STRENGTHENING OF REINFORCED CONCRETE BEAMS SUBJECTED TO TORSION AND SHEAR STRESSES USING FIBRE-REINFORCED-POLYMERS (FRP)

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Abstract:

An experimental investigation is conducted on the improvement of the torsional resistance of reinforced concrete beams using fiber-reinforced polymer (FRP) fabric. The experimental program outlines a comprehensive analysis of the combined effects of shear and torsion on the torsional strengthening of four rectangular reinforced concrete beams with externally bonded glass fiber-reinforced polymer (GFRP) sheets. Three specimens are strengthened with GFRP composite wraps, and one is kept as a control specimen without strengthening. The outcomes of the one non-strengthened specimen are compared to those of the strengthened specimens. The load, twist angle of the beam, and strains were recorded. Improving the torsional resistance of reinforced concrete beams using FRP was demonstrated to be viable .

All specimens are strengthened have the same concrete grade and steel reinforcement ratio. As in the failure torsional moment for various strengthening configurations, as well as performance improvement and crack patterns. The purpose of this study is to assess the efficacy of using epoxy-bonded GFRP fabrics as external transverse reinforcement to reinforced concrete beams subjected to torsion. Torsional results from strengthened beams are compared to experimental results from control beam without the use of FRP. The study demonstrates a significant improvement in the torsional behaviour of all GFRP strengthened beams. using FRP was demonstrated to be viable. The effectiveness of various wrapping configurations indicated that the fully wrapped beams performed better than using strips.

Introduction :

Reinforced Concrete (RC) structural elements, such as the peripheral beams on each floor of multi-story buildings, ring beams at the bottom of circular tanks, shell roof edge beams, beams supporting canopy slabs, and helical staircases, are subjected to significant torsional loading in addition to flexure and shear. If reinforced concrete structural elements subjected to torsion are not properly designed and detailed, they will crack. Modern civilization is dependent on the continued performance of its civil engineering infrastructure, which includes everything from industrial buildings to power plants and bridges. The need for maintenance and strengthening is unavoidable if the existing structural system is to perform satisfactorily. Almost all engineering structures, ranging from residential buildings to industrial buildings, have a life cycle. Previously, the retrofitting of reinforced concrete structures, such as columns, beams another structural elements, was done by removing and replacing the low quality or damaged concrete or/and steel reinforcements with new and stronger material. However, with the introduction of new advanced composite materials such as fiber reinforced polymer (FRP) composites, concrete members can now be easily and effectively strengthened using externally bonded FRP composites Retrofitting of concrete structures with wrapping FRP sheets provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry.

In addition, FRP manufacturing offers a unique opportunity for the development of shapes and forms that would be difficult or impossible with the conventional steel materials. Although the fibers and resins used in FRP systems are relatively expensive compared with traditional strengthening materials, labour and equipment costs to install FRP systems are often lower.

FRP systems can also be used in areas with limited access where traditional techniques would be impractical. Several researchers studied the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines, and experimental investigations of these members in concrete beams and columns retrofitted glass fibre reinforced polymer (GFRP) composites.

The results of various studies on the enhancement of basic parameters such as strength/stiffness, ductility, and durability of structural members retrofitted with externally bonded FRP composites, while encouraging, have many limitations.

More research is needed before FRP composites can be recognised as a potential full-proof structural additive. FRP repair is a simple way to improve a structure's strength and design life.

The application of Fiber Reinforced Polymer (FRP) exhibits considerable potential for structural strengthening and rehabilitation (ACI 1996). FRP offers practical solutions for seismic strengthening and structural element rehabilitation. Many reinforced concrete structures have been strengthened with fiber-reinforced polymer (FRP) despite the absence of rules and standards.

Because FRP materials have a linear trend toward failure, the design was based in every instance on a conservative and reasonable approach to the material properties.

A more recent development is research into the application of FRP for reinforcing structural components. A number of researchers examined the flexural strengthening of reinforced concrete RC components using external epoxy-bonded laminates and fabric (Richie et al., 1991; Arduini et al., (1996). and researchers at a number of institutions, such as the University of Arizona (Saadatmanesh and Ehsani 1990, 1991a,b); the Swiss Federation Laboratories for Material Testing and Research (Kaiser 1989; Meier et al. 1992; Meier and Winistoerfer 1995); the German Institute for Structural Materials, Building Construction, and Fire Protection (Rostasy et al. 1992); the Massachusetts Institute of Technology (Triantafillou and Plevris 1992; Plevris and Triantafillou 1995); and investigators at a number of institutions.

The obtained results demonstrate the effectiveness and efficiency of FRP strengthening. There haven't been many studies done on shear strengthening of RC beams with composite materials. Berset conducted the initial research study in 1992. Shear strengthening of beams was the subject of several investigations after this one, including those by Al-Sulaimani et al. (1994), Chajes et al. (1995), Alexander and Cheng (1996), Chaallal et al. (1998), and Khalifa et al. (2000). There hasn't been much research done on torsional strengthening of structural members using FRP. The specialized nature of the issue and the challenges associated with carrying out representative analyses and realistic tests account for the paucity of research in the field. Torsion affects the design of structural members such as columns subjected to eccentrically applied lateral loads, eccentrically loaded bridge girders, and spandrel beams in structures.

The objective of this investigation is to evaluate the effectiveness of FRP strengthening of steel-reinforced concrete beams and columns subjected to torsion. Discussions are presented regarding the most effective wrapping material, a pattern for upgrading the torsional resistance, and simple design approaches.

Experimental Program:

Test Beams

for identifying effective GFRP wrapping pattern under combined torsion and shear. All beams are having 150 mm × 300 mm cross section and 2000 mm length. The compressive strength of concrete (f_{cu}) on the day of the test was 35 MPa. The top compression steel was two No.10 (10 mm nominal diameter) and the bottom tensile steel was two No. 16 (16.0 mm nominal diameter) bars. All stirrups were made of 8 mm diameter wire. The top and bottom concrete cover was 25 mm and the side concrete cover was 25 mm. The beam designation, bottom steel, and yield strength are listed in Table 2. The dimensions of the beams and reinforcement details are shown in Figure 1.

Test Beams and Wrapping Configurations Total four beam specimen are prepared. GFRP sheets with different configurations are applied to three beams and one beam is not wrapped to serve as control beam. The wrapping patterns of FRP used to strengthen the torsional resistance of the beams are shown schematically in Figure 5 to Figure 7 and summarized in Table 1.

Schematic representation and identification of specimen with different wrapping configurations are the tested beams were divided into two groups.

The first group (N) contain one beam (N1) was tested under combined torsion and shear, as a control beam is shown in Figure 1.

The two group (G) contain three beams (G1, G2 and G3) were tested under combined torsion and shear stress and were tested with GFRP are shown in Figure 2,3and Figure 4. In all the strengthening schemes, one layer of FRP was used. Beam G1, was fully wrapped with GFRP, is shown in Figure 5. Beam G2, was U shape wrapped around the beam (U-jacket) with GFRP, is shown in Figure 6. Beam G3, was wrapped using 100 mm wide GFRP strips, respectively and spacing of center to center 200 mm is shown in Figure 7. The orientation of fibre strips are 90° with longitudinal axis of beam.

Table 1 . Tested Specimens Details For Specimens .

specimen	composits sheets	No.of. Layers	Dim. Beam			reinforcement bars					NO.Of. Strain Gauges
			Length (mm)	Hight (mm)	Width (mm)	bottom	top	shrinkage	stirrups	type stirrups	
N1	Reference beam	None	2000	300	150	2Ø16	2Ø10	-	5Ø8	ordinary	2
G1	GFRP (Full wrap)	1	2000	300	150	2Ø16	2Ø10	-	5Ø8	ordinary	2
G2	GFRP (U-jacket)	1	2000	300	150	2Ø16	2Ø10	-	5Ø8	ordinary	2
G3	(GFRP) (Full Strip)	1	2000	300	150	2Ø16	2Ø10	-	5Ø8	ordinary	2

- N is a control beam test and G indicates glass fiber wrap.
- All top longitudinal steel is 2 #10.
- All stirrups are 8 mm diameter.

Table 2 : Beam test parameters and material properties.

Beam ID		Compressive stress F cu *(MPa)*	Concrete strength fc′ *(MPa)*	Tensile Stress F ctr *(MPa)*	Bottom longitudinal steel	Yield Stress, fy (MPa)	Material Type	Sheet Thickness (mm)	Strengthening system with GFRP sheets
Group-(N)	N1	35	28	3.55	2ϕ16 mm	360	--	--	Control Beam
Group-(G)	G1	35	28	3.55	2ϕ16 mm	360	GFRB	0.168	one layers of strips continuous bonded with the full length of the beam (full wrap)
	G2	35	28	3.55	2ϕ16 mm	360	GFRB	0.168	one layers of strips continuous bonded to bottom and sides of beam (U-Wrap)
	G3	35	28	3.55	2ϕ16 mm	360	GFRB	0.168	one layers of strips (100mm), were layered with an angle 90° to the longitudinal section of beam

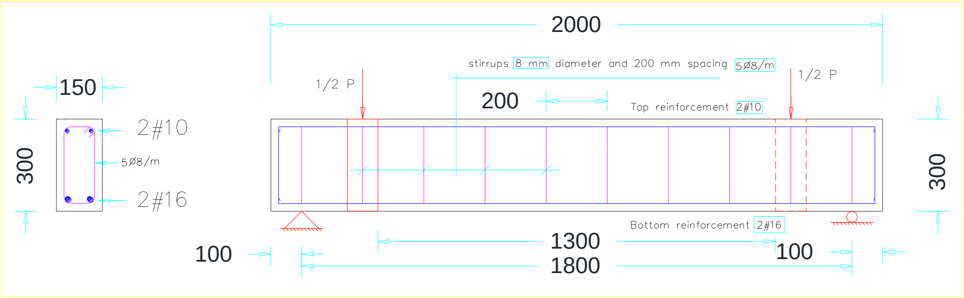

Figure 1: Control Beam (N1) .

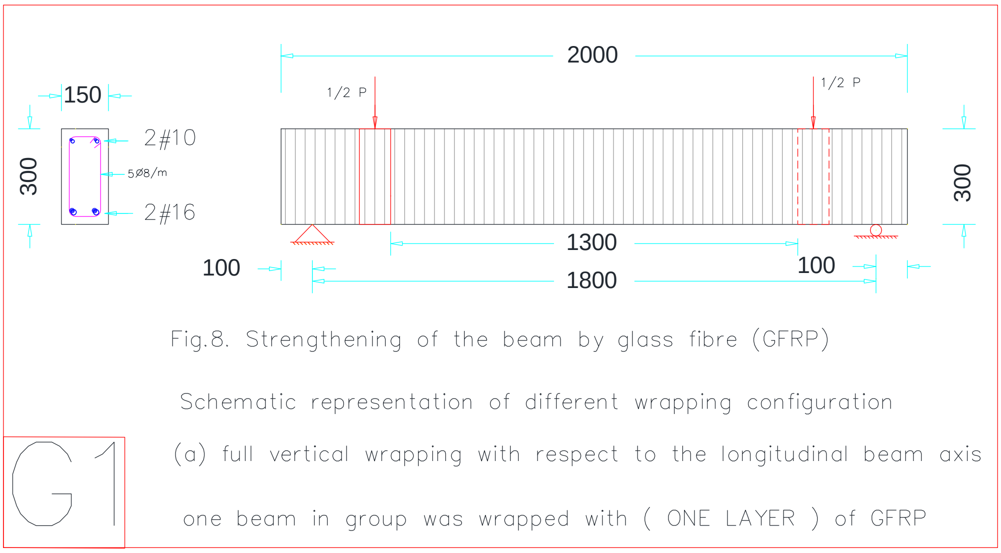

Figure 2 : Strength Beam (G1) .

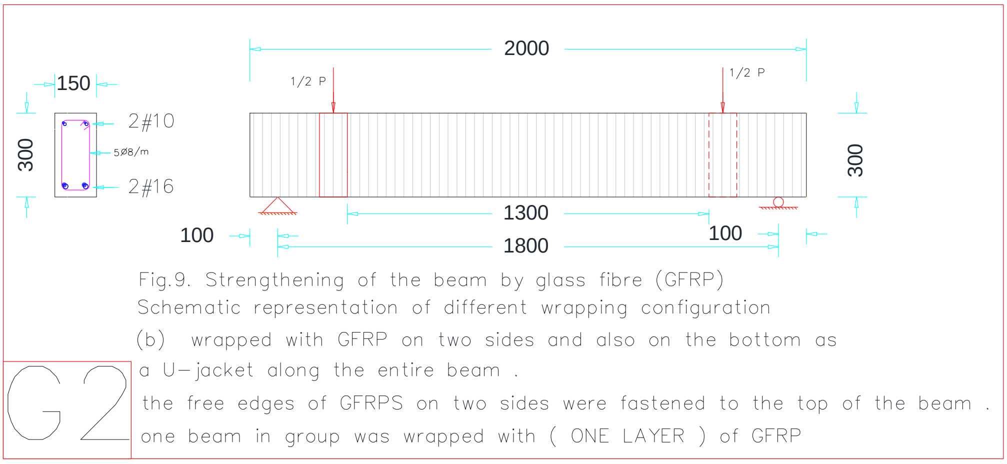

Figure 3 : Strength Beam (G2) .

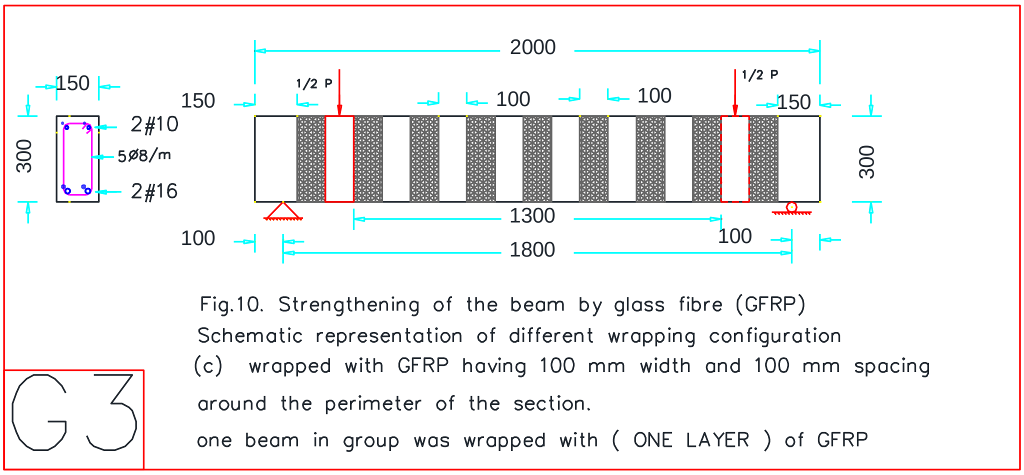

Fig.10. Strengthening of the beam by glass fibre (GFRP)
Schematic representation of different wrapping configuration
(c) wrapped with GFRP having 100 mm width and 100 mm spacing
around the perimeter of the section.
one beam in group was wrapped with (ONE LAYER) of GFRP

Figure 4 : Strength Beam (G3) .

FRP Material Properties:

The testing program made use of the Master Builders Technologies (2001) supplied SikaWrap® FRP system. The primer, saturant, and GFRP fabric or strips make up this system. Table 3 lists the mechanical and physical characteristics of the glass fiber fabric composites as supplied by the manufacturer. A low viscosity epoxy material serves as the saturant. This polymer is (Sikadur®-330) shown Table 4. The epoxy material has flexural and compressive strengths of 25 and 35 MPa, respectively.

Table 3 : Fiber Properties as per Manufacture's Specifications .

Physical and mechanical properties	Sika Wrap EG430 glass fiber
Thickness (mm)	0.168
Fiber density (gm/cm^3)	2.56
Tensile strength (n/mm^2)	2500
Tensile modulus (n/mm^2)	72000
Tensile elongation, ultimate (%)	2.70%

Table 4 : Sikadur-330 (Impregnating Resin)Provided by the manufacturer .

Appearance	Comp. a: white Comp. b: grey
Density	1.31 kg/l (mixed)
Mixing ratio	A : B = 4 : 1 by weight
Open time	30 min (at + 35°C)
Viscosity	Pasty, not flowable
Application temperature	15° C+ 35° C (ambient and substrate)
Flexural E-modulus	3800 MPa (cured 7 days at +23°C)
Tensile strength	30 MPa (cured 7 days at +23°C)

Specimen Preparation:

The edges of the reinforced concrete beam were rounded to eliminate any sharp corners that might weaken the fibers before they were wrapped with fibers. The corners of the beams were rounded using a grinder. After cleaning the concrete surface, a thin coat of primer was put on. A few hours were spent allowing the primer to solidify. The two sides of the fiber sheets were coated with a layer of cold cure solvent after the primer had been applied. Wet layup was used to apply the prepregnated fibers to the concrete surface. A steel roller was used to release the trapped air. The composites were not exposed to elevated heat during post cure. After the polymer solidified, which took about four days.

Test Setup:

The beams underwent testing in the "Structural Engineering" Laboratory's loading frame at Mataria's Faculty of Engineering of Helwan University. Every specimen is subjected to the same testing process. The beams must first cure for 28 days before having their surface cleaned with sandpaper to make fissures visible. To test beams, a two-point loading configuration was used. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. Two-point loading is conveniently provided by the arrangement shown in Figure (5),(6) and Figure (7).

Through a load cell and spherical seating on a spreader beam, the load is transmitted. In order to provide a level, smooth surface, the spreader beam is mounted on rollers that are set on steel plates that are cemented to the test member. The test member is supported by spreader plates that operate as comparable roller bearings. The specimen is positioned so that it is 100 mm away from the ends of the beam from the two steel roller bearings. The square plates, which are positioned 100 mm from the end of the beam and retained over the flange to transmit the load through a load cell.

A 100 Tonne capacity hydraulic jack was used for loading. Figure (7) below provides a clear representation of the experimental setup.

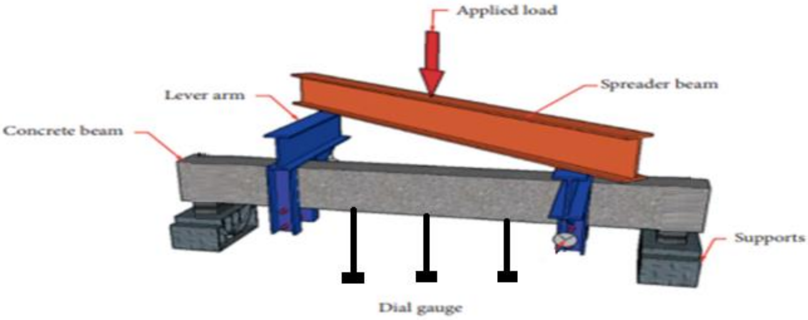

Figure 5 : Schematic of the test setup for applying combined torsion and shear .

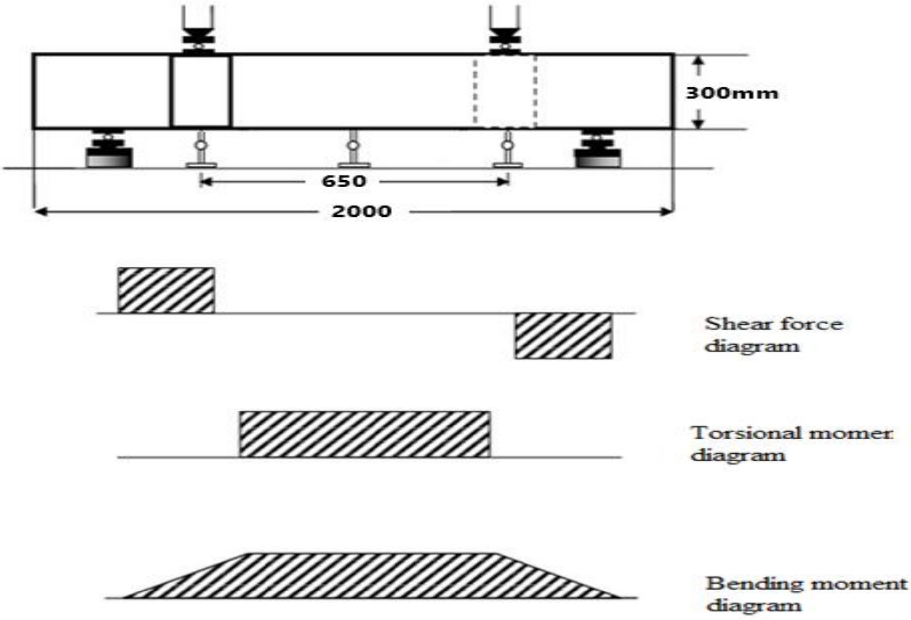

Figure 6: Torsional moment and Shear force diagram for two point loading.

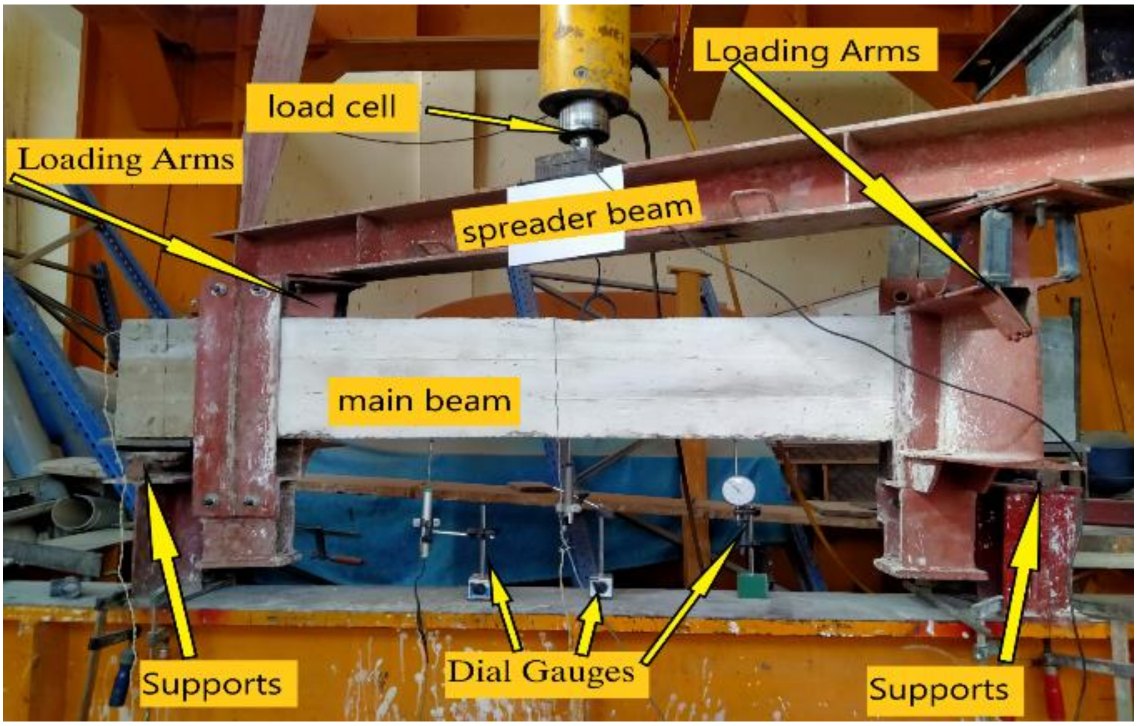

Figure 7: Test setup with the loading frame.

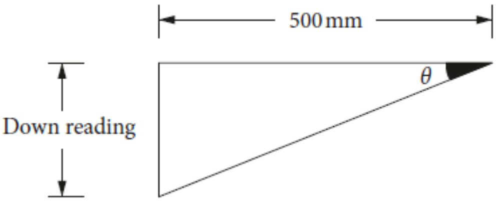

Figure 8 : Angle of twist measurements.

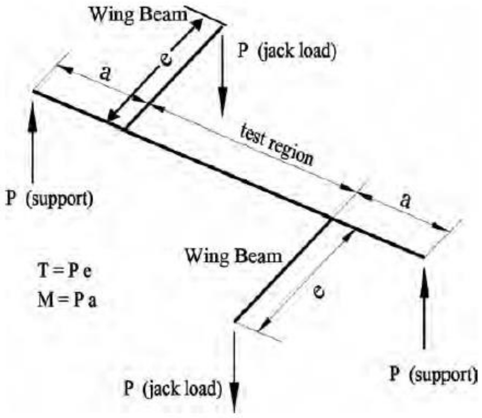

Figure 9 : Test setup for combined torsion and shear.

Results:

The behavior of beams strengthened by utilizing glass fibers (G1, G2 and G3) .

The behavior of the strengthened beams is compared with that of the control beam N1. Again it is observed that the complete wrap of the torsion zone of the reinforced concrete beam G1 is more effective in improving the torsional capacity of the beam as compared with beam G2 and G3, which was strengthened using strips of fiber material .

The fully wrapped beam G1 sustained a strength that was 123.72% more than the control beam N1. (G3) also giving the increase in failure strength of 23.547% as compared with (N1).

Beam G1 showed higher torque resistance than beams G2 and G3 shown Figure (10),(11) and Figure (12).

The U-wrapped beam (G2) showed increase in failure strength by 10.9% with respect to control beam (N1) shown Figure (13) and Figure (14).

The comparison between the behavior of beams wrapped with vertical G1 and G2 or strips (G3) of glass fibers is shown in Figure (15) with the behavior of the control beam N1.

After reaching the load failure, the fibers glass in specimen G3 failed in torsion with very rapid deterioration in the load-carrying capacity of the beam shown Figure (15).

The steps in the descending curve of the torque orientation plots indicate that more fiber failures occurred as a result of the attempts to apply small increments of load to ascertain the post failure behavior.

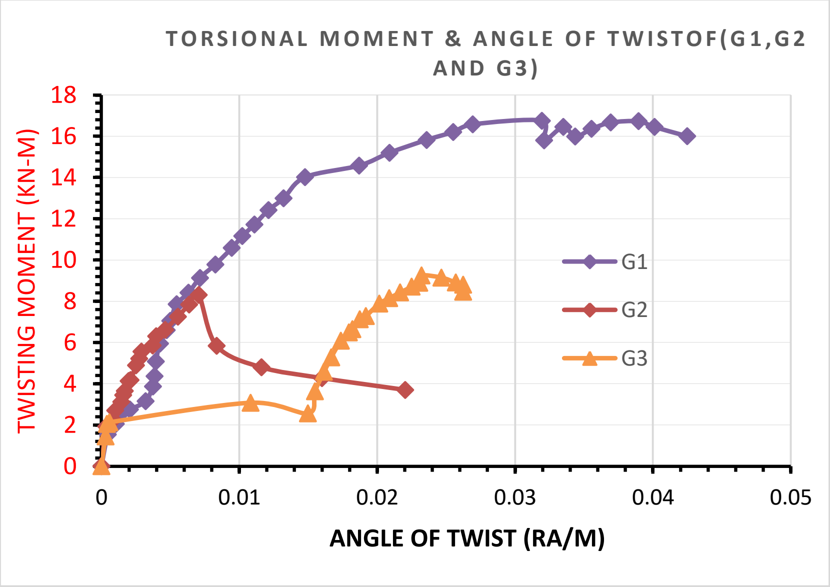

Figure 10 :Behavior of all beams wrapped with vertical GFRP .

Figure 11 :Fully Wrapped beam after Cracking .

Figure 12 : Cracks Pattern in G1 after removal of FRP .

Figure 13 : Beam wrapped around the beam having U-warp for web after cracking (G2).

Figure 14 : Cracks Pattern in G2 .

Figure 15 : Failure mode of beam G3 wrapped with vertical glass strips.

The behavior of beam G1 is close to that of beam G3 is close to that of beam G2 . However, after the concrete cracks, the fiber stiffness has little effect on the behavior. In effect, there is little difference in the post cracking behavior of beams strengthened using GFRP. This is because the fiber provides little confinement due to the rectangular geometry of the section and thus significant concrete cracking takes place, which causes debonding of the fiber sheets, thus allowing cracks to widen. Except for beam G1 the FRP did not reach failure in tension.

It is concluded that wrapping the beams has in general improved the torsional moment capacity . Higher torsional moment capacity corresponds to a larger covered area of the beam with FRP. As the torsional moment capacity of beams wrapped with vertical glass or carbon fibers are almost the same, the use of glass fiber is more economical in this application.

Conclusions:

The main objective of this study is to investigate the effectiveness of the use of epoxy-bonded FRP fabrics as external transverse reinforcement. Within the range of variables and obtained measurements, the following conclusions can be drawn:

- The complete wrap of the torsion zone of a reinforced concrete beam is far more effective in strengthening the torsional resistance than a beam strengthened using strips of various configurations.
- When a beam is strengthened using fiber strips, the failure is delayed but inevitably occurs in the unwrapped space between the strips.
- The cracking and failure torque of all strengthen beams were greater than those of the control beams. The increase in magnitude depends on the FRP strengthening configurations.
- Beams U wrapped with 90^0 oriented GFRP stripes showed lowest torsional resisting capacity. Since shear flow stresses take a close path during torsional loading , torsion would not be well resisted in case of U-jacketing strengthening.
- Strengthened beams using GFRP strips as the transverse reinforcement exhibited better overall torsional performance than the non-strengthened control beams.
- The use of continuous FRP strips that wrapped around the cross-section of R-beams caused a significant increase on the failure torsional strength. It is concluded that full wrapping with continuous strips is far more efficient for torsional upgrading than the use of wrapping with the discrete strips and U-jacket.
- Although the use of wrapping with the discrete strips strengthening technique relatively less effective than the FRP full wrapping strengthening technique, it yielded promising results in terms of strength and ductility while being quite feasible for most strengthening practical situations.
- There is little difference in the post cracking behavior of beams strengthened using vertical GFRP fiber wrap. This is because the fiber provides little confinement due to the rectangular geometry of the section.
- Significant concrete cracking occurred, which caused premature debonding of the fiber sheets and thus allowed concrete failure.
- G1 resulted in a 123.72 % increase in torsional capacity over the control beam .
- G2 resulted in a 10.9% increase in torsional capacity over the control beam N1.
- G3 Increase strength of beam was 23.547% as the control beam.

REFERENCES

1) Ameli, M. and Ronagh, H.R. (2007). "Behavior of FRP strengthened reinforced concrete beams under torsion",Journal of Composites for Construction, 11(2), 192-200.
2) Ameli, M., and Ronagh, H. R. (2007), "Analytical method for evaluating ultimate torque of FRP strengthened reinforced concrete concrete beams" ,Journal of Composites for Construction ,11, 384– 390.
3) Amir, M., Patel, K. (2002)."Flexural strengthening of reinforced concrete flanged beams with composite laminates",Journal of Composites for Construction, 6(2), 97-103.
4) Chalioris, C.E. (2006). "Experimental study of the torsion of reinforced concrete members", Structural Engineering & Mechanics, 23(6), 713-737.
5) Chalioris, C.E. (2007b). "Tests and analysis of reinforced concrete beams under torsion retrofitted with FRP strips", Proceedings 13th Computational Methods and Experimental Measurements (CMEM 2007), Prague, Czech Republic.
6) Chen, J.F. and Teng, J.G. (2003a). "Shear capacity of fiber-reinforced polymer-strengthened reinforced concrete beams: Fiber reinforced polymer rupture", Journal of Structural Engineering, ASCE, 129(5), 615-625.
7) Chen, J.F. and Teng, J.G. (2003b). "Shear capacity of FRP-strengthened RC beams: FRP debonding", Construction & Building Materials, 17, 27-41.
8) Deifalla A. and Ghobarah A.(2010), "Full Torsional Behavior of RC Beams Wrapped with FRP: Analytical Model", Journal of Composites for Construction,14,289-300.
9) A. Deifalla and A. Ghobarah (2005) "Simplified analysis for Torsionaly Strengthed RC beams using FRP'Proceedings of the International Symposium on Bond Behaviour of FRP in Structures (BBFS 2005).
10) Hii, A. K. Y., and Al-Mahadi, R. (2007). "Torsional capacity of CFRP strengthened reinforced concrete beams." Journal of Composites for Construction,11,71–80.
11) Hii, A.K.Y. and Al-Mahaidi, R. (2006). "An experimental and numerical investigation on torsional strengthening of solid and box-section RC beams using CFRP laminates"", Journal of Composite Structures, 75, 213-221.
12) Mahmood, M. N. and Mahmood, A. Sh.(2011) "Torsional behaviour of prestressed concrete beam strengthened with CFRP sheets" 16th International Conference on Composite Structures, ICCS 16 .
13) Panchacharam, S. and Belarbi, A. (2002). "Torsional behaviour of reinforced concrete beams strengthened with FRP composites", Proceedings 1st FIB Congress, Osaka, Japan, 1-10.
14) Pham, H. B., and Al-Mahaidi, R. (2004). "Experimental Investigations into flexural retrofitting of reinforced concrete beams using fiber reinforced polymer." J. Compos. Constr., 6(4), 257-263.
15) Reinforcement For Concrete Structure , ACI 440R-96, American Concrete Institute ,Farmington Hills, Michigan.

16) Salom, P.R., Gergely, J.M. and Young, D.T. “Torsional strengthening of spandrel beams with fiber-reinforced polymer laminates”, Journal of Composites for Construction, 8(2), 157162.
17) Tastani, S.P. and Pantazopoulou, S.J. (2004). “Experimental evaluation of FRP jackets in upgrading RC corroded columns with substandard detailing”, Engineering Structures, 26, 817 .
18) Zojaji A.R. and Kabir M.Z. (2011) “Analytical approach for predicting full torsional behavior of reinforced concrete beams strengthened with FRP materials”. Scientia Iranica A.19.