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TORSIONAL BEHAVIOR OF R.C T-STRENGHENED AGAINST TORSION WITH CFRP STRIPS AND ANCHORS

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Abstract

Fiber reinforced polymer (FRP) is a promising and a recent development material for strengthening and rehabilitation of deficient concrete elements. The most recent report by ACI Committee (440.2R-08) suggested that any proposed anchorage system for externally strengthening should be heavily inspected before field application [2]. The conducted researches on torsion shows that the torsional behavior of flanged beams externally strengthened with FRP systems has not been fully investigated. The objective of the present experimental study is to have a better understanding the Torsional Behavior of R.C T-beams strengthened Against Torsion with CFRP Strips and anchors. Seven R.C beams were tested; All the specimens had the same reinforcement, and dimensions. Two specimens were control beams without strengthening, the other beams were strengthened using external CFRP strips. The variables were the strengthening techniques and using anchor or not. The strengthening techniques used were: unanchored extended U-jacket strips, anchored extended U-jacket strips, fully wrapped strips and semi fully wrapped strips with steel or fiber anchors. Externally strengthening the beams with CFRP improved the ultimate strength of all the tested beams. However, the level of strengthened externally is dependent on the selected strengthening method. Using the anchors do improve torsional strength and ductility.

***Keywords*:** Torsion; Flanged beam; Strengthening; Anchor; CFRP; Strip, Semi fully wrapped.

الملخص:

البوليمرات المسلحة بالالياف من المواد الواعدة والمتطورة لتدعيم وتقويه العناصر الخرسانية. واقترح الكود الامريكى الاحتياج الى الكثير من الدراسات لإستخدام المثبتات مع البوليمرات المسلحة بالالياف لتقويه الكمرات خارجياً قبل تنفيذها فى الحياة العمليه. واظهرت الدراسات التى اجريت على الالتواء ان سلوك الكمرات الخرسانيه ذات الشفه المقواة خارجيا باستخدام البوليمرات المسلحة بالالياف لم يكتمل بعد. والهدف من هذة الدراسه هو الفهم الجيد لسلوك هذة الكمرات وكذلك باستخدام المثبتات. تم اختبار سبع كمرات لهم نفس الابعاد والتسليح منهم اثنين بدون تقوية خارجيه والباقى مقوى خارجيا باستخدام الالياف الكربونيه. ومتغيرات البحث هى طرق التقويه واستخدام المثبتات من عدمه. طرق التقويه المستخدم هو الشرائح الممتدة على شكل حرف **U** بدون استخدام المثبتات وباستخدام المثبتات والشرائح الملفوفه بكامل القطاع والشرائح الشبه ملفوفه بكامل القطاع باستخدام المثبتات من الحديد والبوليمرات المسلحة بالالياف. وتم التوصل الى ان استخدام الالياف الكربونيه للتقويه الخارجية حسن مقاومة اللى لجميع الكمرات ولكن نسبه التحسين تتوقف على الطرق المستخدمة.كما ان استخدام المثبتات حسن بشكل ملحوظ من مقاومة اللى والممطولية.

1. INTRODUCTION

For the satisfactory performance of the existing structural system, the need for maintenance and strengthening is inevitable. Commonly encountered engineering challenges such as increase in service loads, changes in use of the structure, design and/or construction errors, deteriorations or degradation problems, changes in design code regulations and seismic retrofits are some of the causes that led to the need of rehabilitation of existing structures. Complete replacement of an existing structure may not be a cost-effective solution and is likely to become an increasing financial burden if upgrading is a viable alternative. In such occasions, repair and rehabilitation are the commonly used solutions.

Some reinforced concrete (RC) elements are subjected to significant torsion such as edge beams of slab and shells and inverted flanged beam. In the late 1980s, the torsion failure of R.C beams was prevented by externally strengthening the beams with steel plates [1]. However, fiber reinforced polymer (FRP) fabrics have many advantages over steel plates [2,3]. The use of epoxy-bonded fiber-reinforced polymers (FRP) on the surface of reinforced concrete (R.C) members acting as external reinforcement is a promising and a recent development technique for strengthening and rehabilitation of deficient concrete elements because of their superior properties such as lightweight, high stiffness and strength, as well as, ease of installation when compared to other repair materials. Also, the non-corrosive and nonmagnetic natures of these materials, along with its resistance to chemicals make the FRP an excellent option for external reinforcement.

Most existing researches have demonstrated the effectiveness of the use of strengthened externally with FRP for R.C beams under bending moments or shear forces [5–8]. A small number of studies have focused on the torsional behavior of RC beams with FRP as external or internal reinforcements [9–18].

Ghobarah et al. [10] experimentally investigated the effectiveness of carbon, glass FRP sheets and strips as additional external reinforcement to rectangular beams with bars and stirrups under torsion, and simple design approaches were also discussed. Salom et al. [11] studied experimentally and analytically the torsional behaviour of six spandrel beams with bars and stirrups, which had been strengthened with FRP laminates using a special anchoring system. Chalioris et al. [13] experimentally investigated the effectiveness of the use of epoxy-bonded carbon FRP fabrics as external transverse reinforcement to under-reinforced concrete beams with rectangular and flanged cross-section subjected to pure torsion. Deifalla et al. [18] experimentally investigated the behavior of flanged beams externally strengthened using FRP and subjected to torsion. Eleven R.C beams with various cross section shapes (i.e., rectangular, T-shaped and L-shaped) were tested and the following strengthening techniques were used: U-jacket strips, extended U-jacket strips and fully wrapped strips.

A careful examination of the previous studies showed the following: (1) all studies addressed that, in general, FRP materials caused a significant increase on the torsional capacity of the tested beams; (2) Both Salom et al. and Deifalla et al. indicated that more studies were required to fully understand and quantify the effect of anchors as well as refine their conclusions[11,15,18]; (3) Salom et al. studied flanges through anchors and continuous jackets, which can be impractical and uneconomic in many cases [11]; (4) Both Chalioris and Deifalla et al. studied T-shaped beams and continuous jackets, even though in many cases continuous jackets can be uneconomic with respect to strips[13,5], (5) Deifalla et al. studied flanged beams, strip jackets and indicated that The level of torsional behavior enhancement for flanged beams strengthened externally with FRP was not only dependent on the ratio of the FRP reinforcement but also on the effectiveness of the implemented strengthening method[18].

A survey of the previous experimental tests conducted on concrete beams strengthened externally using FRP under torsion is presented in Table 1 [9,10,19-21,11,22,12,14,23,13,24,18]. We can see that a total of 99 beams strengthened externally using FRP as follows:

(1) 74% have a rectangular cross-section; (2) 22% have a flanged cross-section; (Although most beams, in nature, are connected to a flange either as a part of the floor slab (i.e., the slab and beam are monolithically cast together) or as an inverted flanged beam) and (3) 12% of the tested beams examined the usage of anchors. The American Concrete Institute Committee (440.2R-08) indicated that mechanical anchorages could be used at the termination points of FRP fabrics to develop larger tensile forces or to increase stress transfer. However, the effectiveness of these mechanical anchorages, along with the level of tensile stress they can develop, should be heavily scrutinized and substantiated through representative physical testing prior to field implementation [2].

Table (1): Survey of the torsional previous experimental tests, [9,10,19-21,11,22,12,14,23,13,24,18]

Study	Number of tested beams	Cross section		Anchored	Strengthening methods			Direction		Longitudinal	
		Rectangular	Flanged		fully wrapped	U-Jacket	Extended U-jacket	Inclined 45 deg.	Vertical	Strips	Continuous
Zhang et al. [9]	9	9	–	–	7	–	–	–	7	7	–
Ghobarah et al. [10]	8	8	–	–	8	–	–	2	6	5	2
Panchacharam and Belarbi [19]	7	7	–	1	4	3	–	–	2	4	3
Biddah et al. [20]	4	4	–	–	4	–	–	–	4	–	4
Sharobim and Mokhtar [21]	7	7	–	–	5	2	–	–	5	5	2
Salom et al. [11]	4	–	4	3	–	4	–	1	3	–	4
Deifalla and Ghobarah [22]	4	–	4	4	2	1	1	4	–	–	4
Hii and Al-Mahaidi [12]	4	1	–	–	4	–	–	–	–	4	
Ameli et al. [14]	10	10	–	–	6	4	–	–	10	4	6
Genidi [23]	16	10	6	–	8	8	–	2	14	14	2
Chalioris [13]	8	6	2	–	6	2	–	–	8	3	5
Mohammadizadeh and Fadeel [24]	10	10	–	2	8	2	–	–	10	2	8
Deifalla ,Awad and Elgarhy [18]	8	2	6	2	3	4	1	3	5	8	-
Total	99	74	22	12	65	30	1	11	67	56	40
		75%	22%	12%	66%	30%	1%	11%	68%	57%	40%

Strengthened externally beams using FRP anchorage systems have been recently gaining attention [25–27]. Kalfat et al. listed over 100 successful experimental tests for using anchorages in shear, but only a handful of successful experimental tests for using anchorages in torsion [26].

Available design guides [2, 28] cover most cases of beams strengthened externally using FRP systems subjected to flexure and shear. However, the case of flanged beams strengthened externally using an FRP system while subjected to significant torsion is not addressed. More testing of beams strengthened externally using FRP systems under torsion is required, with an emphasis on investigating flanged beams, U-jackets, anchors, strips and inclined jacket techniques.

The literature review presented later in this paper shows that the torsional behavior of flanged beams strengthened externally with FRP systems (i.e., anchored extended U-jacket strips or unanchored extended U-jacket strips) has not been fully investigated, and also the rectangular and flanged beams are jointly tested in order to acquire comparative results.

The objective of the present study is to evaluate the effect of proposed strengthening techniques on the behavior of flanged R.C beams subjected to pure torsion and evaluate the effectiveness the anchor on torsional behavior for strengthened flanged beam with CFRP strips. Seven RC t-beams were tested and the following strengthening techniques were used: unanchored extended U-jacket strips, anchored extended U-jacket strips, fully wrapped strips and semi fully wrapped strips with steel or fiber anchors.

The present study also contributes to the limited existing studies on torsional tests of strengthened flanged beams with FRP materials. The recent increase interest for the use of these materials, the catastrophic character of the torsional failure and the lack of relative studies are the main motives behind this research.

2. EXPERIMENAL PROGRAM

The effectiveness of externally bonded CFRP strips for strengthening T-beams under torsion was studied by using seven test specimens, one specimen was Rectangular and the others were T cross-section. All specimens had the same reinforcement, and length. Two specimens were control beams without strengthening and the other beams were strengthened using externally bonded CFRP strips.

2.1 specimen characteristic

All tested beams with rectangular and T cross-section had total depth of 300 mm and web width of 150 mm with a total length of 1700 mm. For flanged specimen, a flange width equal of 800 mm and a flange thickness of 80 mm were implemented.

All specimens had the same reinforcement, longitudinal steel reinforcement 2Φ12 mm top and bottom, stirrups were 5Ø8/m` at the middle part or test zone. The flange reinforcement was mesh of 5Ø8/m` in both directions.

For concrete arm, the shear reinforcement was Ø8/75mm and the flexure reinforcement was 3Φ12 top and bottom. Fig 1 shows the overall layout of the tested beams (plan, elevation, and section) with full dimensions and reinforcement arrangement, details of stirrups, arrangement of heavily reinforcement parts and positions of loads.

The strengthening techniques used in this investigation were chosen to suit various practical limitation for CFRP application as shown in Fig. 2 and the table.

In the unanchored extended U- jacket, the FRP fabrics are bonded to the web and further extended to the flange. This technique can be used where only one side of the flange or the slab is accessible. In the anchored extended U- jacket, as the unanchored extended U-jacket the second group, with different usage of anchors at end strip in the flange. In the fully wrapped jacket strip, the FRP fabrics are wrapped all around the perimeter of the cross section. This technique has limited applications, such as the case of unrestricted access to the entire cross section. It is used primarily as a reference for comparison to provide valuable insight for the effectiveness of the other tested strengthening techniques. In the semi fully wrapped, the FRP fabrics are bonded to the web, further extended to the flange, top flange and connected with steel anchor or CFRP anchor. This technique can be used where two side of the flange or the slab are accessible. This technique is easier than the last technique and more accessible for application. The variable in this technique was the usage of anchor where one was steel and other was CFRP.

The width of all strips and the spacing between strips were constant and equal 100 and 200 mm, respectively.

The code of the tested beams consisted of two parts, indicted as follow: The first part of beam code is a letter indicates the shape of cross section were R: rectangular cross section, T: flanged cross section. The second part of code beam indicates strengthening techniques where C: control beam without strengthening, U: extended U jacket CFRP strip without anchorage system, UN: extended U jacket CFRP strip with anchorage system, F: the fully wrapped CFRP strip, SN: the semi fully wrapped with steel anchor, SF: the semi fully wrapped with CFRP anchor.

2.2 Materials

The concrete mix used for the tested beams had a nominal compressive strength of 40 MPa. The longitudinal steel reinforcements were high tensile steel with a nominal yield stress of 400 MPa and the shear reinforcements were mild steel with nominal yield strength of 340 MPa. Sika wrap Hex-230 carbon fiber reinforced polymer (CFRP) sheets were used and the resin was epoxy Sikadur-330. The CFRP fabric without resin, had thickness and ultimate strain values of 0.14 mm and 1.8%, respectively.

2.3 Application of strengthening system

During the strengthening procedure, special attention was paid to attaining a full bond between the RC beam and the FRP fabrics. Preparation of the concrete surface and the application of the CFRP were conducted using the same standard procedure each time as follows

1. The concrete surface was leveled and the aggregate was exposed using a hand held grinder, which benefits the bond between the FRP fabrics and the concrete.
2. The concrete edges and corners were rounded with the grinder, in order to minimize the stress concentration in the fibers at the edges.
3. The concrete surface was cleaned from any loose particles and dust using compressed air.
4. The prepared concrete surface was impregnated with the resin, especially at the reentrance between the flange and the web.
5. Each CFRP layer was impregnated with the resin.
6. These resin impregnated CFRP layers were rolled over the concrete surface and pressed to eliminate air bubbles.

An additional steel angle (50x50x5 mm) was used at the entrant of the flange and the web to delay or prevent the local deboning of the FRP. The applied force generates tension stresses in the FRP sheets. The resultant of which is a force pulling the FRP sheets away from the beam causing local deboning at this region. The steel angle was fixed using Sikadure 31CF and bolts.

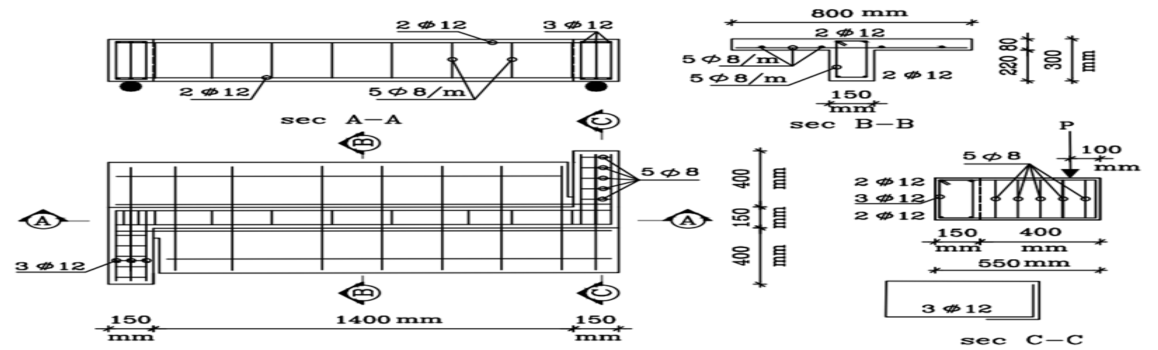

Fig 1 : Dimensions and Reinforcement details of tested beam.

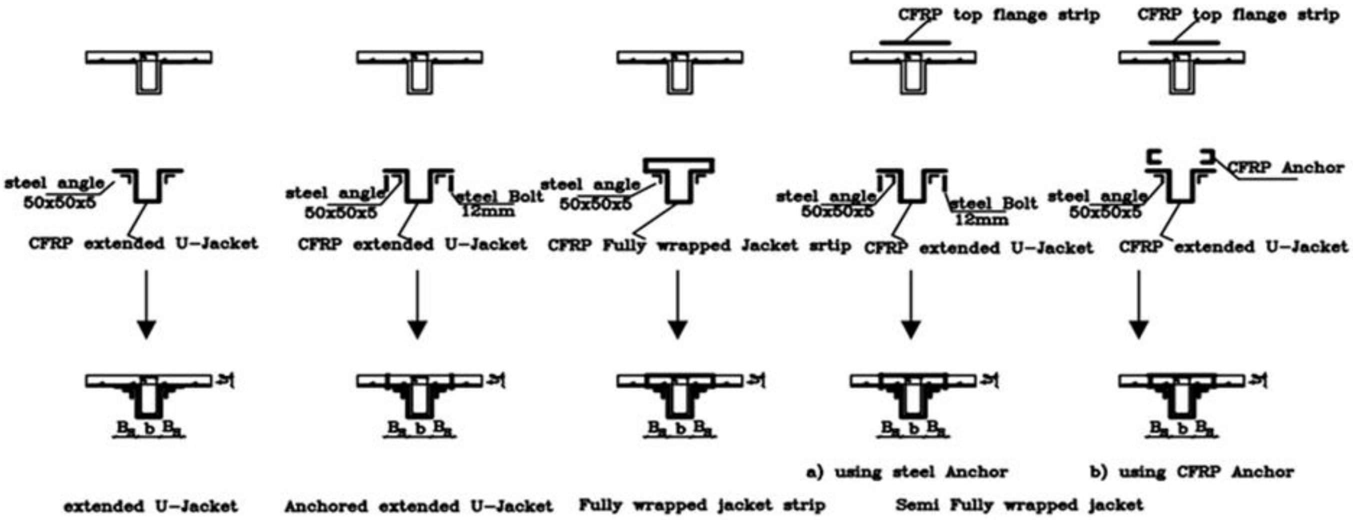

Fig 2 : Implemented strengthening schemes.

Anchors were used in these techniques in order to delay or prevent end anchorage failure. The nchors used in the techniques were steel bolts of 12-mm diameter. Anchors were fixed using Sikadure 31CF with spacing 20mm along the longitudinal direction of the tested beams.

3.3 test setup

The experimental setup is a commonly used torsional test rig and it is shown in Fig. 3. In order to exert pure torsional moment on the longitudinal part of the tested beam specimen, the beam was loaded by applying two downwards concentrated loads at the ends of the concrete arm. Two hinged supports are used at both joints of the Z-shape, both hinged supports are capable of rotation and inclination in the vertical plane in order to allow pure torsional moment to be transferred from both concrete arms to the longitudinal part of the specimen.

The total applied load was measured by a load cell. Three linear variable differential transformers (LVDTs) with accuracy 0.001 mm were used to measure displacements at the different location on the beam. In order to acquire information about the failure modes of the tested beams, the strains of stirrups, steel reinforcement and FRP were measured by electrical resistance strain gauges. The beams were tested by monotonically increasing torque moment until the ultimate torsional strength. The loading was terminated when the beam resistance significantly dropped down.

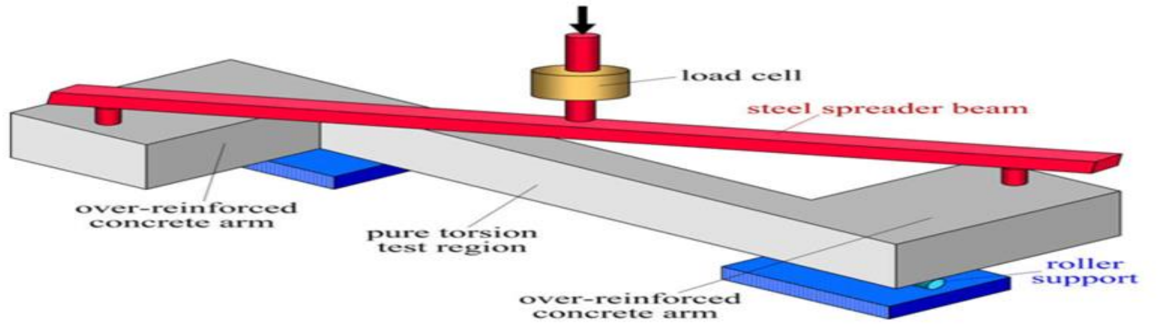

Fig 3: test setup

3. EXPERIMENTAL RESULTS

The behavior of all tested beams is described in this section. Table 2 contains a summary of the experimental results, which included the tested beams of groups versus the initial torsional rigidity (GK), torsional moment at cracking (Tcr), the angle of Twist per unit length at cracking (θcr), the post-cracking ultimate torsional moment (Tu), the angle of twist per unit length at ultimate strength (θu), the stirrup strain at ultimate strength (Ɛt) and the failure mode.

3.1 Torsional behavior

The torsional behavior of all the tested beams of groups is presented in Fig 4, in terms of experimental curves for torsional moment (T), versus angle of twist per unit length (θ). The torsional behavior of all tested beams was similar. It can be seen that the torsional moment twisting angle relationship is linear at the first portions of the curve, with a relatively large torsional rigidity (GK) until cracking. After the cracking, the relationship showed non-linear portions, indicating the post cracking behavior. The measured torsional moment at cracking (Tcr), the angle of twist per unit length at cracking (θcr), the post- cracking ultimate torsional moment (Tu) and the corresponding angle of twist per unit length (θu) are presented in Table 2.

3.2 Stirrups strain

The stirrup strain versus the applied torque for all the tested beams of groups is presented in Fig 5. As expected, strain values were very small until the onset of cracking. After cracking, the stirrup strain values increased rapidly. The recorded values of the stirrup strain at the ultimate resistance were listed in Table 2. The stirrups strain for all the tested beam reached the yield strain, valued 1690 µ. That was excepted from control rectangular beam. For the rectangular beams, the recorded value of the transversal reinforcement strain was 1355 µ. For the control flanged the recorded value of the transversal reinforcement strain was 1698 µ. For the unanchored extended U- jacket, the recorded value of the transversal reinforcement strain was 2029µ for beam T-U. For the anchored extended U- jacket, the recorded value of the transversal reinforcement strain was 2312µ for beam T-UN. For the fully wrapped jacket strip, the recorded value of the transversal reinforcement strain were 2239µ for beam T-UN. For the semi fully wrapped, the recorded values of the transversal reinforcement strain were 2280µ and 2242µ for

beams T-SN and T-SF respectively.

The stirrups strain changed with various FRP strengthening techniques.

3.3 Cracking patterns and failure modes

Due to torsion, beams resisted a wave of diagonal compressive and tensile forces. Both the FRP and steel carry the tensile forces while the concrete carries the compressive forces. Failure was defined as complete collapse and no ability to sustain any more loads (i.e. the concrete is broken whether by concrete crushing due to compression or section is separated due to excessive cracking). All tested beams exhibited diagonal spiral cracking (i.e. cracks were propagating all around the cross section in a continuous form)

Table (2) Experimental results.

Beam	GK^{a} (kN.m^2)	$T_{cr}{}^{b}$ (kN.m)	$\theta_{cr}{}^{c}$ (°/m)	$T_u{}^{d}$ kN m	$\theta_u{}^{e}$ (°/m)	$\varepsilon_t{}^{f*}$ (μ)	Failure mode
R-c	1720	6.00	0.200	7.36	0.773	1355	Mode A
T-C	1646	9.00	0.313	10.97	0.904	1698	Mode B
T-U	1729	12.56	0.416	14.63	1.323	2029	Mode C
T-UN	1766	13.13	0.426	17.23	1.680	2312	Mode C
T-F	1845	13.88	0.431	18.05	1.863	2239	Mode C
T-SN	1735	13.69	0.452	18.00	2.031	2280	Mode C
T-SF	1803	13.879	0.441	18.00	1.972	2242	Mode C

a: the initial torsional rigidity
b: torsional moment at cracking
c: the angle of Twist per unit length at cracking
d: the post-cracking ultimate torsional moment
e: the angle of twist per unit length at ultimate strength
f: the stirrup strain at ultimate strength
*: yield strain of stirrups steel is 1690μ

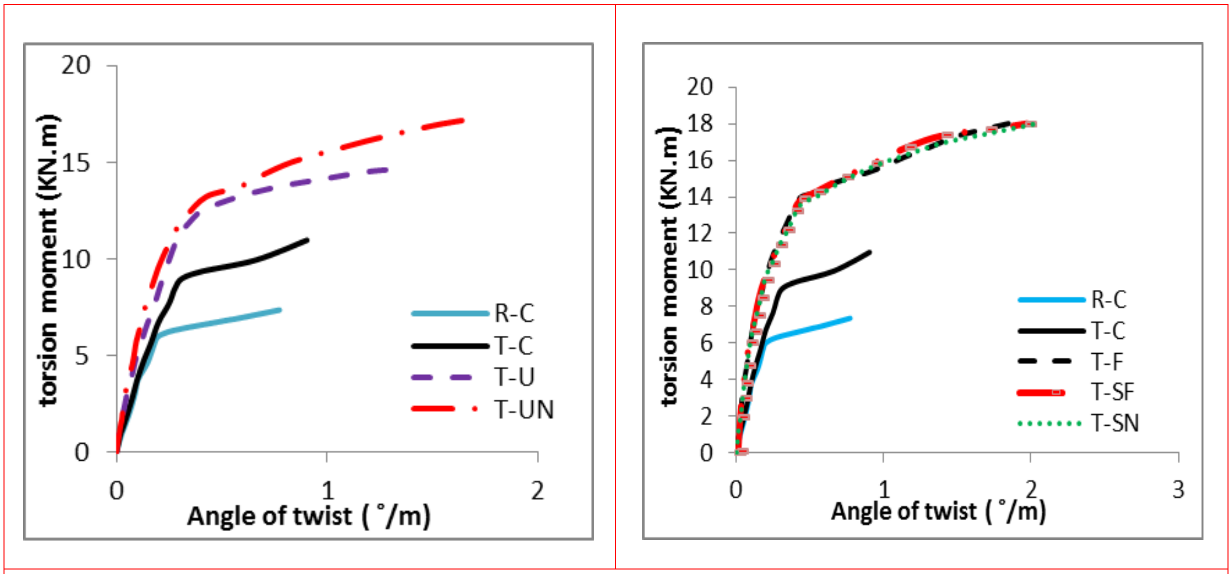

Fig 4 :Comparison relation between torsion moment and angle of twist for strengthened specimens and control beams.

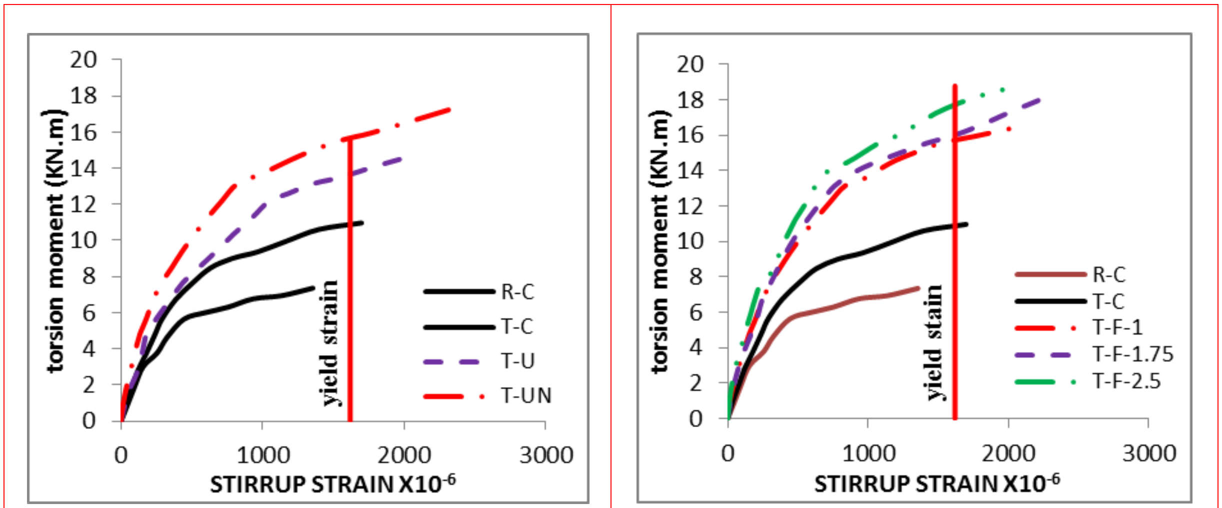

Fig 5 : Comparison relation between torsion moment and stirrups for strengthened specimens and control beams.

combined with steel stirrups yielding before failure, otherwise, the rectangular control beam. However, the cracking pattern and the failure mode were dependent on the implemented strengthening method and the strengthened width of flanged beam. Three failure modes were observed: Mode (A) is characterized by brittle torsional failure by concrete crushing before steel stirrup yielding where developed showing a single helical crack, the bars prevented the splitting of the specimens in two parts. Mode (B) is characterized by stirrups strain yielding before concrete crushing by diagonal failure as the torsion increased some of these cracks became excessively wide (i.e. either concrete strut crushing due to compression forces or excessive diagonal cracking due to diagonal tension forces).Mode (C) is characterized by stirrups strain yielding followed by FRP peeling off (intermediate FRP de-bonding, along the crack direction and at the crack location) and finally diagonal failure.

For control beams, the rectangular control beam (RC) experienced diagonal cracking and crushing of concrete in the bottom and the top (as shown in Fig. 6a) .The beam failed due to Mode (A).for the control flanged beam (T-C), the number of the cracks increased and beams failed due to Mode (B) (as shown in Fig. 6b).

For strengthening beams, all the tested beam failed due to Mode (C). The beam T-U, the failure accompanied with concrete bottom spalling (as shown in Fig. 7a).

The beams T-UN experienced more diagonal cracks between the strips, the width of the crack

more increased resulting in the separating in the FRP (as shown in Fig. 7b).

The beam T-F failed accompanied with concrete cover and bottom chord spalling (as shown in Fig. 8a). For beam T-SF, the crack width was bigger than the cracks of the beam T-SN-1(as shown in Fig. 8b-c).

4. FRP CONTRIBUTION

To evaluate the contribution of the FRP external reinforcements on the torsional behavior, the measured experimental data recorded during the tests was analyzed. The FRP contribution for each measured response (i.e., cracking torque; ultimate torque) was calculated as the difference between the measured values for the response of the beam strengthened externally using FRP and that of the control beam. All beams had the same cross-section shape, dimensions and internal reinforcements.

Fig 6: Cracking pattern of: (a) R-C and (b) T-C

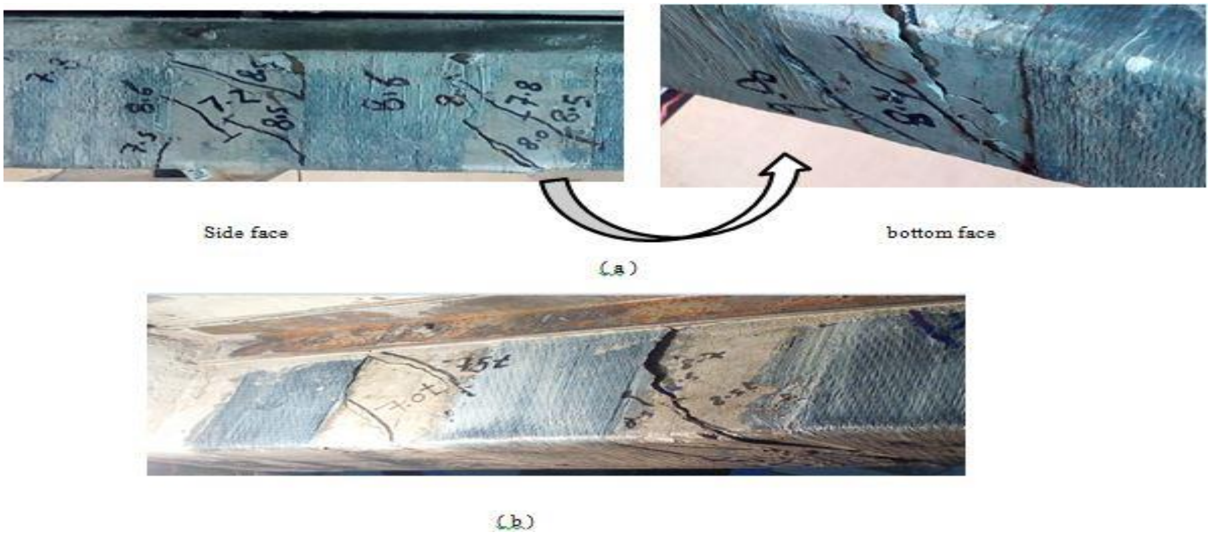

Fig 7 :Cracking pattern of: (a) T-U and (c) T-UN

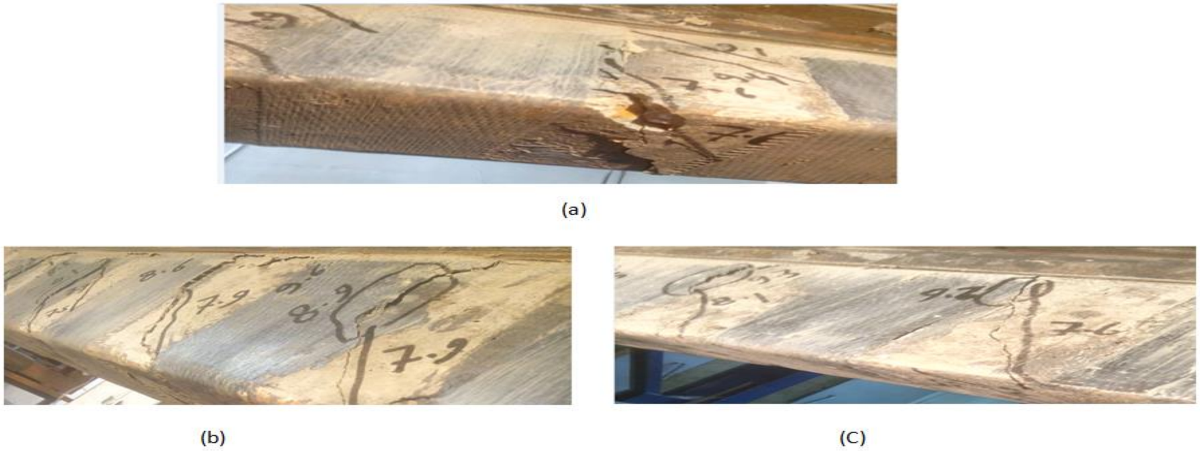

Fig 8 :. Cracking pattern of: (a) T-F, (b) T-SFand (c) T-SN

Table (3) Contribution of FRP for strengthened beams.

Tested Beams	ΔT_{cr}^{a} (%)	ΔT_{u}^{b} (%)	$\Delta\theta^{c}$ (%)	ΔGK^{d} (%)
T-U	40	33	46	5
T-UN	46	57	86	7
T-F	54	65	106	12
T-SN	52	64	125	5
T-SF	54	64	118	10

a: The percentage ratios of the FRP contributions for the cracking strength
b: The percentage ratios of the FRP contributions for the ultimate strength
c: The percentage ratios of the FRP contributions for the ultimate angle of twist
d: The percentage ratios of the FRP contributions for the initial rigidity

The percentage ratio of the FRP contribution of any response was calculated as the percentage ratio between the FRP contributions divided by the response of the control beam. The percentage ratios of the FRP contributions for the cracking strength (denoted as ΔT_{cr}), the ultimate strength (denoted as ΔT_u), the ultimate angle of twist (denoted $\Delta\theta_u$) and the initial rigidity (denoted as ΔGK) of the strengthened groups are shown in Table 3.

4.1Cracking strength

All the beams strengthened externally using FRP systems exhibited an increase in the cracking torque over the control specimen with the same cross-section (ΔT_{cr}), which was due to the FRP strips arresting the concrete cracks. However, each strengthening method yielded a different level of improvement. From **Table 3**, we can determine the following:

1. The cracking torque of beams T-U improved by 40% over the control beam.
2. The cracking torque of beam T-UN improved 46% over the control beam.
3. The cracking torque of beam T-F improved 54% over the control beam.
4. The cracking torque of T-SN-1.75 improved by 52% over the control beam.
5. The cracking torque of T-F-1.75 improved by 54%, respectively, over the control beam

The degree of cracking strength enhancement depends on the effectiveness of the chosen external strengthening method.

4.2Ultimate strength

In general, using FRP as an external reinforcement confined the concrete and stopped the cracks, thus causing a delay in the failure and an increase in the ultimate torque (ΔT_u). From Table 3, we can determine the following:

1. The ultimate torque of T-U improved by 33% over the control beam.
2. The ultimate torque of T-UN improved by 57% over the control beam.
3. The ultimate torque of beam T-F improved by 65%, over the control beam.
4. The ultimate torque of T-SN-1.75 improved by 64% over the control beam.
5. The ultimate torque of T-F-1.75 improved by 64% over the control beam.

Externally strengthening the beams with FRP improved the ultimate strength of all tested beams. However, the level of enhancement is dependent on the selected strengthening method.

4.3Ductility enhancement ($\Delta\theta_u$)

Deifalla and Ghobarah [22], defined the ductility as the increase in the ability of the beam to sustain larger deformations before failure due to the external FRP reinforcements. Moreover, Chalioris and Karayannis [29], have used indices-ratios of the rotation at the point of 85% of the maximum torsional moment (assumed as the end of the reliable response range) to the rotation at the maximum torsional moment (or to the rotation at the cracking torsional moment) to measure the torsional ductility.

In the present study, the enhancement of ductility was indicated as the ratio between the increase in the maximum deformation of the beam strengthened externally using FRP to that of the control beam with the same cross-section shape and details. From table 3, we can determine the following:

1. The ductility of beams T-U improved by 46% over the control beam.
2. The ductility of beams T-UN improved by 86over the control beam.
3. The ductility of beams T-F improved by 106% over the control beam.
4. The ductility of T-SN improved by 125% over the controls beam.
5. The ductility of T-F improved by 118% over the controls beam.

The ductility enhancement for each beam is significantly dependent on the effectiveness of the strengthening technique

4.4 Initial torsional rigidity

The initial torsional rigidity was calculated as the rate of change of the applied torque with respect to the unit angle of twist before cracking. In general, the effect of FRP external reinforcements (ΔGK) was insignificant, ranging between 3% and 15%. From Table 4, we can determine the following:

1. The torsional rigidity of beams T-U improved by 5% over the control beam.
2. The torsional rigidity of beams T-UN improved by 7% over the control beam.
3. The torsional rigidity of beams T-F improved 12% over the control beam.
4. The torsional rigidity of T-SN improved by 5% over the control beam.
5. The torsional rigidity of T-SF improved by 10% over the control beam.

The initial torsion rigidity was slightly improved due to externally strengthening of the beams using FRP systems. However, the level of enhancement depends on the strengthening technique.

5. EFFECTIVENESS OF STRENGTHENING TECHNIQUES

5.1 Extended U-jacket

Although the FRP U-jacket strips are suitable as a strengthening method for most practical situations, their effectiveness is poor when compared with other techniques. The extended U-jacket strips are suitable as a strengthening method for most practical situations and more effective from U-jacket strips [18].

In this study, using extended U-jacket strips (T-U) significantly increased the strength over the control beam (T-C) by values of 133%. When comparing the extended U-jacket strips with fully wrapped strips, the strength and ductility of the extended U-jacket strips were 47% and 43% of the fully wrapped strips, respectively.

5.2 Anchored Extended U-jacket

The American Concrete Institute Committee (440.2R-08) indicated that mechanical anchorages could be used at the termination points of FRP fabrics to develop larger tensile forces or to increase stress transfer [2].

In this study, using anchored extended U-jacket strips (T-UN) significantly increased the strength over the control beam (T-C) by values of 157%.

Also using anchored extended U-jacket strips significantly increased the strength and ductility over the unanchored extended U-jacket strip by values of 173% and 187%.

When comparing the anchored extended U-jacket strips with fully wrapped strips, the strength and ductility of the extended U-jacket strips were 88% and 81% of the fully wrapped strips, respectively.

It is deduced that the anchored extended U-jacket strip is better than the unanchored extended U-jacket strips and is as effective as the continuous fully wrapped strip.

5.3 Semi fully wrapped

Fully wrapped has limited applications, such as the case of unrestricted access to the entire cross section, but semi fully wrapped is easier and accessible for application.

In this study, using semi fully wrapped with fiber anchor (T-SF-1.75) and semi fully wrapped with steel anchor (T-SN-1.75), significantly increased the strength over the control beam (T-C) by value of 164% for both.

When comparing semi fully wrapped with fully wrapped strips, the strength and ductility of the beam (T-SF-1.75) was 99% and 106% of the fully wrapped strips, respectively and the strength and ductility of the beam (T-SN-1.75) was 99% and 118% of the fully wrapped strips, respectively.

It is deduced that semi fully wrapped with steel or fiber anchor is more effective from fully wrapped because it give the same torsional strength and is easer and accessible for application.

6. CONCLUSION

The objective of the present study is to evaluate the effect of proposed strengthening techniques on the behavior of flanged R.C beams subjected to pure torsion and evaluate the effectiveness the anchor on torsional behavior for strengthened flanged beam with CFRP strips. Seven RC t-beams were tested and the following strengthening techniques were used: unanchored extended U-jacket strips, anchored extended U-jacket strips, fully wrapped strips and semi fully wrapped strips with steel or fiber anchors. Based on the test results presented herein, the following concludes are drawn:

- The flanged beam is more effective in torsional strength from rectangular beam without flange otherwise if don't use flanged transversal Reinforcement. The flanged beam improved torsional strength by 49%, over rectangular beam.
- Externally strengthening the beams with FRP improved the ultimate strength of all the tested beams. However, the level of enhancement is dependent on the selected strengthening method. Extended U – jacket, an anchored extended U –jacket and fully wrapped strips improved torsional strength by 33%, 57% and 65%, respectively, over the control beam.
- Using the unanchored extended U-jacket strips increased the ultimate strength and ductility by 51% and 43% ,respectively, relative to the fully wrapped strip.
- Using the anchored extended U-jacket strips increased the ultimate strength and ductility by 88% and 81%, respectively, relative to the fully wrapped strip.
- The semi fully wrapped beam with steel or fiber anchor is more effective than the fully wrapped because it give the same torsional strength and is easier and more accessible for application. When comparing semi fully wrapped with fully wrapped strips, the strength and ductility of the semi fully wrapped with fiber anchor was 99% and 106% of the fully wrapped strips, respectively and the strength and ductility of the semi fully wrapped with steel anchor was 99% and 118% of the fully wrapped strips, respectively.

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