Performance of Reinforced Concrete Beam using CFRP, GFRP and SSWM Subjected To Torsion

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***Abstract*—A comparative investigation of the torsional behavior of RC beams subjected to torsion with CFRP (carbon fiber reinforced polymer), GFRP (glass fiber reinforced polymer), and SSWM (stainless steel wire mesh) is presented. Ansys tool was utilized to facilitate the finite element analysis of a FRP-layered RC beam. In order to provide a plausible explanation for the efficacy of frps and sswm in terms of torsional strengthening, a series of simulations have been designed to make comparisons between different orientations. The study has analyzed the 1200mm long, 150mm wide, and 300mm deep m30 grade concrete fixed end support beam. CFRP, GFRP, and SSWM configurations are comprised of U-shaped, vertical, and diagonal strips along the full length. The torsional capacity of three sets of beams will be compared prior to and following strengthening with twists and ductility factor. On the basis of experimental studies, most suitable frps and sswm configurations are implemented into beam analysis. Results reveal that the FRP as well as SSWM layers will strengthen the structural beam.**

Keywords: CFRP, GFRP, SSWM, Torsional strenthening, Angle of twist, Finite Element Analysis, RC Beam, Ansys, Utimate torsional moment, fleural strength, shear strength;

I. INTRODUCTION

Using fiber reinforced polymer (FRP) composites, repair and new design procedures for reinforcing reinforced concrete (RC) structures have been developed in recent years. The FRP composite materials are gaining popularity due to their high strength-to-weight ratio, resilience to the elements and ease of application in comparison to materials such as steel. The characteristics is different that of of conventional steel reinforcement. Unlike steel, FRP materials exhibit strong tensile strength solely in the direction of the reinforcing fibers, making them anisotropic. Moreover, prior to failure, FRP composites do not display ductile behavior. The FRP composite strips are utilized to reinforce concrete externally at a predefined failure plane in order to resist shear pressures in shear friction. The FRP & SSWM composite strips are used to externally strengthen concrete at a predetermined failure plane in order to resist shear forces in shear friction. Epoxy resin or adhesive is used to adhere the FRP sheet to the tension face of the flexural member.

The majority of research has been undertaken to examine the influence of FRP on improving flexural and shear behavior. Few studies have utilized FRP and SSWM to reinforce beams subjected to torsion. Punam Patil has studied from an experimental work based on comparison of torsional strengthening of rc beam using CFRP and GFRP winding. It was discovered that GFRP had a shorter fatigue life than CFRP. GFRP delivers shear strength to the beam, although not as much as CFRP. Compared to GFRP, CFRP has greater torsion strength. Depending on the slenderness ratio, CFRP failure may be caused to debonding or crushing. Failure of carbon fiber reinforced polymer can be caused by critical diagonal crack (CDC) debonding, concrete cover separation, plate end interfacial debonding, and concrete crushing. CFRP laminates or strips can be wrapped in a U-shape to increase shear strength. To enhance flexural strength, CFRP laminates can be applied to the bottom. It was determined that the degree of fiber orientation has a substantial impact on the torsional strength of RC beams.

The numerical study employed in Ansys 19.2, finite element software is in a good agreement with the experimental results. It could predict the torsional strength using SSWM as well retrofitting effects with similar to other FRPs. The results showed that the improvement in behavior using ± 45 fiber orientation was more effective for higher values of twisting to bending moment ratios. The thickness of SSWM and FRP has significantly improved the bonding, overall strength and life span of structure. The specification of Reinforced Concrete rectangular continuous deep 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 spaced 100 m. The stress-strain behavior of the beam's rebars is considered to be bilinear and isotropic. The given material parameters of the geometry are listed in table.

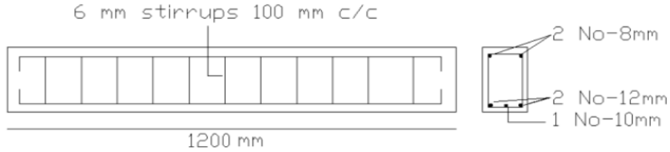


Fig.1.1 Reinforcement details

II. MECHANICAL PROPERTIES

A. Concrete

The concrete beam is a solid element that can crack under strain and crush under compression. When the reinforcing capacity of a solid element's rebar is available, particularly for concrete material. From the perspective of nonlinear material properties, the valuable element is one that, like concrete, is capable of cracking, crushing, plastic deformation, and creep.

Parameters	concrete
Density(kg/m3)	2300
Elastic modulus in x direction (GPa)	2.5e4
Poisons ration in X-Y Plane	0.20

Table 2.1

B. CFRP

CFRP is similar to a layered base orthotropic material whose strength depends on the orientation of its fibers. The CFRP consists mostly of a very thin fiber-based layered surface. Mechanical properties of Carbon fibers are as given in following Table 2.2

Parameter's	CFRP
Density(kg/m3)	1.518e-09
Elastic modulus in x direction (GPa)	1.2334e05
Elastic modulus in y direction (GPa)	7780
Elastic modulus in z direction (GPa)	7780
Shear modulus in xy direction (GPa)	5000
Shear modulus in yz direction (GPa)	5000
Shear modulus in zx direction (GPa)	3080
Poisons ration in X-Y plane	0.27
Poisons ration in Y-Z plane	0.27
Poisons ration in Z-X plane	0.42

C. GFRP

The externally bonded unidirectional glass fiber sheets with layers increase the beam's stability and ductility and reduce the shear failure. The glass fiber sheets are additionally wrapped externally and bonded to the RC deep beams with epoxy resin and its associated hardener. The GFRP sheets are available in a variety of sizes and thicknesses, and the effectiveness of the various sizes varies.

Property(Orthotropic elasticity)	Notation in ANSYS	Value	Unit
Density	ρ	2050	Kg/m3
Young's Modulus X direction	E1	36.3	GPa
Young's Modulus Y direction	E2	10.8	GPa
Young's Modulus Z direction	E3	10.8	GPa
Poisson's Ratio XY	v12	0.28	
Poisson's Ratio YZ	v13	0.09	
Poisson's Ratio XZ	V23	0.28	
Shear Modulus XY	G12	4	GPa
Shear Modulus XY	G13	3	GPa
Shear Modulus XY	G23	4	GPa
Tensile X direction	Xt	596	MPa
Tensile Y direction	Yt	55	MPa
Tensile Z direction	Zt	55	MPa
Compression X direction	Xc	550	MPa
Compression Y direction	Yc	120	MPa
Compression Z direction	Zc	120	MPa
Shear XY	Sxy	86	MPa
Shear YZ	Syz	44	MPa
Shear XZ	Sxz	86	MPa

Table 2.3

D. SSWM

SSWM is a durable strong and corrosion resistant material. It is a locally available material having different wire thicknesses and opening size. Stainless Steel refers to a series of corrosion-resistant iron (FE)-based alloys that contain at least 10.5% chromium (Cr). On the surface of the steel, chromium develops a thin coating of oxide known as the passive layer. This avoids additional surface corrosion. Increasing the amount of chromium strengthens the passive coating, hence enhancing its resistance to corrosion. Molybdenum (MO) and nitrogen (N) are additional components that reinforce the passive film and increase its corrosion resistance. In the presence of air or water, the passive film will spontaneously reform if it is removed or damaged.

Physical and Mechanical properties	AISI 304 SSWM
Density Kg/m3	7850
Wire thickness (100 mesh) mm	0.1
Wire thickness (200 mesh) mm	0.05
Young's modulus GPa	200
Yield strength MPa	280
Ultimate tensile strength MPa	565
Elongation %	52
Compression strength MPa	257
Shear modulus	77
Poisson's ratio	0.275
Hardness, Vickers (HV)	190

Table 2.4 SSWM Physical and Mechanical properties

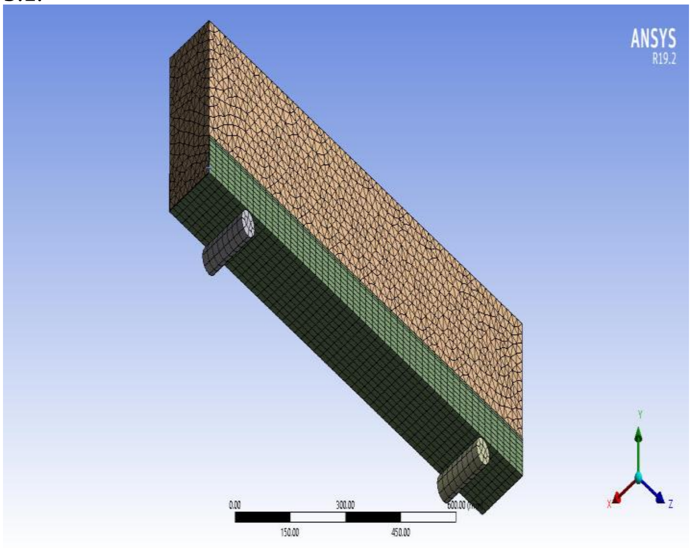
III. MATERIAL MODELING AND NUMERICAL ANALYSIS

Important for load distribution and result generation is the model's meshing. Meshing is the process of dividing a solid into small elements, which reveals the loading effects on each element's behavior. The bond between the beam and FRP and SSWM is to be considered the ideal bond. Before applying load to a beam, the beam's constraints must be specified. Beam has zero degrees of freedom UX, UY, and UZ. Moreover, for the mesh and limited condition depicted in Figure3.1. 6 geometries have been designed for the present study. Outer dimensions of all beams have been kept same. Added U wrapping of CFRP,GFRP and SSWM. CFRP of 2mm, 3mm, 4mm in vertical and angular direction (90º & 45º) is compared with ultimate torsional moment. From the literature experiment are conducted for CFRP & GFRP it shows the initial hair crack from 16.67KN & 15.74 KN started before the load failure occurs 36.82 KN & 34.85 KN . By selecting appropriate element, meshing technique and load, generating the total deformation. After cracking stage, the response is nonlinear until the maximum torque. Beyond the cracking torsional Moment 11.17 kN.m, the nonlinear behavior extends until the failure takes place. The ultimate torque and the corresponding angle of twist of control beam were found to be 24.66kN.m and 0.054 rad/m, respectively.

A. Finite element meshing

FEA Meshing of structural models in Ansys Mechanical is all about balancing accuracy versus computational expense. Typically, finer meshes with smaller elements produce more accurate results.

The meshing for the analyzed deep beams is shown in Figure-3.1.



B. Loading and boundary conditions

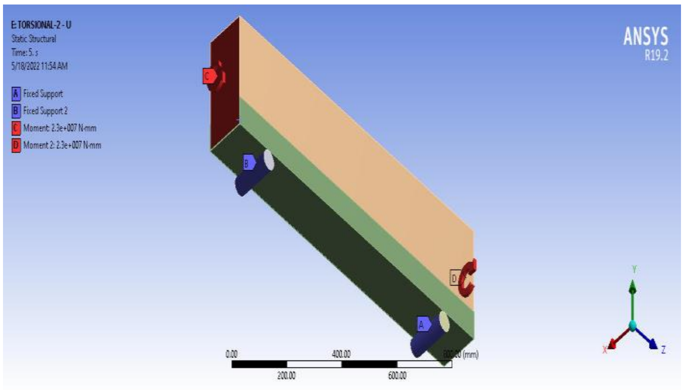


Fig3.2 Loading and boundary conditions

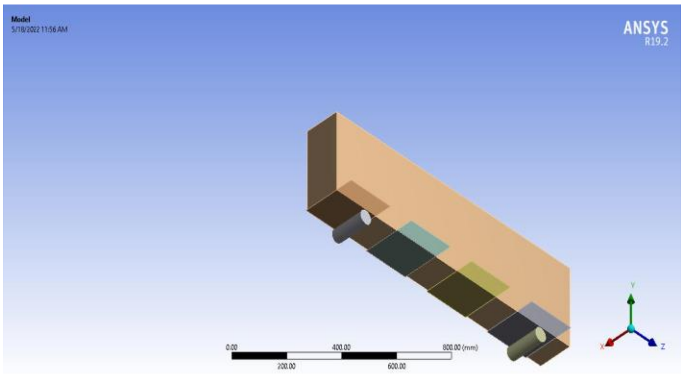


Fig 3.3 GFRP U wrap 45º

- The behavior of the beam will be evaluated with and without FRP/SSWM wrapping at the bottom.
- In CFRP, the orientation also plays a significant role in reducing beam deflection. Therefore, analyzing the CFRP wrapping method for a structure (beam) with respect to the orientation and thickness of its CFRP layers under its loading conditions. Generally, the analysis orientations [45°, 90°] are taken for each single layer.

The CFRP wrapped in a U-shape throughout its length has a higher ultimate torsional moment (UTM) of 24.66 kNm compared to its cracking torsional moment of 11.17 kNm. In cracking, the angle of twist is 0.00436 rad, while the ultimate angle of twist is 0.054 rad. The ultimate torsional moment for GFRP is 23.35kNm, whereas the cracking torsional moment (CTM) is 10.52kn. The angle of twist at fracture is 0.00326 rad, whereas the angle of twist at failure is 0.054 rad. The ultimate torsional moment for SSWM is 23.86kNm, whereas the cracking torsional moment (CTM) is 10.77kn

The CFRP wrapped in U-shaped 45º orientation along its length for UTM is greater than CTM, which is 10.05kNm, by 21.98kNm. The cracking and ultimate twist angles are 0.00333 rad and 0.058 rad, respectively. UTM is 20.62kNm and CTM is 8.55kNm for GFB5. The cracking and maximum angle of twist are 0.00313 rad and 0.0562 rad,. The ultimate torsional moment for SSWM is 21.07kNm, whereas the cracking torsional moment (CTM) is 8.75kn respectively.

Material (2mm)	Orientation 90º u-wrap (UTM)
CFRP	24.66
GFRP	23.35
SSWM	23.86

Table 3.1 material comparison to ultimate torsional moment

Comparing the strength CFRP imparts more strength to the RC beam. Secondly, SSWM is found to be stronger than GFRP. Overall strength achievement can be plunged to 86%. The thickness of FRP can lessen the strain and deformation. Since the effect of CFRP is higher, based on 2mm, 3mm, 4mm the thickness variation effects is also done.

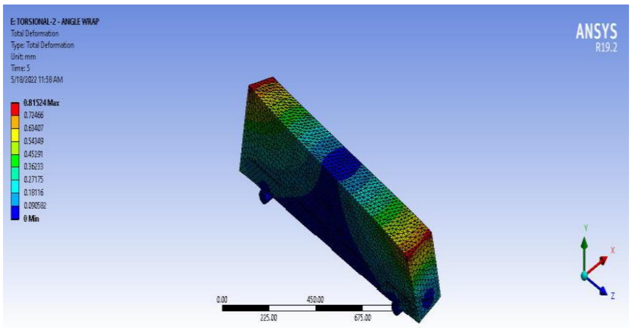


Fig 3.4 Torsional effect on 45 u wrap CFRP

Slno.	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	19.72	13.22	0.051	
2	CFRP 45º Uwrapped 2mm	15.006	10.05	0.00333	32.78	21.98	0.058	66.263
3	GFRP 45º Uwrapped 2mm	12.74	8.55	0.00313	30.79	20.62	0.056	55.98
4	SSWM 45º Uwrapped 2mm	13.75	9.20	0.00326	31.71	21.07	0.057	56.08
5	CFRP 90º Uwrapped 2mm	16.67	11.17	0.00436	36.82	24.66	0.054	86.536
6	GFRP 90º Uwrapped 2mm	15.74	10.52	0.00326	34.85	23.35	0.054	76.62
7	SSWM 90º Uwrapped 2mm	16.11	11.31	0.00380	35.86	23.93	0.054	81.79

CFRP (thickness in mm)	90ºorientation (ultimate torsion moment) kN.m	45ºorientation (ultimate torsion moment)
2 mm	24.66	21.98
3 mm	28.35	25.27
4 mm	34.52	30.77

Table 3.2 CFRP ultimate torsional moment

IV. RESULTS AND DISCUSSION

- By assigning acceptable material parameters and an appropriate relationship between concrete and FRP, a numerical study can be utilized to anticipate the behavior of retrofitted reinforced concrete beams more precisely.
- Most researchers examined rectangle beams for flexural and shear strengthening with different types of FRP with constant thicknesses of GFRP and which are strengthened with one, two, and three layers of FRP without curtailment. They discovered that the strength increased with the number of layers, but in a decreasing manner.
- The flexure and shear performance of carbon-reinforced polymer is superior than the performance of glass fiber-reinforced polymer and stainless steel wire mesh.
- The conclusion of an experimental study was that composite pattern/configuration can directly alter the behavior of load versus deflection. Both the load and deflection of the beam were changed by composite configuration. Analysis of the different configurations of FRP and SSWM under torsion Later on, the author can implement the optimal configuration for various support situations and loads.
- Deflection of the retrofitted beam with CFRP is minimized by approximately 86.53 percent compared to the controlled beam, deflection of the retrofitted beam with GFRP is minimized by approximately 76.62 percent compared to the controlled beam, deflection of the retrofitted beam with SSWM is minimized by approximately 81.79 percent compared to the controlled beam, and the load carrying capacity of the retrofitted beam is greater than the controlled RC beam specimen.

V. TORSIONAL STRENGTHENING

a) In current practise, torsional strengthening of concrete members is accomplished by one of the following techniques: 1) increasing the member cross-sectional area and adding transverse reinforcement, 2) using externally bonded steel plates and pressure grouting the gap between the plate and concrete element, or 3) applying an axial load to the member by post-tensioning. Torsion in beams is often divided into two categories: main and secondary. Primary torsion, also known as equilibrium torsion, is essentially a strength issue in which members break when torsional loads surpass the member's torsional strength. This is most prevalent in statically determined structures. In contrast, secondary torsion, which is the outcome of continuity needs in statically indeterminate structures, is the latter type, which in some cases can cause catastrophic damage if continuity requirements are disregarded. When torsion acts on an RC member, it generates two orthogonal diagonal loops, one of which is in compression and is often opposed by concrete, and the other in tension and is typically opposed by steel or other reinforcements.

b) Torsion setup

Lever arms were attached to the specimen to create a torsional moment, as seen in Figure 5.1. The specimen underwent pure torsion when the placement of a lever arm corresponded with the location of the support. The lever arm was kept beyond the two supports to apply bending and torsion simultaneously.

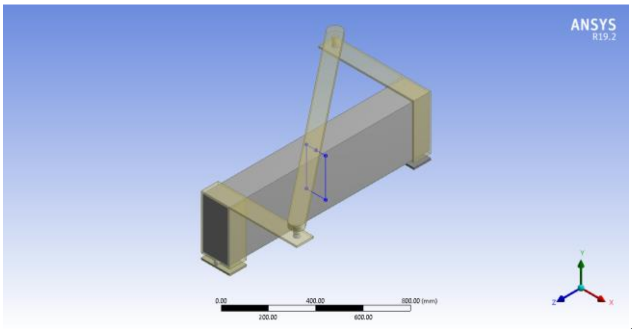


Fig 5.1 torsion test

ACKNOWLEDGMENT

I 'am grateful to the Almighty who is the "source of knowledge" and one who guides us in all aspects to bring out this paper work a successful one. I express my deep respect and profound gratitude to our college management committee for providing us an opportunity and infrastructure to undertake this paper work. I express my sincere gratitude to Prof. Dr. Vinod P

Vijayan, Principal, Mangalam College of Engineering and Prof. Dr. D. Ramesh Kumar, Head Of Civil Department for providing an opportunity to undertaken this work. I express sincere gratitude to my family and friends for encouraging in the completion of this work.

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