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Procedia Technology 24 (2016) 140 – 147
Procedia Technology

International Conference on Emerging Trends in Engineering, Science and Technology (ICETEST - 2015)

Comparative Experimental Study on Torsional Behavior of RC beam using CFRP and GFRP Fabric Wrapping

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Abstracts

Fiber reinforced polymer (FRP) as an external reinforcement is used extensively to enhance the strength requirement related to flexure and shear in structural systems. But the strengthening of members subjected to torsion is yet to be explored as Torsion failure is a brittle form of failure. In present experimental study deals with the torsional strengthening of Reinforced Concrete beams using epoxy bonded Fiber-Reinforced Polymer (FRP) fabric. Total Thirty nine rectangular beams of size 150mm × 300 mm and 1200 in length are casted. Out of which, three beams are control beam and remaining thirty six beams are classified into two groups. One with CFRP fabric wrapping and another with GFRP fabric wrapping. With various wrapping patterns. The applied CFRP and GFRP configurations are U-jacketed, vertical strips with spacing, and edge strips along with vertical strips along its entire length. Torsional capacity of beams of two groups is compared with control specimen with respect to torsional moment, angle of twist and ductility factor and it was observed that CFRP fabric bonded beam shows more torsional strength than the GFRP bonded beam.

Peer-review under responsibility of the organizing committee of ICETEST – 2015

Keywords: Torsion, CFRP fabrics, GFRP fabrics, Torsional capacity, angle of twist, ductility.

Nomenclature

CFRP	Carbon fibre reinforced polymer
GFRP	Glass fibre reinforced polymer
FRP	Fibre reinforced polymer
FB1	Fibre reinforced Beam 1
CFB1	Carbon Fibre reinforced Beam 1
GFB1	Glass Fibre reinforced Beam

1. Introduction

Structural members curved in plan, members of space frame, eccentrically loaded beams, curved box girders in bridges, spandrel beams in buildings, and spiral stair cases are typical examples of the structural elements subjected to torsional moment. and torsion cannot be neglected while designing these members structural members subjected to torsion are of different shape such as T-shape ,inverted L-shape, double T-Shapes and box sections .

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2212-0173
Peer-review under responsibility of the organizing committee of ICETEST – 2015
doi:10.1016/j.protcy.2016.05.020

These different configurations make the understanding of torsion in RC members a complex task . In case of torsion, the cracks follow the spiral crack pattern and failure of structural member occurs.

Therefore, strengthening becomes necessary for the achievement of satisfactory strength and serviceability

The load carrying capacity of structural member damaged by deterioration and overloads have been needed the effective techniques. The different strengthening and upgrading procedures are available, out of which, application of FRP is the best solution for torsional strengthening. In the last previous decades, the research has been conducted on the strengthening of Reinforced Concrete beam using epoxy bonded fabric and laminates. The advantages of this technique of FRP bonding are decreased due to construction limitation of structural members and de-bonding of FRP fabrics and laminates. Due to presence of slab, complete wrapping of FRP fabrics and laminates are not possible practically around the cross section of R.C.member.

2. Review of liturature

Previous studies on the torsional strengthening conducted on different parameters such as different configurations of FRP, various thickness of FRP, different epoxy resin used as bonding material etc. Some of the literature studies shown below:

A. Deifalla et al were focused on the experimental study of behavior and analysis of inverted T- shaped RC beams under shear and torsion (Elsevier 2014) that the flange stirrups is more efficient in resisting torsion moment over shear force. Sure Naveen et al were conducted their study on torsional behavior of RC T- beams strengthened with GFRP (ISC 2014) that GFRP proved more effective in strengthening of RC. T- beam when applies to flange at different configurations and fiber orientation. A Deifalla et al shows in effectiveness of externally bonded CFRP strips for strengthening flanged beams under torsion (Elsevier 2013) that full wraps, anchored U- jackets and extended U-jacketed strips found to be more effective compare to the un-anchored U-jackets. Therefore, the objective of the present experimental study is to evaluate and compare the effectiveness of the use of epoxy-bonded carbon and glass FRP fabrics with different configuration as external reinforcement to rectangular Reinforced Concrete beams subjected to torsion. The applied CFRP and GFRP configurations are U-jacked, vertical strips with different spacing, edge strips with vertical strips along its entire length. Torsional capacity of beams of two groups will compare before and after strengthening with twists and ductility factor.

Table 1 -FRP fabric properties

FRP	Young's modulus Gpa	Tensile strength Mpa	Strain at failure (%)	Density (gm/cm2)
GFRP	390-760	3000-4800	3.5 -5.5	2.5-2.6
CFRP	70-90	2400-5100	0.5-1.73	1.85-1.9

3. Experimental work

4.

In the experimental program total thirty nine rectangular RC beams were casted , out of which three are controlled specimens and remaining thirty six are grouped in two categories one with GFRP fabric and another with CFRP fabric with six different bonding patterns as shown in fig-3 and each pattern is having average of three test specimens .

3.1 *Specimen characteristics*

The thirty nine Reinforced Concrete rectangular beam of cross section of 150 × 300 mm and 1200 mm long were casted by using, 2 No's-12 mm and 1 No-10 mm diameter reinforcing bar at bottom and 2 No's-8mm diameter bars at top (Fe500) with 6mm stirrups at spacing 100 mm c/c. (Fe250)

3.2 Material properties

1].Concrete properties : All the RC beams were casted using M30 grade of concrete with 53 grade Ultra tech OPC cement , 20 mm maximum size of coarse aggregate with sp. Gravity 2.66 and river sand having sp. gravity 2.71 with water cement ratio of 0.45 mix proportion ratio by using I.S 10262-2009 is 1: 1.76:2.77. The clear concrete cover to the outer side of stirrup was 20 mm. And these beams were cured in water for 28 days. As the size of beams is considerably bulky, beams are cured in the artificially prepared pond cum tank at the site where all beams were casted.

2] FRP material properties

1. 12k carbon UD fabric - HinFab™ HCU202
2. Glass UD Fabric - HinFab™ HGU900
3. HinPoxy C Epoxy Saturant- Resin + Hardener

Mixing Ratio-

HinPoxy C Resin: HinPoxy C hardener = 100:300 (w/w), Gel time at 30˚ C- 120 minutes.

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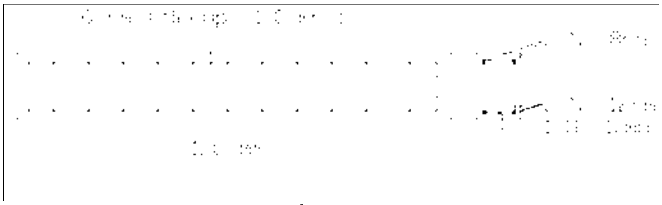


Fig1 Reinforcement in Beam

Fig 2.(a) FRP bonded beam

CFRP AND GFRP Fabric wrapping details :

1. For the three beams, three strips of CFRP are bonded with epoxy resin to the beam which having size 300×300 for both sides front and back with spacing 50 mm from the end .And 100 mm spacing is provided between the strips.
2. Other three beams are bonded with 150×300 strips of CFRP having spacing 100 from the end and 150 between the strips.
3. Next three beams are having 200×300 size of four number strips of CFRP with spacing 50 mm between the strips.
4. Three beams are bonded with the 200 × 300 mm size of strips of CFRP with spacing 50 mm and 75 mm edge strips are also applied at both side along the length.The Bottom strip added to the beam along the length as shown in figure.

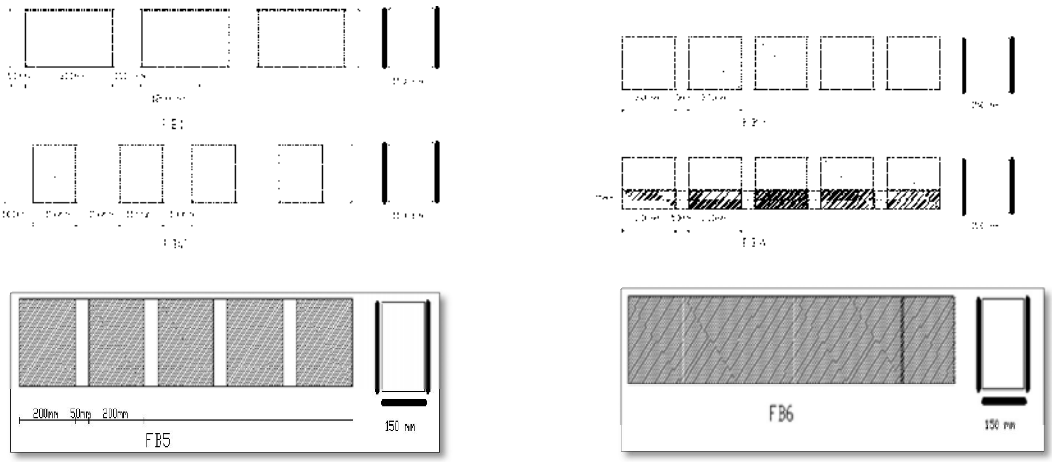


Fig 3 Configurations of CFRP and GFRP

5. Test setup

From the paper convenient assembly is selected and torsion testing assembly is fabricated to fix the beam on the Universal Testing Machine (UTM) as shown in fig 6. So that it can hold the beam in proper position and for the equal distribution of load through lever arm to produce torsion in the beam.

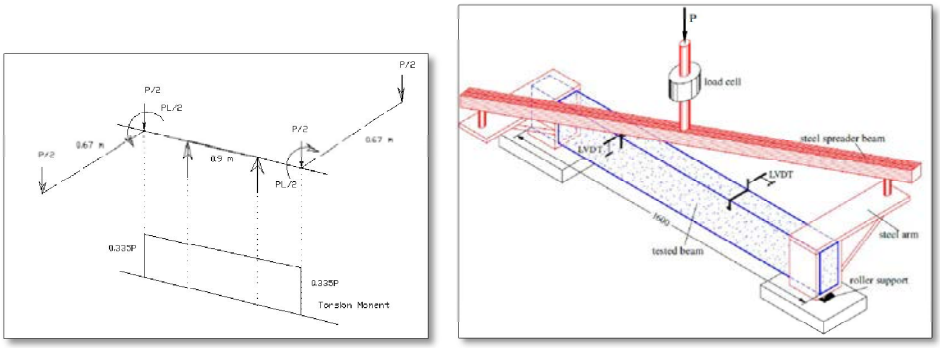


Fig-4 : (a) Mechanism of Torsion ; (b) Testing setup

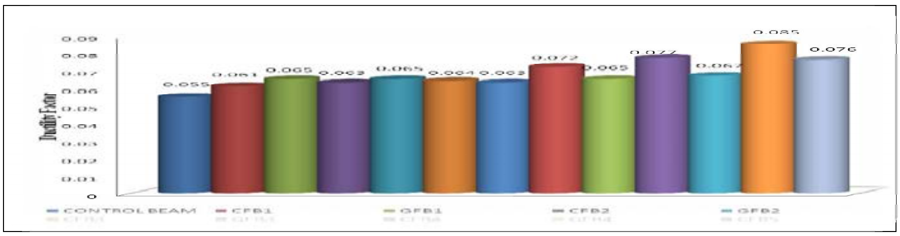
5. Methodology

5.1 Preparation of concrete surface: Beam surface IS cleaned with sand paper because dust, grease and other contaminates may lower the quality of the bond between beam surface and the fabric. After cleaning of concrete surface, we can apply putty to get even surface of concrete.

5.2 CFRP and GFRP bonding: After the surface preparation irregularities can be filled with putty, epoxy resin as an adhesive is prepared by mixing two solutions i.e. Hinpoxy C Resin and Hinpoxy C Hardener in 1:3 proportions. Now after proper mixing of epoxy, one coat is applied to the concrete surface . When it would become partially dry then second coat of epoxy is applied to concrete surface and the fabric is put in position Pressure is applied to the fabric with roller so that the epoxy is uniformly distributed over the surface

5.3 Testing : Testing of the beam includes fixing of the beam on the torsion assembly so that load can be equally distributed through the lever arm. After fixing of the assembly with beam, it is mounted on Universal Testing Machine. Gradual application of load will create the equal and opposite Torsional moment that can be recorded. Recorded readings will provide deflection on dial gauge and it will give angle of twist. Also crack width is measured by using vernier caliper. This will provide the actual Torsional capacity of RC beam strengthen by CFRP and GFRP. Comparison of parameters is done such as torsional capacity,crack width, angle of twist for the RC beam strengthen by CFRP and GFRP wrapping fabric, with controlled beam

Fig 5 Test beam fixed to torsion assembly



Graph 1 Ductility factor of all CFRP and GFRP beam

6. Test result and discussion

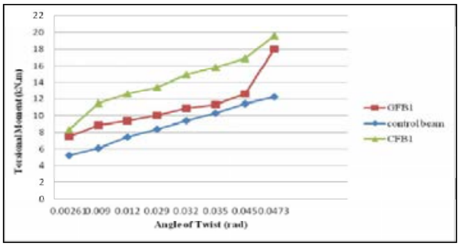
6.1 Test Results

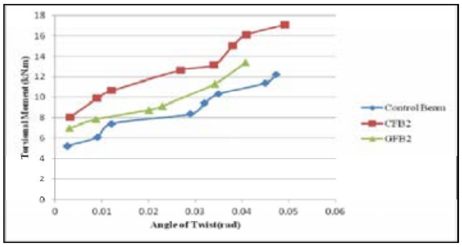
Table 2 Test results of all carbon fibre and glass fibre beams

Sr No	Test Beam	Avg. Cracking Load (kN.)	Avg. Cracking Torsional Moment (kN.)	Avg. Cracking angle of twist (rad)	Avg. Ultimate Load (kN.)	Avg. Ultimate torsional moment (kN.)	Avg. Ultimate angle of twist (rad)	Percentage increase in ultimate torsional moment
1	Control Beam	7.81	5.237	0.00261	19.726	12.22	0.0473	-
2	CFB1	12.433	8.33	0.0033	29.27	19.61	0.0539	60.47
3	GFB1	11.39	7.50	0.00316	26.90	18.02	0.048	47.46
4	CFB2	12.04	8.07	0.0031	25.54	17.11	0.0492	40.02
5	GFB2	10.39	6.96	0.00305	22.99	15.4	0.047	26.02
6	CFB3	12.52	8.39	0.00323	25.55	17.12	0.0505	40.10
7	GFB3	10.78	7.22	0.00310	19.84	13.29	0.049	8.76
8	CFB4	13.94	9.34	0.0038	31.15	21.87	0.0573	70.79
9	GFB4	11.45	7.67	0.00327	28.39	19.021	0.050	55.65
10	CFB5	15.006	10.05	0.00433	33.54	32.46	0.056	83.90
11	GFB5	12.74	8.55	0.00353	30.78	20.62	0.053	68.74
12	CFB6	18.21	12.2	0.00536	36.81	24.66	0.063	101.8
13	GFB6	15.52	10.52	0.00426	33.467	22.423	0.056	83.49

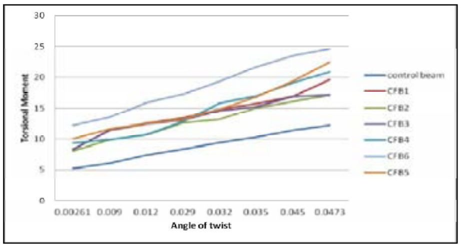
6.2 Discussions

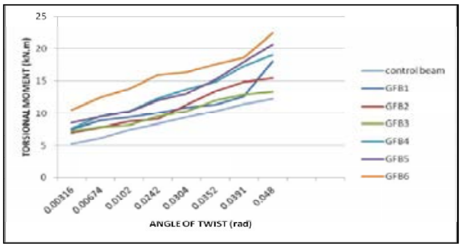
1. The Torsional strengthening is done by using CFRP and GFRP wrapping fabric and on the basis of test results, it shows that the CFB1 has maximum strength than GFB1 and control beam
2. Ultimate Torsional moment of control beam, CFB2 and GFB2 is 12.22 kN.m ,17.11 kN.m ,15.4 kN.m resp. The ultimate angle of twist 0.0473 rad , 0.0492 rad and 0.047 rad for control beam, CFB2 and GFB2 resp.The percentage increase in torsional strength of CFB2 and GFB2 is 40.02% and 26.02%
3. When we make comparison of third pattern, after that the percentage increase in ultimate torsional moment for CFB3andGFB3 is 40.10% and 8.76 % respectively and also it reaches its torsional moment up to 17.12 kN-m for CFB3 and 13.29 kN.-m for GFB3.
4. CFB4 and GFB4 had better results in torsional strength than control beam and percentage increase in torsional moment reaches up to 70.79 % and 55.65 % resp.
5. Test Result shows that the fully U- wrapped fabric is more effective in increasing the torsional strength of CFB6 and GFB6. The torsional moment of CFB6 is greater than GFB6 i.e. 24.66kN.m and 22.423 kN.m respectively and the percentage increase in torsional moment is 101.8% and 83.49 % for CFB6 and GFB6.
6. The ductility factor is the ratio of deflection of RC beam at cracking load to deflection at ultimate load as shown in graph 1.The fully U-wrapped CFRP bonded RC beam having the greater ductility factor i.e. 0.085 and 0.076 for CFB6 and GFB6.As we study the crack width and crack pattern it indicate that the crack width is maximum for control beam i.e. 13.6 mm.As we studied the test result, the CFB6 having lesser crack width i.e. 3 .1 mm as compared to GFB6 i.e 4.1 mm
7. The crack width of CFB2 and GFB2 is 6.8 mm and 5.65 mm respectively.
8. The crack width decreases in the first pattern i.e. 4.2 mm for CFB1 and 5.6 mm for GFB1.
9. CFB5 and GFB5 having crack width 3.2 and 4.3mm





Graph 2 Torsional moment -angle of twist for control beam, CFB1 and GFB1 ; Graph 3 Torsional moment -angle of twist for control beam,CFB2 and GFB2





Graph 6 Torsional moment -angle of twist for comparison control beam,all CFB beams ; Graph 7 Torsional moment -angle of twist for comparison control beam,all GFB beams**.**

Fig 6 Crack width of control beam

Fig 7 CFRP bonded RC beam1 CFB1) beforer testing

Fig 8 CFRP bonded RC beam1 (CFB1) after testing

7. Conclusion

1. It is observed that the torsional moment taking capacity of CFB1 and GFB1 increases by 60.47% and 47.46% with respective to the control beam.
2. The torsional moment capacity of CFB6 and GFB6 is giving highest value and successively decreases for patterns CFB5, CFB4, CFB3, CFB1 and CFB2 and same trend was observed for CFB beams. (Refer fig 3.8)
3. The maximum increase in torsional moment capacity of CFB beam is 101.8% and GFB beam is 83.49%. Also, minimum increase in torsional moment capacity of CFB beam is 40.02 % and 8.76 for GFB beam.
4. As we compare CFRP bonded RC beam with GFRP bonded RC beam then experimentally it proved that CFRP fabric having maximum torsional strength than GFRP fabric.
5. CFRP and GFRP failure may be due to debonding of CFRP and GFRP or crushing of concrete.
6. We can say that crack width decreases due to use of CFRP and GFRP fabric.
7. Due to CFRP and GFRP , ductility of the member also increases. The ductility factor for control beam is 0.055 whereas 0.085 for CFB6 and 0.076 for GFB6 which is the maximum value.
8. The angle of twist is maximum for the CFB6 and GFB6 i.e. 0.063 and 0.053 respectively whereas least i.e. 0.0473 for control beam.
9. Hence, finally we can conclude that, the torsional strength , angle of twist, ductility factor are having maximum value for CFRP bonded beam than GFRP bonbed beam.
10. As we consider the pattern, then fully wrapped U- jacketed beam of both CFRP and GFRP are proved to be more efficient in Torsional strength.

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