Samarra J. Engineering Sci. and Res. , 2024; 2 (3): 94-111

IRAQI Academic Scientific Journals

SAMARRA JOURNAL OF ENGINEERING SCIENCE AND RESEARCH

S.J.E.S.R

Comparison of TRM and FRP in Torsional Strengthening of RC Beams Using Carbon Fibers Under Repeated Loads

Hudhaifa F. Ismael[1*], Saad M. Raoof [1], Muyasser M. Jomaah [1]

[1] Department of Civil Engineering, University of Tikrit, Tikrit_ Iraq

Article Information

Received: 05/06/2024

Accepted: 05/08/2024

Keywords:

TRM, FRP, Carbon fiber, Repeated load, Torsional strengthening.

Corresponding Author

E-mail: **hudhaifa.f.ismael@tu.edu.iq**

Mobile:009647702879615

Abstract

This article investigates the effectiveness of textiles reinforced mortar (TRM) and fiber reinforced polymer (FRP) in torsional enhancing of RC beams subjected to cyclic loads due to the continuous process of loading and unloading, environmental degradation, ageing, and lack of maintenance, rustled to structural deficiencies may occur in several infrastructures such as multi-story parking garages, ports, bridges, and airport facilities. The factors that were taken into consideration were the kind of strengthening techniques (TRM vs. FRP), the configuration of the strengthening (partially vs. entirely), and the inclination of the strengthening (45° vs. 90°). Seven full-scale specimens were cast and tested until they failed. There was one specimen that served as a reference, three that were reinforced with TRM and three that were reinforced with FRP. The main findings were as follows: (a) Both TRM and FRP composites enhanced torsional capacity to a comparable extent. (b) In both systems, partially strengthening configurations increased torsional capacity more than fully strengthening configurations. (c) In both techniques, the 90° strengthening inclination improved torsional capacity more than the 45° strengthening inclination. (d) Specimens enhanced with TRM and FRP failed in several ways, such as fibers slipping through mortar, fiber rupture with concrete crushing, and deboning from the concrete substrate.

Introduction

The RC beams in multi-story parking garages, ports, bridges and airport facilities may be subjected to repeated loads. Due to the continuous process of loading and unloading, environmental degradation, ageing, and lack of maintenance, rustled to structurally deficiencies may occur Therefore, strengthening is considered an important issue in overcoming these challenges [1].

In last years, FRP has demonstrated high superiority in external strengthening for RC torsion in comparison to other methods due to low weight, flexibility of application, corrosion resistance and high strength and stiffens. On the other hand, FRP had several drawbacks recorded in [2-4]. It is worth noting, all these drawbacks are associated to use an organic matrix (epoxy resin) [5-7].

In order to address these issues, a new kind of material called Textile-Reinforced Mortar (TRM) has been created. This composite consists of textile fibres that have been impregnated with an inorganic substance, such as modified cement mortar, which acts as a bonding agent to separate it from the concrete substrate [8, 9]. The advantages of this composite material are recorded in [10-12].

Several studies in the last decades have concerned with use of FRP in torsional enhancing for RC subjected to monotonic loads [13-18]. On the other hand, only one study used FRP for torsional enhancing of RC beams subjected to repeated loads (7 cycles of 60% of the peak load of the reference beam) by Tais and Abdulrahman (2023) [18]. Eight specimens were casted and strengthened by CFRP strips for different configuration 45°; one strip fully wrapped; double strip fully wrapped; and spiral strip around the sample. The main conclusions of this study were: (a) The double strip fully wrapped showed higher enhancement in torsional capacity for both monotonic and repeated loads; (b) The behavior of the specimens was identical under monotonic and repeated loads. And, (c) The torsional capacity reduced due to loading and unloading under repeated loads compared with monotonic loads [18].

The survey in the literature demonstrated that the only studies on the use of TRM for torsional strengthening under monotonic load are limited. these studies were conducted by Alabdulhady et. al. (2017) and Al-Abdulhadi and Sneed (2018)[3, 19]. In particular, the study conducted in [19] examined the torsional characteristics of rectangular beams that were strengthened using PBO-TRM. Five beams were created, strengthened, and subjected to torsional testing under a monotonic load. The parameter under consideration was the configuration of strengthening (i.e. fully and partially). The fully configuration exhibited a greater enhancement in torsional capacity compared to the partially configuration. In addition, Al-Abdulhadi and Sneed (2018) investigated the effect of different strengthening orientations (90° and 45°), strengthening configurations (fully and partially), and the number of strengthening layers (one and two) on torsional strength. PBO-TRM was used to strengthen ten rectangular RC beams. They concluded that the 90° enhancing inclination was better than the 45° enhancing inclination, and increasing the layers number significantly improved the torsional ability [3].

It is clear that the available literature does not cover adequately the subject of strengthening of RC beams in torsion under repeated loads using TRM did not covered yet. In particular, the effectiveness of TRM versus FRP in torsional strengthening due to the significance of repeated loading as they apply to numerous loading scenarios in practice, including the passage of vehicles on bridges, offshore loading, pedestrian loads, machine loads, and seismic loading. Therefore, the current study, provides for the first-time a comprehensive comparison of TRM versus FRP for strengthening of full-scale RC beams in torsional by carbon fibers under repeated loads. Taking into account variety of variables, namely; (a) strengthening configurations (fully & partially) and (b) strengthening inclination (90° & 45°).

Experimental program

2.1. Test specimens and examined factors

The main purpose of this research is to evaluate the performance of textiles reinforced mortar versus fiber-reinforced polymer when subjected to cyclic loads using full-size reinforced concrete beams. In order to achieve this purpose, seven beams were reinforced after casting to a cross section of 150 * 200 mm with an actual length of 2200 mm and a total length of 3000 mm as shown in Figure 1. 0.4% transverse reinforcement was used while the longitudinal reinforcement ratio was 1.52%, the beams were designed according to the ACI 318 code [20], where:

A_{sl}: Area of longitudinal bars ($\rho_{sl} = A_{sl}/A_c$)

$A_{c:}$ area of concrete ($A_c = b \times h$)

A_{st}: area of one stirrup ($\rho_{st} = \frac{Ast}{Ac}\frac{pt}{s}$)

$p_{t:}$ perimeter of stirrup

S: spacing between stirrups (center-to-center).

RC beam dimensions and details are in (Fig. 1).

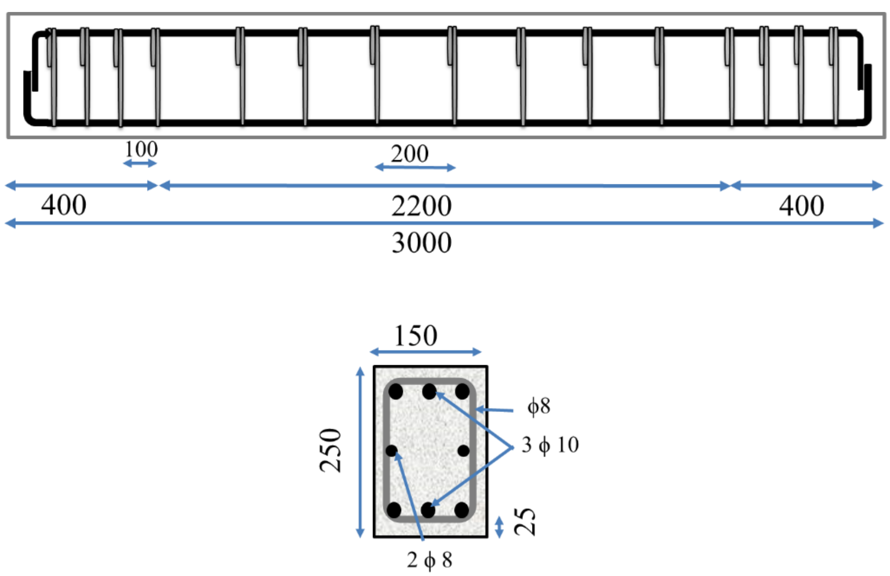


Fig. 1: Dimensions of beam arrangement and reinforcement (mm)

In order to prevent local failure due to stress concentration in the clamp region, the transverse reinforcement ratio was increased to 0.8% as shown in Figure 1. For the closed stirrups, 8 mm diameter reinforcement was used, while 10 and 8 mm diameter reinforcement were used for the longitudinal reinforcement. (See Fig. 1). A tensile test was conducted to evaluate the mechanical properties in accordance with [21]. The results of the test are presented in Table 1.

Table 1. Tensile properties of steel reinforcement

Material	**Steel reinforcement**	
	8 (mm)	**10 (mm)**
Yield strength, (MPa)	432	525
Ultimate strength, (MPa)	551	618

The investigated variables were: (a) strengthening system (TRM vs. FRP), (b) strengthening shape (partial or full) and (c) strengthening inclination (45° and 90°).

The strengthening beams were named X_{θ}-C-Z-T where X: type of strengthening technique (TRM or FRP), θ: strengthening inclination (θ = 45° or 90°) perpendicular to the longitudinal axis of the beam, C: type of fiber material (dry carbon), Z: strengthening shape (P partial and F full) and T: type of loading (M for monotonic and R for repeated).

Six specimens were enhanced as shown in Fig. 2. The remaining specimen was used as a reference specimen, and all specimens were strengthened in the shape of the U as a casing surrounding the beam from three sides only (U-jacket) (Fig. 2) because in most real applications, beams and slabs are cast monolithic (T), so the closed side is not available for strengthening.

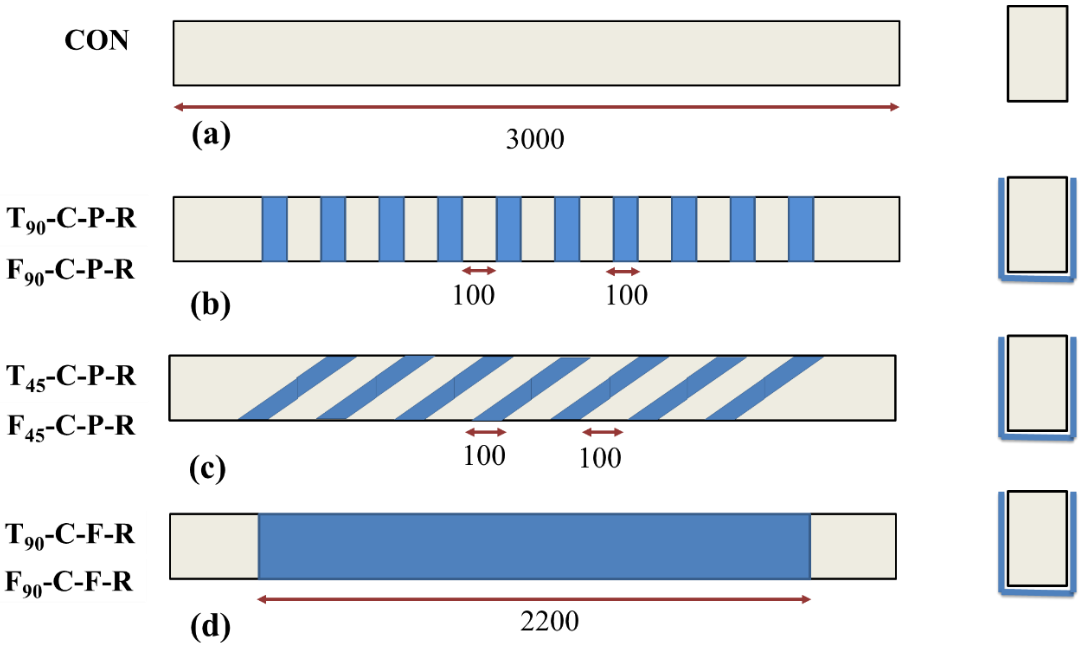


Fig. 2: Groups of samples

2.2. Materials properties

The concrete compressive and splitting tensile strength were measured using average results of three cylinders with dimensions of 150 × 300 mm. The test was performed on the testing day, following the guidelines set by ASTM C39&C496 [22, 23]. The modulus of rupture was also evaluated using prisms with dimensions of (100 × 100 × 500 mm) according to ASTM C78 [24]. The mechanical properties of the concrete are listed in Table 2.

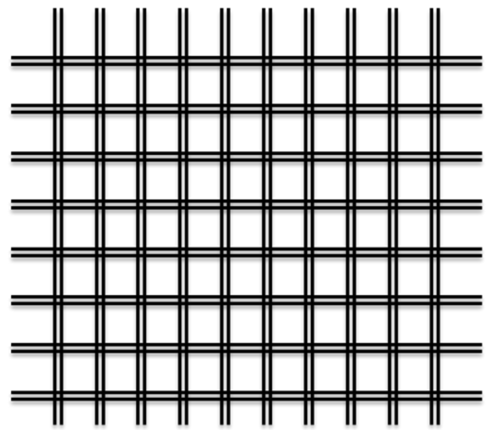
Table 2. Measured concrete properties.

Material	Concrete
Compressive strength, (MPa)	25
Splitting tensile strength, (MPa)	2.34
Modulus of rupture, (MPa)	3.24

A dry carbon-fiber textile (C) was used for strengthening. The textile weight, mesh size, and thickness are listed in Table 3.

Table 3. Details of the textiles according to the manufacturer datasheets

Dry carbon textile	
Thickness(mm)	0.095
Weight (g/m²)	170
Mesh size (mm)	10*10
Density (gm/cm³)	1.75
Tensile strength (Mpa)	4800
Elastic Modulus (Mpa)	>240
PTFE content (%)	-



A uniaxial tensile test was performed on TRM coupons to evaluate mechanical characteristics of the composite. Fig. 3a shows the coupon's geometric properties, whereas Fig. 3b illustrates the setup process, and Fig. 3c shows the coupon failure mode. The value of ultimate stress (f_{fu}) was 3150 Mpa of TRM coupons (average of three specimens).

The TRM binding material was an inorganic modified cement mortar with a water-to-cement ratio of 0.17:1. According to ASTM C39 and C496 standards,[22, 25]. its mean compressive strength was 40 MPa, and its mean tensile strength was 3.6 MPa. For FRP strengthening, a commercial epoxy resin was used, mixed at a 4:1 ratio.

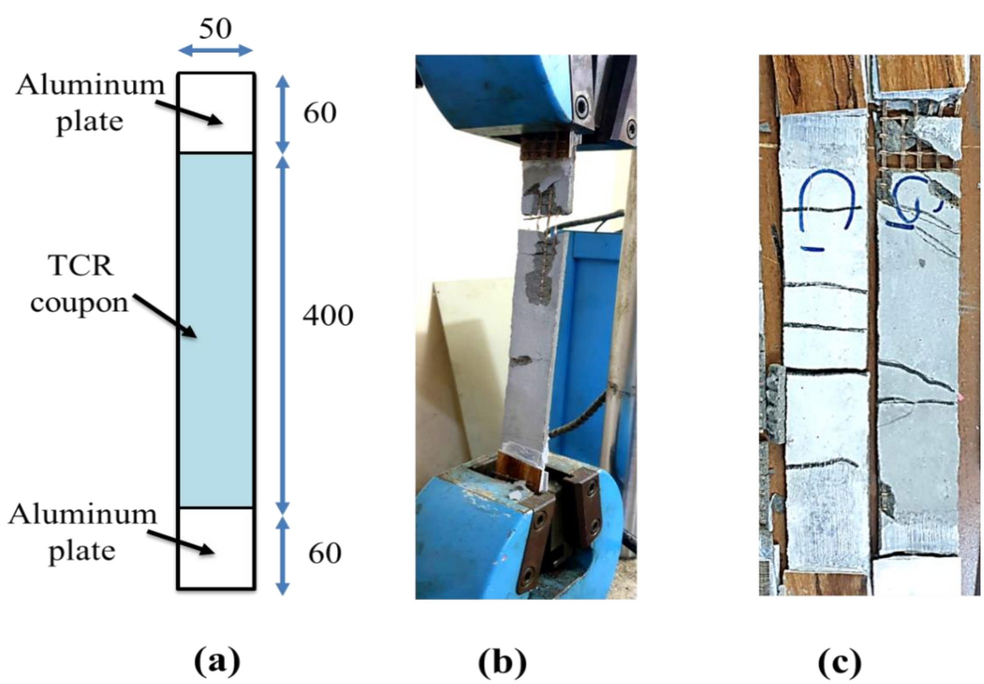


Fig. 3: (a) TRM coupon geometry (millimeter dimensions) (b) test arrangements (c) textile coupon failure mode

2.3. Strengthening procedure

The strengthening system (TRM or FRP) was applied externally according to the strengthening configuration (Fig. 2). Both strengthening techniques followed the steps described below:

- Using a grinding machine and with a depth of 3 mm, a grid of grooves with dimensions of 100*100 mm was made, after which the concrete was cleaned using compressed air (Fig. 4a).
- TRM application is accomplished in three steps: (a) the concrete surface is wetted with water, (b) a layer of mortar is applied to the concrete surface (Figure 4b), and (c) to ensure good impregnation of the fabric with cement, the fabric is pressed into the mortar by hand (Figure 4c).
- For the GFR reinforced beams, a plastic roller over a thin layer of resin was used to impregnate the textile fibers (Fig. 4d).

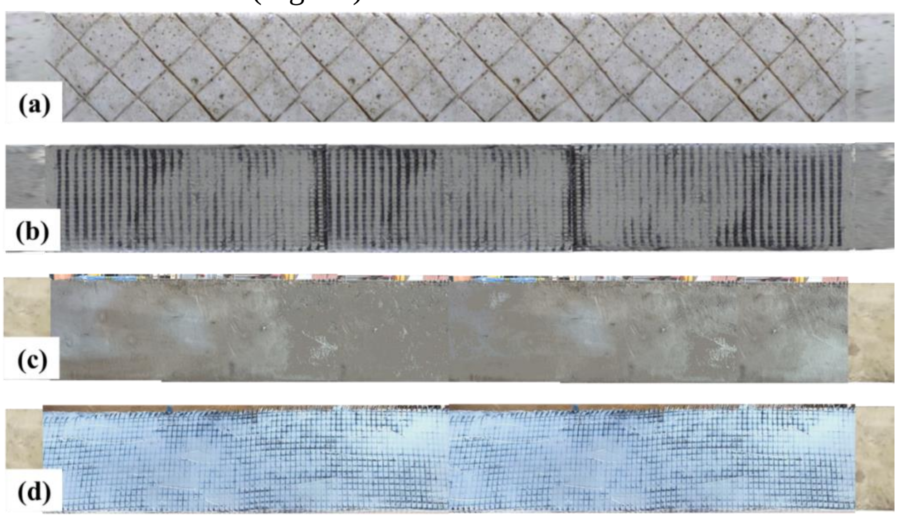


Fig.:4 illustrates the process of strengthening, which involves two steps: (a) preparing the surface and (b) applying TRM. (c) The ultimate surface of TRM specimens. (d) The ultimate surface of FRP reinforced specimens.

2.4. Test setup

The test setup is shown in (Fig. 5a & b). In previous works [3, 26], a loading arm that was 700 mm eccentric with regard to the centroid of the cross-section was used to apply torque to the specimens using a hydraulic jack that had a 500 kN capability. Sixty percent of the control specimen's experimental ultimate load was applied as part of the loading process. Based on the American Society of Highway and Transportation Engineers' 2012 requirements, the load was about the same as the highest expected loads that beam specimens may sustain in bridge engineering applications during the service stage [27]. After seven cycles of this recurrent load, the specimen was subjected to an increase in twist until it failed completely. In order to determine the angle of rotation, a linear displacement transducer (LVDT) was fastened to the loading arm's side at a point 150 mm from the beam's longitudinal axis (see Fig. 5c).

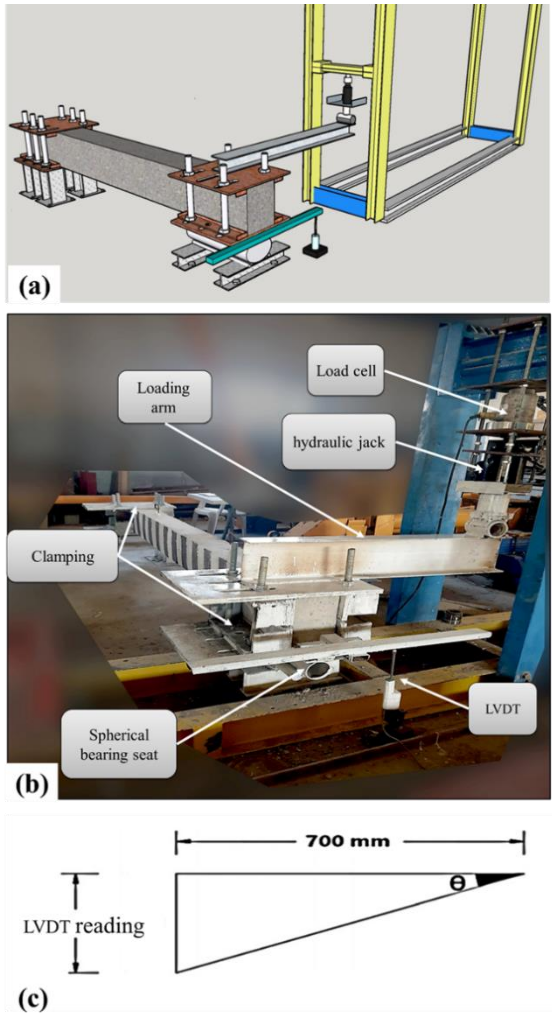


Fig. 5: The test setup consists of three parts: (a) a high-level 3D image (b) information on the instruments, and (c) readings of the LVDT angles of twist

Experimental results

(1) The table contains the cracking torque (Tcr).

(2) The percentage of the enhanced cracking torque in the reinforced specimens relative to the control.

(3) The angle of twist at which cracking occurs, known as the cracking angle of twist (θcr).

(4) The maximum torque (Tu). The percentage of increase in final torque is 5.

(5) The maximum angle of rotation (θu) that corresponds to the maximum torque.

(6) The augmentation of the maximum angle of torsion in relation to the control sample and (7) the manner of failure.

Table 5. Summary of test results

Specimens name	**T_{cr} (kN.m) (1)**	**increase in cracking torque (%) (2)**	**θ_{cr} (deg./m) (3)**	**T_u (kN.m) (4)**	**increase in ultimate torque (%) (5)**	**θ_u (deg./m) (6)**	**$\theta_u/\theta_{u,con}$ (7)**	**Failure mode * (8)**
CON-M[1]	5.6	-	3.05	7.42	-	7.9	-	CC
CON-R	4.97	0.88	1.99	6.70	0.9	4.86	0.62	CC
TRM-retrofitted								
T_{90}-C-F-R	6.65	34	2.79	9.1	36	7.59	1.56	SR
T_{90}-C-P-R	7	41	2.3	12.6	88	6.36	1.31	RC
T_{45}-C-P-R	7.7	55	2.29	11.85	77	7.8	1.60	RC
FRP- retrofitted								
F_{90}-C-F-R	9.1	83	2	9.8	46	4.19	0.86	R
F_{90}-C-P-R	8.26	66	2.8	10.8	61	7.32	1.51	DR
F_{45}-C-P-R	7.7	55	2.48	10.01	49	4.95	1.02	RC

* CC: Concrete crushing; SR: slippage and partial rupture of the fibres through the mortar; RC: fiber rupture accompanied by concrete crushing; DR: deboned from the concrete substrate with rapture of fibers.
[1] Specimen included in “TRM verses FRP in Torsional Strengthening of RC Beams “submitted as a journal paper to Composites Part C: Open Access”.

Torque-twist response

The loading level for each cycle was 60% of T_u of the corresponding specimen tested under monotonic load (Fig. 6). Since it was difficult to record all torque information, such as the angles of twist, first cracks, and torque during the completely repeated loading if applied several huge loops. Therefore, seven loops were adopted to control the record of data from loading. After there, the load increased until failure.

The torque-twist response for all experimental specimens under repeated loads is presented in Fig. 7. In general, torque-twist relationship all of specimens was identical comprising three stages: The first stage was un-cracked stage. The second stage: development of cracks until yielding the steel reinforcement, and the third stage: post-yielding response up to failure.

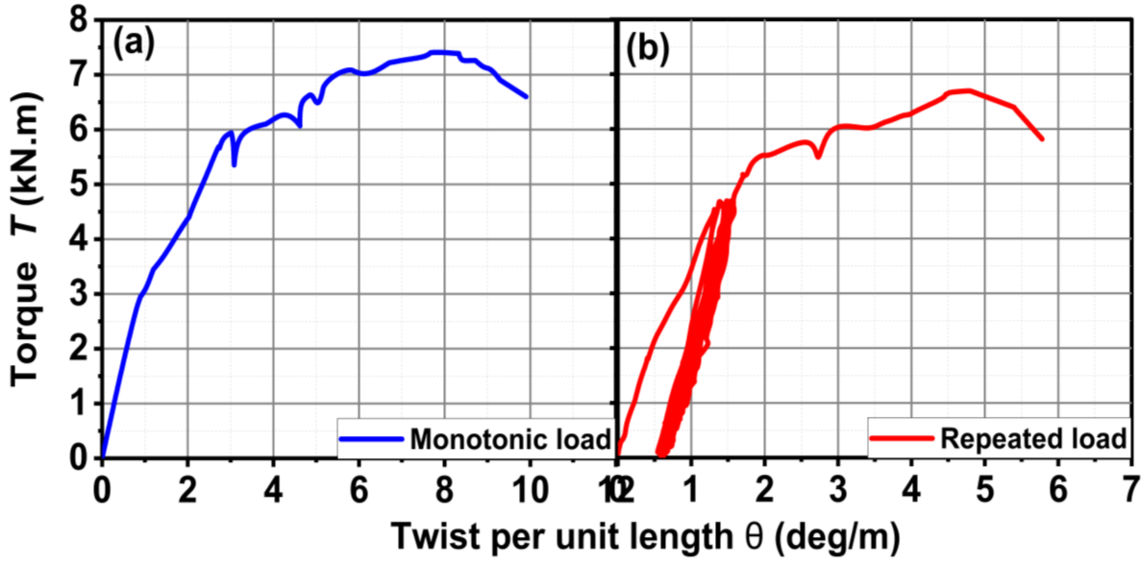


Fig. 6: torque T-twist θ responses of control specimens (a) monotonic load (b) repeated load

At the beginning of loading, the torque-twist curve was nearly linear, with a relatively high stiffness until first crack occur (first stage). After cracking, the behavior continued to be approximately linear, with relatively lower stiffness than un-cracking stage. This was attributed to the transfer of stresses from the concrete to the steel reinforcement. At this stage, the composite materials (TRM & FRP) were activated and increased the beam torsional resistance (second stage). Before reaching the ultimate capacity, the behavior became nonlinear with significant drop in the stiffness. Finally, the loading was terminated when the specimen capacity significantly dropped down (the beam demonstrated noticeable increase in the twist angle without any corresponding increase in the torque).

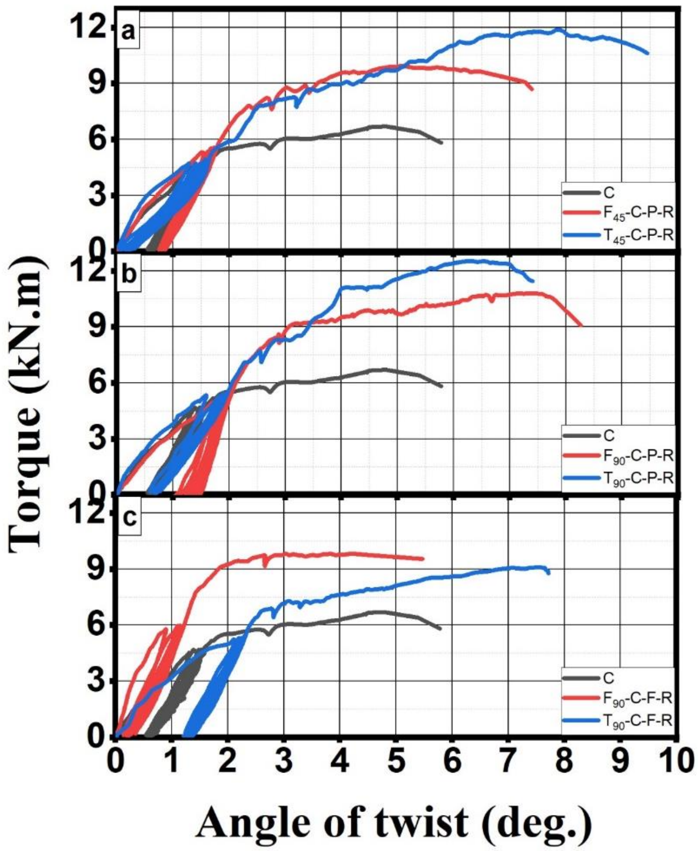


Fig. 7: torque T-twist θ responses of test specimen

Table (6) presents the values of stiffness at the pre-cracking and cracking stages. The torsional stiffness was calculated according to [28].

Table 6. Comparison of stiffness at pre-cracking and post cracking stage

Specimens name	**Stiffness (kN.m/deg)**	
	Pre-cracking	**Post-cracking**
CON-R	2.50	0.60
TRM-retrofitted		
T_{90}-C-F-R	2.38	0.51
T_{90}-C-P-R	3.04	1.38
T_{45}-C-P-R	3.36	0.75
FRP-retrofitted		
F_{90}-C-F-R	4.55	0.32
F_{90}-C-P-R	2.95	0.56
F_{45}-C-P-R	3.10	0.94

Ultimate torque

The values of peak torque of all tested specimens under repeated loads are listed in Table 5. The ultimate torque of reference specimen (T_u) was 6.7 kN.m while the corresponding angle of twist (θ_u) was 4.86 deg/m.

All TRM-strengthened specimens failed in torsion at loads more than the reference beam (Table 5). The maximum torque obtained for the specimens T_{90}-C-F-R, T_{90}-C-P-R and T_{45}-C-P-R was 9.1, 12.6 and 11.85 kN.m. Hence, the enhancement of various TRM strengthening configuration in increasing the torsional capacity was 36%, 88%, 77%, respectively.

On the other hand, for FRP strengthened specimens. The maximum torque recorded for specimens F_{90}-C-F-R, F_{90}-C-P-R, and F_{45}-C-P-R was 9.8, 10.8, and 10 kN.m, therefore, the recorded increase in the torsional capacity was 46%, 61%, 49% respectively.

Failure modes

The failure modes observed for all tested beams are shown in Figs. 8&9. The control beams demonstrated typical RC torsional behavior, with continuous helical diagonal cracks with a main angle of twist approximately 45° w.r.t the axis of rotation (Fig. 8a_1, a_2). Failure was controlled by crushing the concrete strut in one-third of the tested zone after steel yielding of the stirrups (Fig. 8a_1, a_2).

Depending on the strengthening configuration and materials, TRM-strengthened specimens (Fig. 8) failed in several different modes:

- The failure mode of specimen T_{90}-C-F-R was due to forming of continuous helical diagonal cracks, due to the loss of the effectiveness of TRM composite leading to slippage and partial rupture of fibers through the cement mortar (Fig. 8b).
- Specimens T_{90}-C-P-R & T_{45}-C-P-R demonstrated continuous helical diagonal cracks in mid-span of beam and finally the specimens failed due to partially rupture of fiber followed by concrete crushing between struts (Fig. 8 (c & d)).

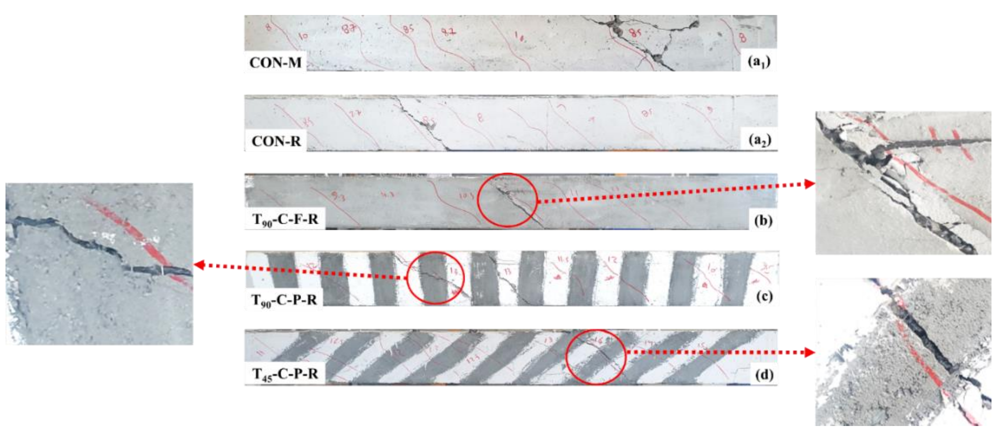


Fig. 8: Failure mode of TRM Strengthened specimens.

For FRP-strengthened specimens, different distinct failure modes were noticed as illustrated in Fig. 9a-c below:

- Specimen F_{90}-C-F-R failed due to the rupture of the fibers at their tensile face. (Fig. 9a).
- The specimen F_{90}-C-P-R failed due to debonding of the FRP composite from the concrete surface accompanied with rupture of fibers and crushing between struts (Fig. 9b).
- The Specimen F_{45}-C-P-R, failed due to the combination of concrete crushing and rupture of fibers (Fig. 9c).

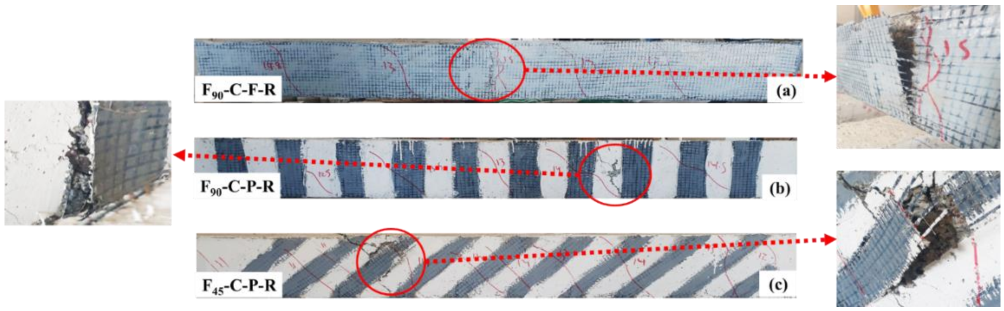


Fig. 9: Failure mode of FRP Strengthened specimen

Discussion

TRM vs FRP effectiveness

Table 7 present the effectiveness factor (*k*) of TRM versus FRP. This factor was defined as the ratio of the ultimate torque of TRM strengthened specimens to the ultimate torque of the counterpart FRP strengthened specimens. This factor varied from 0.93 to 1.18 depending on the examined variables.

In specific, the effectiveness factor for specimens T_{90}-C-F-R was 0.93. This could be attributed to the failure mode which was premature slippage of the fiber through the mortar compared to the counterpart FRP strengthened specimens that failure due to fiber rupture, hence fully utilized of fiber strength was achieved.

Specimens T_{90}-C-P-R and T_{45}-C-P-R had an effectiveness factor of 1.17 and 1.18, respectively. This disparity could be attributed to the failure mode which was debonding of the FRP composite from the concrete surface and concrete crushing between struts in counterpart specimens (F_{90}-C-P-R and F_{45}-C-P-R) respectively. (Fig. 8c&d and Fig. 9b&c) (Fig. 10) illustrates the torsional capacity increase of TRM versus FRP.

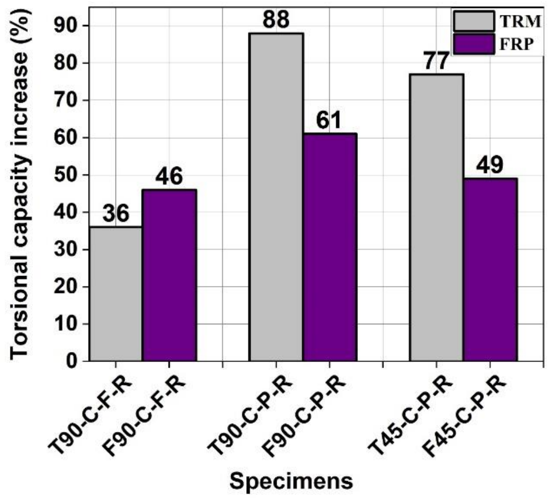


Fig. 10: Comparison of TRM vs FRP system

Strengthening configurations

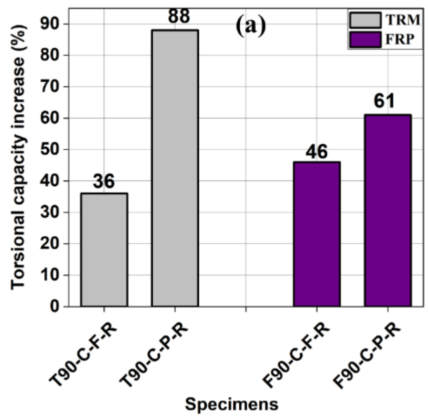
In general, the partially configuration specimens showed higher torsional capacity compared to the corresponding fully strengthened specimens (Fig. 11a). Specifically, for TRM-strengthened specimens T_{90}-C-P-R recorded higher torsional enhancement of 1.38 times than specimen T_{90}-C-F-R, respectively. the lower contribution of fully configuration-strengthened specimens could be attributed to abrupt jacket debonding accompanied by slippage of fibers due to repeated load (Fig. 8c&b).

Similarly, for FRP-strengthened specimens (Fig. 11a). F_{90}-C-P-R recorded higher torsional enhancement of 1.10 times than specimens F_{90}-C-F-R, respectively. the reason for less effectiveness for fully configuration strengthened specimens was related to the final failure mode, which was premature depending of the FRP composite from the concrete substrate due to repeated loads accompanied by rupture of fibers (Fig. 9b&a).

Strengthening orientations

As shown in Fig. 2, two strengthening orientations (45°& 90°) were adopted. As shown in Fig.11b, for TRM-strengthened specimens, the 90° strengthening orientation was more effective in increasing the torsional capacity than the 45° strengthening orientation. In specific, specimen T_{90}-C-P-R showed higher effectiveness of 1.06 times than T_{45}-C-P-R. Similarly, for FRP-strengthened specimens, the specimens F_{90}-C-P-R showed enhancement of 1.08 times than specimens F_{45}-C-P-R.

The identical failure mode observed for strengthening orientation specimens which is related to the rupture of fibers and concrete crushing as shown in (Fig. 8c&d and, Fig. 9b&c). Repeated loads resulted in premature failure for 45° orientation strengthening compared to 90° orientation strengthening, hence reduced the torsional capacity in the 45° strengthening orientation.



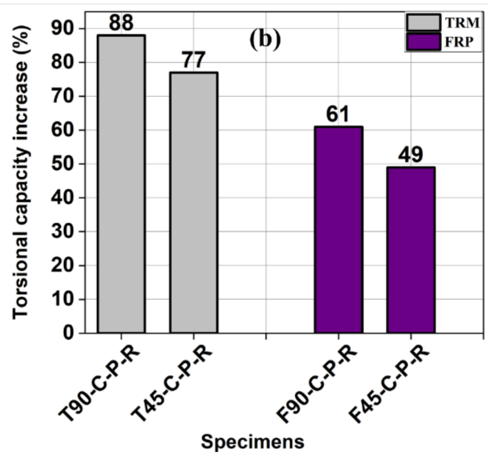


Fig. 11: (a) Influence of strengthening configurations on torsional capacity ;(b) influence of strengthening orientation on the torsional capacity.

Conclusions

This study experimentally evaluated the performance of TRM and FRP composites for torsional strengthening of RC beams subjected to repeated loads. Several factors were examined, including: (a) the type of reinforcement material (TRM vs. FRP), (b) the configurations of the strengthening, and (c) the orientation of the strengthening. The results led to the following conclusions:

- TRM composite had approximately the same effectiveness compared to FRP composites in increasing the torsional capacity. However, the effectiveness varied depending on the investigated parameters.
- The partially strengthening configurations was more effective in increasing the torsional capacity than the fully strengthening configurations in both strengthening systems (TRM & FRP), and the specimen F_{90}-C-P-R achieved higher torsional enhancement of 88 % compared to reference specimen.

- The 90° strengthening orientation was more effective in enhancing the torsional capacity than the 45° strengthening orientation in both strengthening system (TRM & FRP).
- For TRM- strengthened specimens, different failure modes were noted namely: slippage of the fibers through the mortar with partial rupture (T_{90}-C-F-R), fiber rupture accompanied by concrete crushing (T_{90}-C-P-R and T_{45}-C-P-R,), Similarly, for FRP-strengthened specimens the observed failure mode were: fiber rupture (F_{90}-C-F-R), concrete crushing accompanied by fiber rupture (F_{45}-C-P-R), and deboning from the concrete substrate with concrete crushing (F_{90}-C-P-R).

Recommendations for Future Studies

- Investigate the long-term behavior of TRM and FRP systems in diverse environmental conditions, including exposure to extreme temperatures, humidity, freeze-thaw cycles, and chemical environments.
- Develop models to predict the lifespan and performance of these systems (TRM and FRP) under cyclic loading conditions.
- Investigate the interfacial bond behavior between the RC beam and the strengthening materials under different loading and environmental conditions.
- Evaluate the environmental impact and sustainability of TRM and FRP systems, considering the entire lifecycle from material production to disposal.

References

1. Mahdi, H.M. and R.M. Abbas, *Effect of openings on the torsional behavior of SCC box beams under monotonic and repeated loading.* Civil Engineering Journal, 2023. **9**(09).
2. Raoof, S.M., L.N. Koutas, and D.A. Bournas, *Bond between textile-reinforced mortar (TRM) and concrete substrates: Experimental investigation.* Composites Part B: Engineering, 2016. **98**: p. 350-361.
3. Alabdulhady, M.Y. and L.H. Sneed, *A study of the effect of fiber orientation on the torsional behavior of RC beams strengthened with PBO-FRCM composite.* Construction and Building Materials, 2018. **166**: p. 839-854.
4. Siddika, A., et al., *Performances, challenges and opportunities in strengthening reinforced concrete structures by using FRPs–A state-of-the-art review.* Engineering Failure Analysis, 2020. **111**: p. 104480.
5. Ombres, L., *Structural performances of reinforced concrete beams strengthened in shear with a cement based fiber composite material.* Composite Structures, 2015. **122**: p. 316-329.

6. Sneed, L.H., et al., *Flexural behavior of RC beams strengthened with steel-FRCM composite.* Engineering Structures, 2016. **127**: p. 686-699.
7. Elsanadedy, H.M., et al., *Organic versus inorganic matrix composites for bond-critical strengthening applications of RC structures–State-of-the-art review.* Composites Part B: Engineering, 2019. **174**: p. 106947.
8. Bournas, D.A., et al., *Textile-reinforced mortar versus fiber-reinforced polymer confinement in reinforced concrete columns.* ACI Structural Journal, 2007. **104**(6): p. 740.
9. Signorini, C., A. Sola, and A. Nobili, *Hierarchical composite coating for enhancing the tensile behaviour of textile-reinforced mortar (TRM).* Cement and Concrete Composites, 2023. **140**: p. 105082.
10. Tetta, Z.C., T.C. Triantafillou, and D.A. Bournas, *On the design of shear-strengthened RC members through the use of textile reinforced mortar overlays.* Composites Part B: Engineering, 2018. **147**: p. 178-196.
11. Raoof, S.M., *Bond between textile reinforced mortar (TRM) and concrete substrate*. 2017, University of Nottingham.
12. Dalalbashi, A., B. Ghiassi, and D.V. Oliveira, *Aging of lime-based TRM composites under natural environmental conditions.* Construction and Building Materials, 2021. **270**: p. 121853.
13. Patane, A. and G. Vesmawala, *Experimental and analytical investigation of the behaviour of reinforced concrete beam under pure torsion.* Materials Today: Proceedings, 2023.
14. Askandar, N.H., A.D. Mahmood, and R. Kurda, *Behaviour of RC beams strengthened with FRP strips under combined action of torsion and bending.* European Journal of Environmental and Civil Engineering, 2022. **26**(9): p. 4263-4279.
15. Al-Bayati, G., R. Al-Mahaidi, and R. Kalfat, *Experimental investigation into the use of NSM FRP to increase the torsional resistance of RC beams using epoxy resins and cement-based adhesives.* Construction and Building Materials, 2016. **124**: p. 1153-1164.
16. Elwan, S., *Torsion strengthening of RC beams using CFRP (parametric study).* KSCE Journal of Civil Engineering, 2017. **21**(4): p. 1273-1281.
17. Chai, H., A.A. Majeed, and A.A. Allawi, *Torsional analysis of multicell concrete box girders strengthened with CFRP using a modified softened truss model.* Journal of Bridge Engineering, 2015. **20**(8): p. B4014001.

18. Tais, A. and M. Abdulrahman, *Improving The Torsional Strength of Reinforced Concrete Hollow Beams Strengthened with Externally Bonded Reinforcement CFRP Stripe Subjected to Monotonic and Repeated Loads.* Information Sciences Letters, 2023. **12**(1): p. 427-441.
19. Alabdulhady, M.Y., L.H. Sneed, and C. Carloni, *Torsional behavior of RC beams strengthened with PBO-FRCM composite–An experimental study.* Engineering Structures, 2017. **136**: p. 393-405.
20. ACI, *ACI 318-14. Building code requirements for structural concrete*. 2014, ACI Farmington Hills, MI, USA.
21. Designation, A., *C370-05a,(2005)" Standard Specification for Testing Method and Definitions for Mechanical Testing of Steel Products.* 2005 Annual Book of ASTM Standards, American Society for Testing and Material, Philadelphia, Pennsylvania, Section. **1**: p. 248-287.
22. ASTM, A., *ASTM C39/C39M-18 standard test method for compressive strength of cylindrical concrete specimens.* ASTM International, West Conshohocken, PA. ASTM, AI (2018)." ASTM C, 2018. **192**.
23. ASTM, C., *496/C496M-11.* Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete, ASTM, West Conshohocken, PA, 2011. **5**.
24. ASTM, A., *C78/C78M, ASTM C78/C78M-02-standard test method for flexural strength of concrete (using simple beam with third-point loading).* ASTM Int., 2002.
25. Astm, C., *496/C 496M.* Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 2004.
26. Panchacharam, S. and A. Belarbi. *Torsional behavior of reinforced concrete beams strengthened with FRP composites*. in *First FIB Congress, Osaka, Japan*. 2002.
27. Aljazaeri, Z.R. and J.J. Myers, *Fatigue and flexural behavior of reinforced-concrete beams strengthened with fiber-reinforced cementitious matrix.* Journal of Composites for Construction, 2017. **21**(1): p. 04016075.
28. Peng, X.-N. and Y.-L. Wong, *Behavior of reinforced concrete walls subjected to monotonic pure torsion—An experimental study.* Engineering structures, 2011. **33**(9): p. 2495-2508.