COMPARATIVE EXPERIMENTAL STUDY ON TORSIONAL STRENGTHENING OF RC BEAM USING CFRP AND GFRP FABRIC WINDING

Punam Patil[1], Vishal Yendhe[2]

[1,2] *Construction Management of Technology from MIT College of Engineering, Loni Kalbhor, Pune, Maharashtra, India*

***

Abstract - *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 transverse reinforcement to under-reinforced concrete beams with rectangular beams subjected to pure torsion. Thirty three rectangular beam of cross dimension mm and 1200 mm in length constructed under pure torsion. Out of which three are control beam and remaining thirty beams are classified into two group of according to strengthening with CFRP and GFRP wrapping fabric. The applied CFRP and GFRP configurations are U-jacked, vertical and diagonal strips with spacing, edge strips with vertical and diagonal strips along its entire length. Torsional capacity of beams of two groups will compare before and after strengthening with twists and ductility factor. And failure modes will also discuss later.*

1. INTRODUCTION

From the first concrete structure appeared, it is well known that concrete is a building material with high compressive strength and low in tension strength. A concrete beam for instance without any appearance of reinforcement will be cracked and fail when subjected to a relative small load. The failure of the concrete structure may occur suddenly in most cases and in a brittle manner. Therefore, the most common way to strengthen a concrete structure is to use steel reinforcing bars placed in the structure before casting the concrete. Since concrete structures usually have a long lifespan, they have been plagued by deterioration and destruction. Deterioration and destruction are laws of nature the affect even the most modern structures. The structure may have to carry larger loads in the later date due to the change of usage demands or fulfils a new building code. In some extreme cases the performance of concrete structures may be damaged due to an accident. A further reason is that sometime structures are insufficient to carry loads either due to incorrect design or mistakes during construction phase.

If any of these situations arise it is necessary to determine whether it is more economic to strengthen the existing structure or to replace it. In some cases, comparing to build a new structure, strengthening an existing one is often more complicated.

1.2 Mechanical properties of FRP

Most FRP materials are made of fibers with high tensile strength and stiffness, while their strain at failure is lower than that of the matrix. In fact, it is important the matrix have the capability to suffer a higher strains the fiber, if not there will be cracks in the matrix before the fibers fail and the fibers will be unprotected.

1.2.1 DURABILITY

Durability is one of the key issues when a new material is going to be used in structures. Since the application of FRP in civil engineering is quite new there is a little accurate knowledge of the short term and long term behavior of the FRP. However, according to recent study the durability of FRP depends both on specific environmental conditions (alkaline, moisture, high =temperature.) and long term effects (creep and relaxation, fatigue loading).

1.2.2 Environmental effects

Alkaline

Exiting in the form of water contained in the pores of concrete, alkaline environment may cause degradation of the resin and the interface between FRP and support. Resin damage via alkaline is typically severe than due to moisture. In general epoxy exhibit good resistance to alkaline environment. The resin shall complete its curing process prior to being exposed to alkaline environment.

Moisture

The main effect of moisture absorption concerns the resin. The moisture absorption in FRP material depends on the type of resin, laminate composition, thickness quality, curing conditions, the resin – fiber interface, and the working condition. Generally, moisture effects over short – term cause degradation in strength rather than stiffness levels. Product with an epoxy matrix is less sensitive to moisture compared to matrixes of polyester or vinyl ester.

High temperature

The primary effects of temperature depend on the viscous response of both resin and composite. The Young modulus of elastic of the resin will reduce if the temperature rises. In fact, when the temperature exceeds the glass transition temperature, the performance of FRP materials significantly decreases. In general, thermal cycles do not harmful effects on FRP, however they may cause micro-fractures in systems with high modulus resins. For typical temperature in civil engineering, it is possible to use a system where the glass transition temperature is always higher than the maximum operating temperature of the strengthened structure in order to avoid fire damage.

Ultraviolet radiations (UV)

The mechanical performance of FRP – based systems are rarely degraded due to ultravioletradiations. However, in some cases, ultraviolet radiation may cause some resins to have a certaindegree of brittleness and surface erosion. In general, the most harmful effect relevant to UV exposure is the penetration of moisture and other aggressive agents through the damaged surface. FRP –based system may be protected from such damages by adding filters to the resin or by providing appropriate coatings.

1.2.3 LONG - TERM EFFECTS

Creep and relaxation

For most FRP composite, creep deformation becomes a more important role at high stress levels or high temperatures or a combination of the two. In FRP – based system, creep and relaxation depend on both properties of resins and fibers. Such phenomena are more visible when the load is applied transversely to the fibers or when the composite has a low volume ratio of fibers. Creep may be reduced by ensuring low serviceability stresses.

Fatigue effects

In FRP system the fatigue performance depends on the matrix composition and the type of fiber. In unidirectional composites, fibers usually have few defects; therefore, they can effectively delay the formation of cracks. The propagation of crack is also prevented by the action of adjacent fibres.

FRP reinforcement is a composite material that is composed out of small fibers embedded in a matrix material. The most commonly used fibers in the construction industry are the carbon, aramid and glass fibers, where the carbon is preferred in most cases due to the excellent environmental properties, such as-

Good resistance against UV-light

Excellent mechanical properties, like a high strength 7 GPa and high Young’s modulus

1. 200-800 GPa
2. Corrosion resistant
3. Resistant to many chemical solutions
4. Light weight and Low density (1800 kg/m^3)
5. High Fatigue strength
6. Very low coefficient of thermal expansion.
7. High chemical inertness
8. Making use of Carbon Fiber Reinforced Polymer (CFRP) wet lay- up system or CFRP laminates in this project due to their properties with different wrapping techniques.

1.4.4 Application of CFRP

Retrofitting: Its use in industry can be either for retrofitting to strengthen an existing structure or as an alternative reinforcing (or pre-stressing) material instead of steel from the outset of a project.

To Increase Shear Strength: CFRP can also be applied to enhance shear strength of reinforced concrete by wrapping fabrics or fibers around the section to be strengthened. Wrapping around sections (such as bridge or building columns) can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading.

To increase axial capacity of circular column: If a column is circular (or nearly so) an increase in axial capacity is also achieved by wrapping. In this application, the confinement of the CFRP wrap enhances the compressive strength of the concrete.

Seismic retrofit: seismic retrofit is the major application in earthquake-prone areas, since it is much more economic than alternative methods.

Pre-stressing material: CFRP could be used as pre-stressing materials due to their high strength. The advantages of CFRP over steel as a pre-stressing material, namely its light weight and corrosion resistance, should enable the material to be used for niche applications such as in offshore environments.

3. NEED OF STUDY

3.1 TORSIONAL STRENGTHENING OF BEAMS

The structural elements such as the peripheral beams in each floor of multistoried building, edge beams of shell roofs, helical staircases, ring beams at the bottom of circular tank may have chances to fail due to torsional loading in addition to shear and flexure. In case of torsion, the cracks follows 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.

4. METHODOLOGY

The experimental program includes thirty three rectangular RC beams which are sorted in two groups. Three RC beams left as a control beams without application of FRP fabric. On these three reference beams torsion test is going to be conduct. The two groups of fifteen number of Reinforced Concrete beams strengthened using CFRP and GFRP bonded by epoxy resin as a external reinforcement.

4.1 SPECIMEN CHARACTERISTICS

The thirty three Reinforced Concrete rectangular beam of cross section of 150 × 300 mm and 1200 mm long .

Constructed with 500 , 2 No's-12 mm and 1 No-10 mm diameter reinforcing bar at bottom and 2 No's-8mm diameter each reinforced bars at top with 6mm stirrups at spacing 100 m.

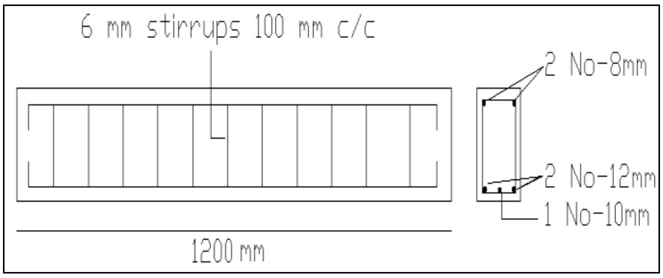


Fig 4.1 Reinforcement details

Fig 4.2 Reinforcing bars and stirrups

M30 Design (IS: 10262: 2009)

Trial Mix Design:

Grade	Comp. load (KN)	Comp. strength (KN/m2)	Weight (Kg)
0.45	560	24.88	8.444
	570	25.88	8.946
	550	24.44	8.882
0.46	520	23.11	8.720
	530	23.55	8.694
	470	20.89	8.552
0.47	510	22.66	8.666
	440	20.21	8.814
	500	22.22	8.780

Volumetric proportion :-

1. 0.15 X0.15 X 0.15 = Vol. of 1m3
2. 3.375 X 10-3 = Vol. of 1m3
3. 3.375 X 10 -3 X 1.3 = Dry concrete
4. 4.3875 X 10 -3 = Dry concrete
5. For 9 cubes = 0.03948 m3

Item	For M30 W/C =0.45 3 cubes	For M30 W/C =0.46 3 cubes	For M30 W/C =0.47 3 cubes
CEMENT	5.382 kg	5.24	5.15
F.A.	9.24 kg	9.28	9.32
C.A.	15.07 kg	15.15	15.20
Water	2.42 kg	2.420	2.42

4.2.2 FRP material properties

1. 12k carbon UD fabric - HCU202
2. Glass UD Fabric - HGU900
3. HinPoxy C Epoxy Saturant- Resin + Hardener
4. Mixing Ratio - HinPoxy C Resin: HinPoxy C hardener 100:300 (w/w)
5. Gel time at 30˚ C- 120 minutes.

Characteristics	Test method	Unit	Specification
Viscosity at 25˚ C	ASTM-D 445	MPa	9000-12000
Epoxy Content	ASTM-D 1662	g/eq	185-192
Density at 25˚ C	ASTM-D 4062	g/cc	1.15-1.20
Flash point	ASTM-D 93	˚C	› 200
Storage life		Years	3

4.3 Configuration of beam

Two groups are formed which contains 15 number of beams. In first group, beams are bonded with CFRP and GFRP with second group of beam. Three beams are left as control beam.

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.

Other three beams are bonded with 150×300 strips of CFRP having spacing 100 from the end and 150 between the strips.

Next three beams are having 200×300 size of four number strips of CFRP with spacing 50 mm between the strips.

These 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.

Same configurations are applied to the Reinforced Concrete beam with GFRP fabric.

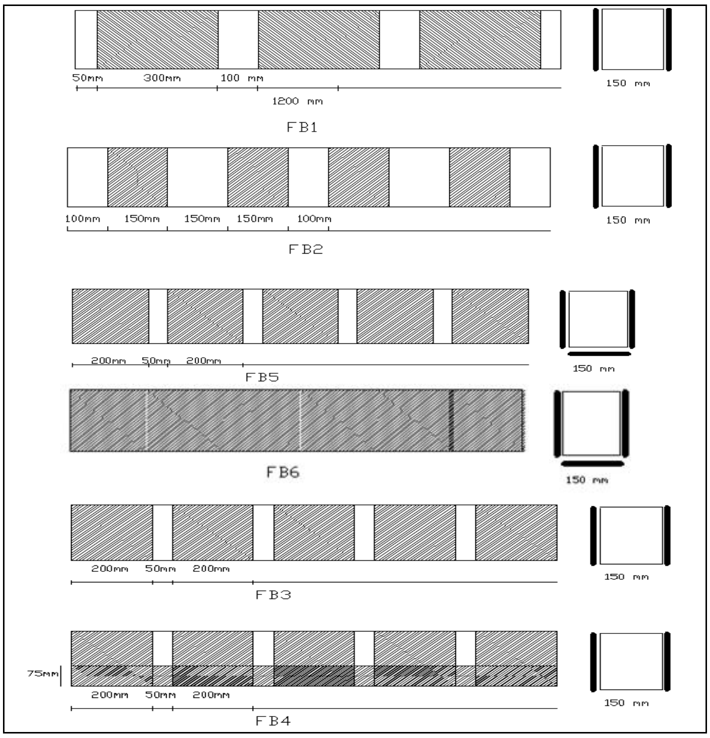


Fig 4.4 Configurations of CFRP and GFRP

4.4 Step by step procedure for bonding CFRP and GFRP to RC beam

4.4.1 Preparation of concrete surface

Beam surface should be cleaned with sand paper because dust, grease and other contaminates may lower the quality of the bond between beam surface and the plate. The Flexural Strengthening of Reinforced Concrete Beams with Pre-stressed FRP Laminates composite will carry high load, therefore it is necessary to create a good bond between the plate and the concrete surface. After cleaning primer is applied over the surface. The primer prevents epoxy from being absorbed by the concrete instead of wetting fibers. The primer also penetrates the concrete via the pores and enhances the bond for the fibre.

4.4.2 CFRP and GFRP bonding

After the surface preparation irregularities can be filled with putty. Epoxy Resin as an adhesive is then applied to the laminate and the laminate is put in place. Pressure is applied to the laminate with roller so that the epoxy is uniformly distributed over the surface. For fabric the adhesive is placed on the concrete surface and the fabric on the adhesive, a new layer of adhesivethat is Epoxy Resin is then rolled on the fabric.

Fig 4.3 CFRP and GFRP bonded RC beam

5. TESTING of RC beams

5.1 Test setup

From the paper convenient assembly is selected and torsion testing assembly is modified to fix the beam on the Universal Testing Machine(UTM) as shown in fig 7. 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.

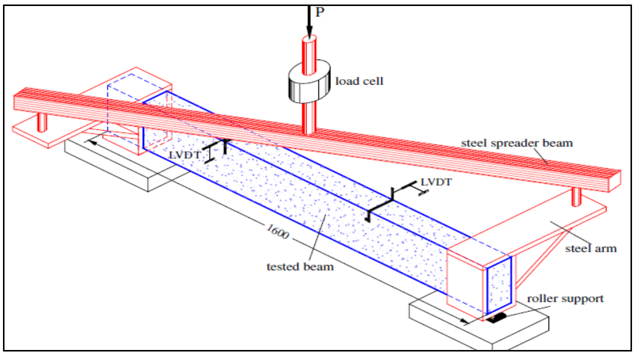


Fig 5.1 testing setup

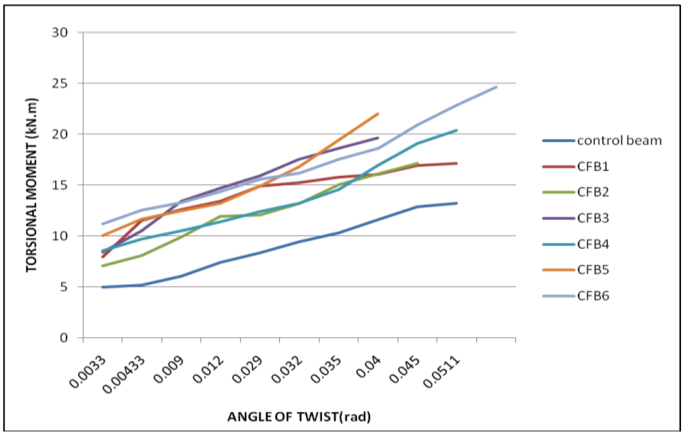
Fig 5.2 Torsion Testing Assembly

5.2 Testing of RC beam

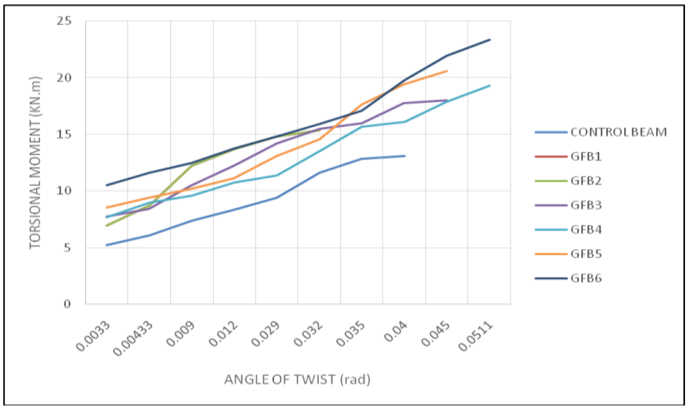
Testing of the beam includes fixing of the beam on the torsion assembly so that load can be equally distributed through the lever arm. After fixing of the assembly with beam, it is mounted on Universal Testing Machine. Gradual application of load will create the equal and opposite Torsional moment that 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 verniercalliper. This will provide the actual Torsional capacity of RC beam strengthen by CFRP and GFRP. Comparison of parameters considered such as torsional capacity, crack width, angle of twist will be done of RC beam strengthen by CFRP and GFRP wrapping fabric.

Sr No	Test Specimen	Cracking Load kN	Cracking Torsional Moment kN.m	Cracking angle of twist (rad)	Ultimate Load kN	Ultimate torsional moment kN.m	Ultimate angle of twist (rad)	Percentage increase / decrease in ultimate torsional moment (%)
1	Control Beam	7.81	5.237	0.0047	19.726	13.22	0.0512	-
2	CFB1	12.04	7.96	0.0033	25.55	17.12	0.0539	29.5
3	GFB1	10.39	6.96	0.00315	23.11	15.4	0.0547	16.491
4	CFB2	12.04	8.07	0.0033	25.551	17.11	0.0539	29.425
5	GFB2	10.39	6.96	0.00315	23.11	15.4	0.0547	16.49
6	CFB3	12.29	8.39	0.00313	29.29	19.61	0.056	48.336
7	GFB3	11.01	7.73	0.00317	26.63	18.02	0.0594	36.309
8	CFB4	12.75	8.53	0.00286	30.81	20.87	0.053	57.867
9	GFB4	11.77	7.67	0.00307	29.36	19.31	0.0537	46.067
10	CFB5	15.006	10.05	0.00333	32.78	21.98	0.058	66.263
11	GFB5	12.74	8.55	0.00313	30.79	20.62	0.0562	55.98
12	CFB6	16.67	11.17	0.00436	36.82	24.66	0.054	86.536
13	GFB6	15.74	10.52	0.00326	34.85	23.35	0.054	76.626

Table No. 5.3 comparison of Test result for all beams



Graph 5.3.1 comparison of Test result for CFRP



5.3.2 Crack width of CFRP and GFRP bonded RC beams

Fig 5.4 Crack width of control beam

Fig 5.4 CFRP bonded RC beam before and after testing

Fig 5.4 GFRP bonded RC beam before and after testing

DISCUSSION

- By testing all the beams, we found that for control beam ultimate torsional moment is greater than cracking torsional moment i.e. 13.22 > 5.237 KN.m cracking angle of twist is 0.0047 rad & ultimate angle of twist is 0.0512 rad

- In wrapping pattern no.1 UTM is greater than CTM i.e. 17.12 kN.m>7.96. cracking angle of twist is 0.0033 rad & ultimate angle of twist is 0.0547 rad. For GFB1 also UTM is greater than CTM i.e 15.4 kN.m>6.96 kN.m cracking angle of twist is 0.00315 rad & ultimate angle of twist is 0.0547 rad

- In wrapping pattern no.2, we found that ultimate torsional moment for CFB2 is 17.11 KN.m which is greater than cracking torsional moment i.e 8.07 KN.m. cracking angle of twist is 0.0033 rad & ultimate angle of twist is 0.0539 rad. For GFB2 results are such that UTM(15.4 KN.m) > CTM(6.96kn.m) &for this cracking angle of twist is 0.00315 rad & ultimate angle of twist is 0.0547 rad.

- For wrapping pattern no.3 for CFB3 UTM is 19.61kN.m and CTM is 8.39kn.m cracking angle of twist is 0.00313 rad and ultimate angle of twist is 0.056 rad. For GFB3 UTM is 18.02kN.m and CTM is 7.73kN.m. cracking angle of twist is 0.00317 rad. And ultimate angle of twist is 0.594 rad.

- In testing of wrapping pattern no.4 for CFB4 UTM is greater than CTM i.e.20.87kN.m>8.53kN.m. Cracking angle of twist is 0.00286 rad and ultimate angle of twist is 0.053 rad. For GFB4 also UTM>CTM i.e. 19.31kN.m>7.67kN.m. Cracking and ultimate angle of twist are 0.00307 rad and 0.0537 rad resp.

- In wrapping pattern no.5 for CFB5 UTM is 21.98kN.m which is greater than CTM which is 10.05kN.m. Angle of twist for cracking and ultimate are 0.00333 rad and 0.058 rad resp. For GFB5 UTM is 20.62kN.m and CTM is 8.55kN.m. cracking and ultimate angle of twist is 0.00313 rad and 0.0562 rad resp.

- In wrapping pattern no.6 we found that UTM of CFB6 is 24.66kn.m and CTM is 11.17kN.m. Angle if twist in cracking is 0.00436 rad and ultimate angle of twist is 0.054 rad. For GFB6 UTM is 23.35kN.m and CTM is 10.52kn.m. Cracking angle of twist is 0.00326 rad and ultimate angle of twist is 0.054 rad.

- From all above results we can see that ultimate torsional moment of CFRP is always greater than GFRP.

- Beams reinforced with CFRP gives more strength than that reinforced with GFRP.

CONCLUSION

- GFRP gives lesser fatigue life comparative of CFRP.

- As GRRP less durable in alkali environment whereas CFRP is more durable in alkali environment.

- GFRP imparts shear strength to the beam but lesser in comparative to the CFRP.

- In case of GFRP angle of twist is slightly greater than the CFRP.

- CFRP is found to be stronger in torsion comparative to GFRP.

- GFRP does not contribute to flexural strength whereas GFRP increase the flexural strength.

- CFRP is effective in strengthening of steel structures to resist higher loads

- CFRP is promising in extending the fatigue life of steel structures.

- The service load on structure can be increased.

- CFRP failure may be due to de-bonding or crushing, depending on slenderness ratio.

- Use of CFRP laminates and sheets that have strength and thickness to increase the overall strength of the structural member and can significantly increase the fatigue life of bridges and other structural systems.

- The use of CFRP sheets and strips is not only effective for restoring the lost capacity of a steel section, as a repair technique, but is also quite effective in strengthening of steel structures to resist higher loads. Strengthening using CFRP results in increasing the yielding load of the steel section. Consequently, the service load can be increased.

- CFRP failure may be due to critical diagonal crack (CDC) de-bonding, concrete cover separation, plate end interfacial de-bonding, crushing of concrete.

- U- Wraps of CFRP laminates or strips can be used to increase shear strength.

- CFRP laminates can be provide at bottom side to increase flexural strength.

REFERENCES

1. Journal of Solids and Structures

2. Joseph W. Tedesco, J. Michael Stallings and Mahmoud EL-Mihilmy(1998) ,'' Rehabilitation Of A Reinforced Concrete Bridge Using Frp Laminates."

3. K. Olivová, J. Bilčík, "Strengthening Of Concrete Columns With CFRP"

4. M.B.S Alferjani, A.A. Abdul Samad, Blkasem. S Elrawaff ,N. Mohamad, M.Hilton and AbdallaA bSinusiSaiah , (2013) " Use of Carbon Fiber Reinforced Polymer Laminate for strengthening reinforced concrete beams in shear"

5. M. Dawood and S. Rizkalla(2008),"Development of a Carbon Fiber Reinforced Polymer System for Strengthening and Repair of Steel Bridges and Structures"

6. M. R. Mohammadizadeh, Mohammad JavadFadaee , and Hamid Reza Ronagh (2009)"Improving Torsional Behaviour of Reinforced Concrete Beams Strengthened withCarbon Fibre Reinforced Polymer Composite", Iranian Composite Journal.

7. R. Santhakumar (2007) "Behaviour of retrofitted reinforced concrete beams under combined bending and torsion", Electronic Journal of Structural Engineering