CON) failed in flexure after yielding of the steel reinforcement and the development of significant plastic deformations. The failure pattern of control slab at the bottom face is illustrated in Fig.8a.Here the diagonal cracks were generated propagating from the centre of the specimens to the corners and also several major and minor cracks are developed. The corners of the slab were progressively uplifted as a result of the significant twisting moments (Fig.9). After the flexural capacity was reached, the load gradually dropped and a circular shaped crack appeared at the top of the slab as a part of collapse mechanisam (marked red in Fig. 8d).This type of crack is visible in all slabs as a result of moment redistribution at very large displacements.



(a) (b)

(c) (d)

Fig.8 Crack pattern at the face of tested specimens

The specimen C1 comprises a few major cracks and several minor cracks on the face of the TRM. Failure of this specimen was as a result of the fibers partial rupture and slippage within the mortar layer across the major cracks that are visible in Fig.8b

The specimen C2 failed in flexure after yielding of the steel reinforcement and slippage of the textile fibers through the mortar, but in a different crack pattern at the face of TRM as illustrated in Fig.8c.The major cracks were developed on the face of TRM at the overlapping region of the two strips (marked blue in Fig.8c). The fibers crossing these cracks were highly stressed and ultimately experienced partial rupture and slippage within the mortar.

Fig.9 Corner uplift of CON slab

III. DISCUSSION OF RESULTS

Experimental investigations were carried out on the control and Nylon textile reinforced mortar specimens. The flexural capacity of the reinforced concrete slabs was substantially increased by all strengthening schemes proposed in this study. The main parameters investigated in this study was strengthening configuration. An examination of the results in terms of maximum load and the first crack load revealed the following information.

F. Strengthening Configuration

Comparing specimen C2 with specimen C1, it is concluded that covering the full face of the slab is more effective in increasing the flexural capacity than applying two strips in a cross configuration. Both the configuration is equivalent in terms of the total amount of fibers used and the cost also. If only the fibers in the direction of strengthening application are considered, it is concluded that applying the textile reinforcement close to the region of maximum moments is much more effective. The strengthening configuration had a marginal effect on cracking load also. The specimen C1 has higher cracking load compared to specimen C2. The deflection decreases by using TRM applied over the full tensile face of the slab compared to TRM applied in a cross configuration (one per direction).

IV. CONCLUSIONS

This paper presents an experimental investigation on the effectiveness of a nylon textile-reinforced mortar (TRM). And also the strengthening configuration on the basis of different configuration and the role of initial cracking in the slab is to be investigated experimentally. The application of TRM layer increased the flexural capacity of two-way RC slabs. Total of three specimens are casted, one control specimen and other two are strengthened with TRM applied over the tensile face.

A comparison of the results of specimens CON, C1, and C2 shows that the effectiveness of TRM in increasing the flexural capacity of two-way RC slabs was nearly depend on the configuration of textile. From the testing of specimens using loading frame following conclusion were drawn;

- Compared to control specimen the specimen C1 has a load increment of 14.2% and specimen C2 has a load increment of 8.56%
- The configuration of the textile has some effect in the load carrying capacity, when the textile is applied over the full tensile face it gives more load carrying capacity than the other. So the C1 type of strengthening configuration is more effective.

- It is concluded that covering the full face of the slab with a textile layer is more effective in increasing the flexural capacity than applying two strips with half-width in a cross configuration.
- Compared to the other textile like basalt, carbon and glass textile[3],[4]; nylon textile is more efficient in strengthening
- Also from the study it is concluded that nylon textile and polymer modified mortar are more effective and achieve sustainability and cost-effectiveness.

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