International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 9 Sep. 2022, pp: 64-77 www.ijaem.net ISSN: 2395-5252

Analysis of Torsional Behavior of Reinforced Concrete Beams Strengthened With Aramid Fiber Strips

Abhirami T. S., Nikhil R.

PG iiStudent, iiDept iiof iiCivil iiEngineering, iiUniversal iiEngineering iiCollege, Thrissur.Kerala.
Assistant iiProfessor, iiDept. iiof iiCivil iiEngineering, iiUniversal iiEngineering College, iiThrissur. iiKerala.

Date of Submission: 01-09-2022 Date of Acceptance: 08-09-2022

ABSTRACT

Torsional failure mostly occurs in earthquake prone areas subjected to rapid failure of buildings. In this research, the strengthening of reinforced concrete (RC) beams for its torsional behavior using aramid fiber strips is carried out. Most of the time aramid fiber is used as an externally bonded reinforcement to increase flexural and shear strength of RC beams. An innovative attempt is made to use it for improving torsional moment carrying capacity of RC beam. Different patterns of aramid fiber strips are selected to wrap around RC beams and torsional behavior of these strengthened beams is studied. The main focus of this research is, to analyze the improvement in torsional moment carrying capacity of RC beam using aramid fibers and by changing the parameters of the FRP wrapping to find the best suited torsional moment carrying capacity.

In this paper, RC beam of M30 grade of concrete is strengthened with aramid fiber strips and the beam size is 150 mm×300 mm and of 1.3 m in length, designed as per IS456- 2000 the following were modeled, analyze, and designed using ANSYS 2021 R2 software. The wrapping of FRP, improve the torsional moment carrying capacity of RC beams and the effect of different configurations of aramid fiber on torsional moment carrying capacity, angle of twist and failure mode of the beams is compared.

Keywords: Aramid fiber, Strengthened beams, Orientations in wrapping, Torsional reinforcement, Angle of twist, Finite-element method

I. INTRODUCTION

The civil engineering structures constructed about 50 years ago are now reaching a crucial stage, enduring deterioration, and experiencing decreasing functionality. Current constructions must be properly protected and strengthened if they are to function satisfactorily. In recent years, strengthening reinforced concrete structures has become a well-known strategy. The purpose of strengthening is to highlight shape flaws brought about by the alteration of building codes. Buildings constructed using outdated codes are currently unable to meet demand. In the majority of cases, the behavior of reinforced and unreinforced beams is investigated using various fiber reinforced polymers (FRP).

After being loaded, reinforced concrete members need to be assessed, and if any of them have some degree of damage, they need to be immediately repaired. In contrast to traditional materials like steel plates, FRP material can be wrapped in any size and shape. FRP is more expensive than other materials since it is made of fibers and resins. But it is simple to install and requires relatively little effort and equipment. In regions with limited access where conventional procedures are impractical, FRP can be deployed. Continuous carbon, glass, or aramid fibers are bonded together in an epoxy, vinylester, or polyester matrix to form FRP composites. In FRP, fibers take on the load while plastic and matrix materials convey shear. FRP is a material that can be strengthened and retrofitted in the form of strips, sheets, or laminates.

II. MATERIALS USED

2.1 FIBER REINFORCED POLYMER (FRP)

A polymer that has fiber reinforcement is referred to as a fiber reinforced polymer (FRP) composite. It stands for a group of materials that are classified as composite materials. Particles of one or more materials are dispersed in another substance to create composite materials, which are surrounded by a continuous network of the first material.

Compared to conventional building materials like steel and aluminum, FRP composites are unique. Steel and aluminum are isotropic, whereas FRP composites are anisotropic. As a result, they have directional qualities, meaning that the direction of the fiber implantation is where the optimum mechanical properties are located. These materials have excellent corrosion resistance, a high strength-to-density ratio, and practical electrical, magnetic, and thermal properties. The qualities of composite materials are frequently controlled by the fibre choice. There are three main types of fibres used in construction: carbon, glass, and aramid. CFRP stands for carbon fibre reinforced polymer, which is how the material is frequently identified. Stiffness and tensile strain are the main characteristics that differ between the various fibre kinds. Here aramid fiber strips of AFRP Kevlar 49 were used.

Fig 2.1: Aramid Fiber Sheet

Table 2.1 Material properties of AFRP

Properties	**AFRP**
Density (Kg/m^3)	1500
Young’s modulus (MPa)	79000
Yield strength (MPa)	1400
Poisson’s ratio	0.3
Bulk modulus (Pa)	6.5833
Shear modulus (Pa)	30385

2.2 CONCRETE AND STRUCTURAL STEEL BARS

Table 2.2 Material properties

Concrete	Grade of concrete – M30
	Density, ρ – 2500 kg/m^3
	Shear modulus, G – 1.14 × 10^{10} Pa
	Bulk modulus, B – 1.52 × 10^{10} Pa
	Poisson's ratio, μ – 0.2

Structural Steel bar	Density, ρ – 7850 Kg/cm^3
	Bulk modulus, B –17.16 × 10^{11} Pa
	Shear modulus, G – 7.92 × 10^{10} Pa
	Poisson's ratio, μ – 0.3

III. MODELLING BEAMS

Reinforced concrete beams are modelled in ANSYS software with different angles of aramid fiber strips. In this, four categories of beams were created with difference in angle and layer of AFRP. It includes:

- Beam with single layer FRP wrapping in 0˚, 30˚, 60˚ angle
- Beam with two layers AFRP wrapping in 0˚, 30˚, 60˚ angle
- Beam with two layers AFRP wrapping in 0˚, 30˚, 60˚ angle by half number
- Beam with single layer of AFRP wrapped in double angle 30˚, - 30˚ and 60˚, - 60˚ respectively.

Table 3.1 Dimensional details of RC beam

Total length of beam, L	1300 mm
Width of Beam, b	150 mm
Depth of beam, d	300 mm

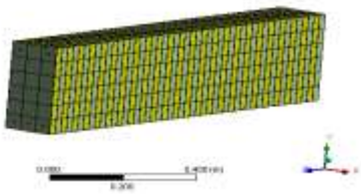
RC beam with steel reinforcement under torsional moment is taken. M30 grade of concrete mix is used and water: cement ratio is 0.45.

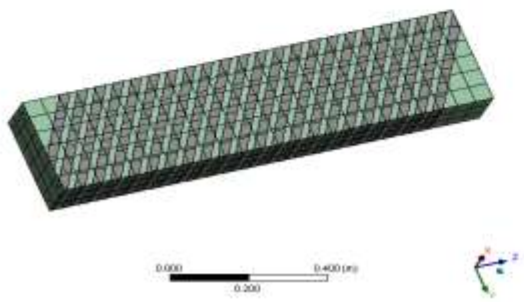
IV. ANALYSIS OF RC BEAM WITH SINGLE LAYER OF ARAMID FIBER WRAPING

Three models are created using ANSYS software with three different angle profile for aramid fiber strips. The different angles used for wrapping are 0˚, 30˚, 60˚. The concrete type used is M30 Grade Concrete.

4.1 Meshing and loading

Reinforced concrete beam is modelled using rectangular mesh which is a 4-noded mesh, having mesh size of 50 mm and in hexahedron shape. Three models where created, 0˚, 30˚, 60˚ angles with same mesh properties.





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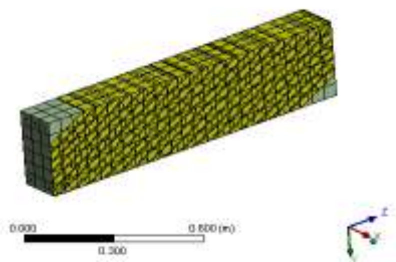

Fig. 4.1 Meshing of RC beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

4.2 Analysis

Analysis is carried out to study the torsional moment carrying capacity of reinforced concrete beams wrapped with two layer of aramid fiber strips. Nonlinear static structural analysis is carried out in ANSYS software. Deformation due to torsional moment and angle of twist is studied for various angle of wrapping. The deformation diagrams are shown below.

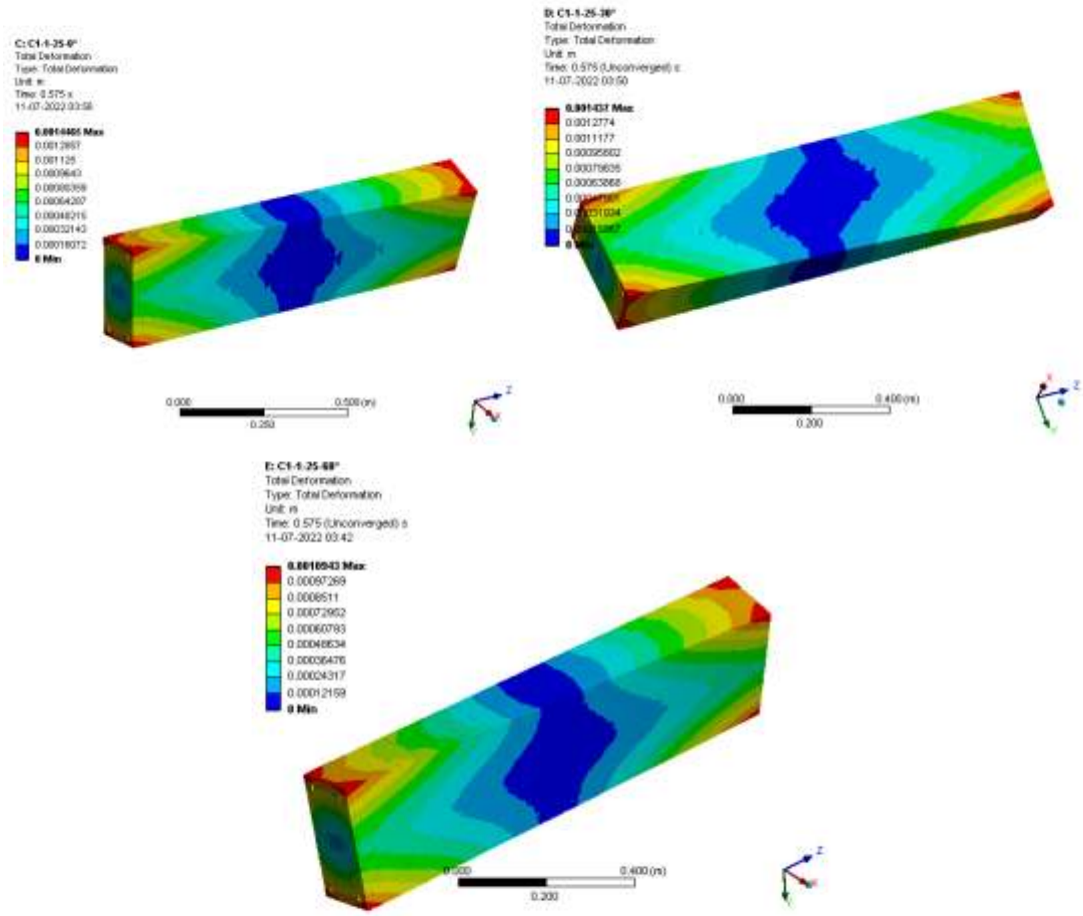

Fig. 4.2 Total deformation of RC Beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

4.3 Results and Discussions

The result obtained from the Nonlinear static structural analysis of reinforced concrete beams wrapped with aramid fiber strips in 0˚ angle, 30˚ angle and 60˚ angle is compared on the basis of total moment carrying capacity. For that

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deformation curve is taken for each model. The highest moment carrying capacity and angle of twist obtained are compared. The Table 4.4 shows the highest torsional moment and rotation of the 3 beams by changing the angle of AFRP wrapping and Fig.4.3 show comparison of Torsional moment and angle of twist. Highest moment carrying capacity shown by C1-1-25-30°.

Table 4.4 Result comparison of Angle of Twist and Moment of RC Beam

Beam Name	Rotation(rad)	Moment (kNm)	Moment (Nm)
C1-1-25-0°	0.02	11.22	11217
C1-1-25-30°	0.02	11.54	11536
C1-1-25-60°	0.0065	11.1	11103

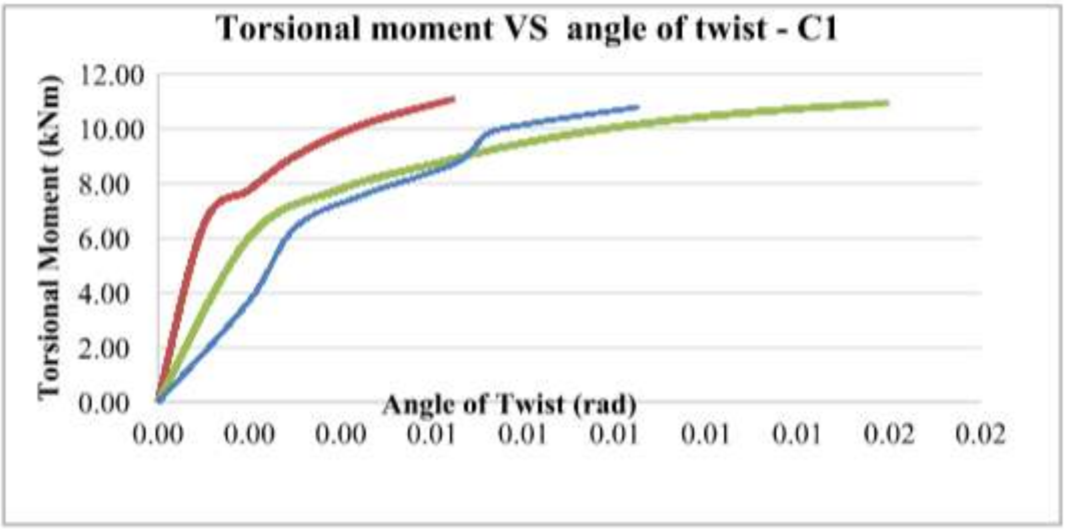

Fig. 4.3 Graph of Torsional moment VS angle of twist

V. ANALYSIS OF RC BEAM WITH TWO LAYER OF ARAMID FIBER WRAPING

Three models are created using ANSYS software with three different angle profile for aramid fiber strips. The different angles used for wrapping are 0˚, 30˚, 60˚. The concrete type used is M30 Grade Concrete.

5.1 Meshing and loading

Reinforced concrete beam is modelled using rectangular mesh which is a 4-noded mesh, having mesh size of 50 mm and in hexahedron shape. Three models where created, 0˚, 30˚, 60˚ angles with same mesh properties.

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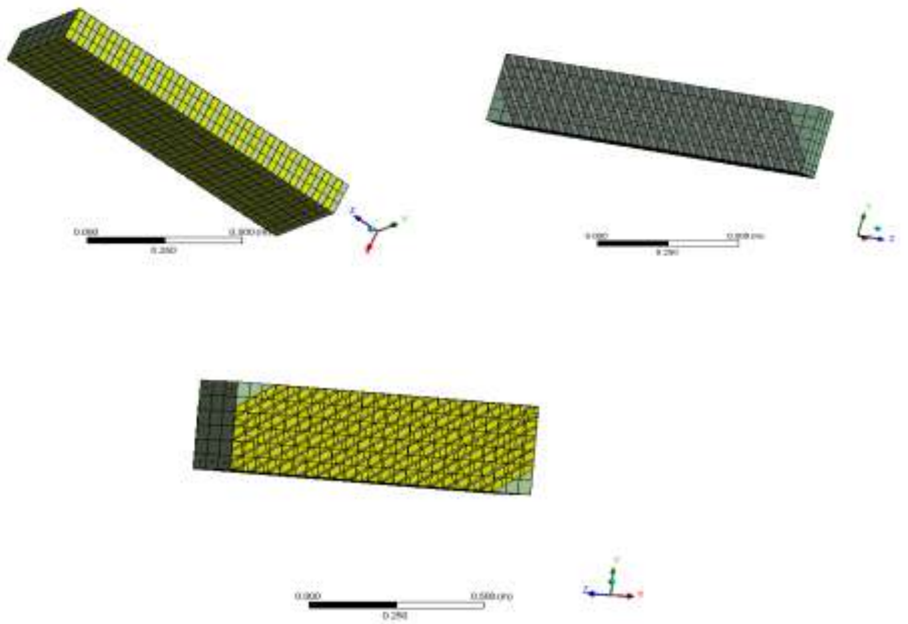
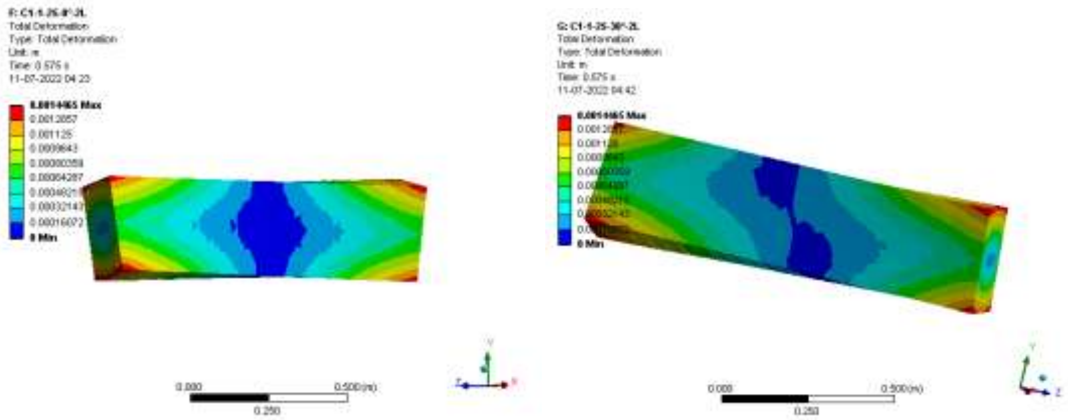


Fig. 5.1 Meshing of RC beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

5.2 Analysis

Analysis is carried out to study the torsional moment carrying capacity of reinforced concrete beams wrapped with two layer of aramid fiber strips. Nonlinear static structural analysis is carried out in ANSYS software. Deformation due to torsional moment and angle of twist is studied for various angle of wrapping. The deformation diagrams are shown below.



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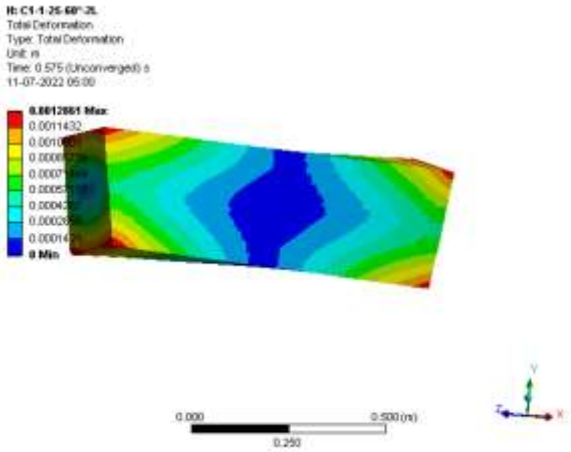

Fig. 5.2 Total deformation of RC Beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

5.3 Results and Discussions

The result obtained from the Nonlinear static structural analysis of reinforced concrete beams wrapped with two layer of aramid fiber strips in 0˚ angle, 30˚ angle and 60˚ angle is compared on the basis of total moment carrying capacity. For that deformation curve is taken for each model. The highest moment carrying capacity and angle of twist obtained are compared. The Table 5.5 shows the highest torsional moment and rotation of the 3 beams by changing the angle of AFRP wrapping and Fig.5.3 show comparison of Torsional moment and angle of twist. Highest moment carrying capacity shown by C1-1-25-30°-2L.

Table 5.5 Result comparison of Angle of Twist and Moment of RC Beam

Beam Name	Rotation(rad)	Moment (kNm)	Moment (Nm)
C1-1-25-0°-2L	0.02	11.64	11636
C1-1-25-30°-2L	0.02	13.25	13248
C1-1-25-60°-2L	0.01	12.94	12938

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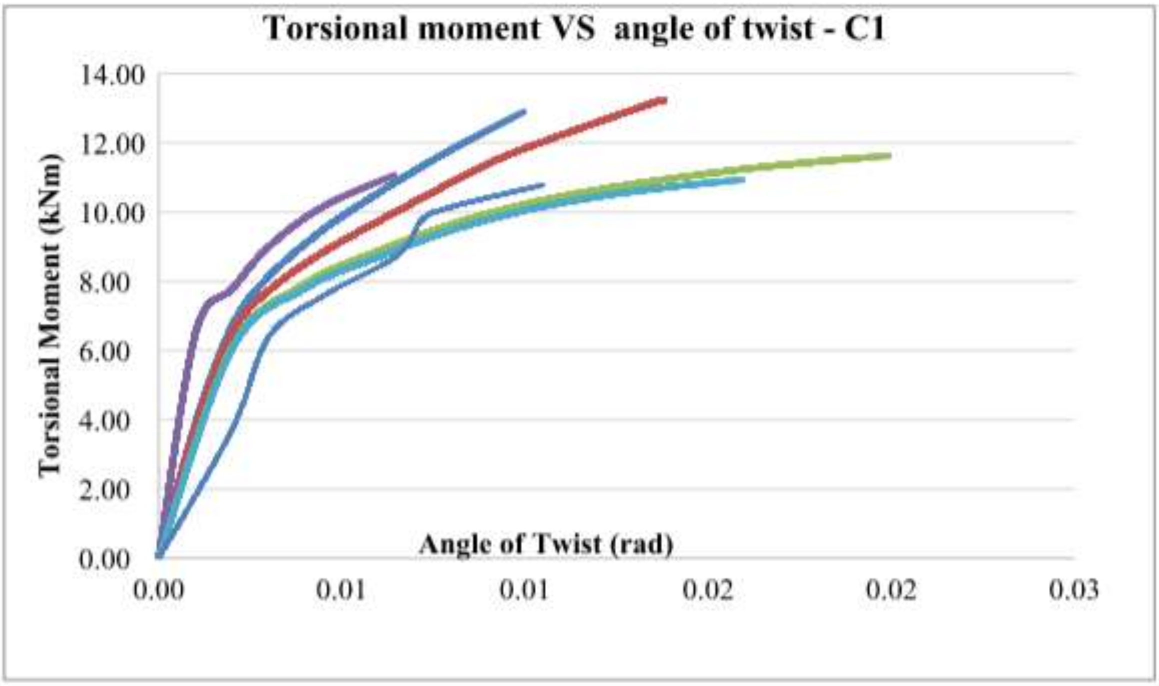


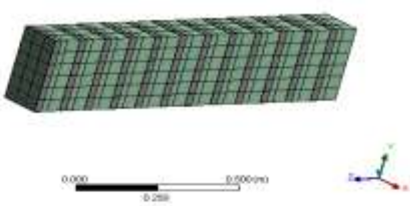
Fig. 5.3 Graph of Torsional moment VS angle of twist

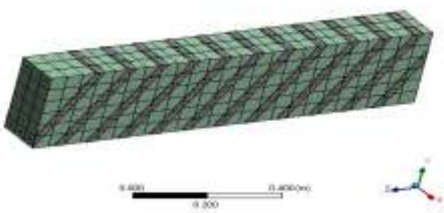
VI. ANALYSIS OF RC BEAM WITH HALF NUMBER OF TWO LAYER ARAMID FIBER WRAPING

Three models are created using ANSYS software with three different angle profile for aramid fiber strips. The different angles used for wrapping are 0˚, 30˚, 60˚. The concrete type used is M30 Grade Concrete.

6.1 Meshing and loading

Reinforced concrete beam is modelled using rectangular mesh which is a 4-noded mesh, having mesh size of 50 mm and in hexahedron shape. Three models where created, 0˚, 30˚, 60˚ angles with same mesh properties.





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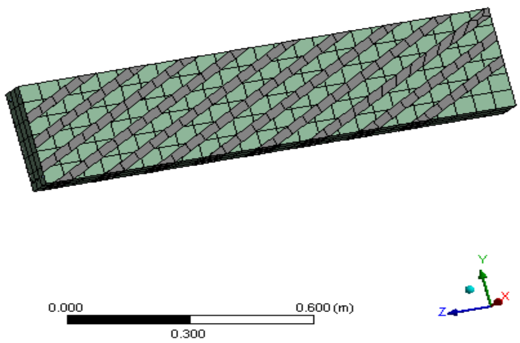

Fig. 6.1 Meshing of RC beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

6.2 Analysis

Analysis is carried out to study the torsional moment carrying capacity of reinforced concrete beams wrapped with half number of two layer of aramid fiber strips. Nonlinear static structural analysis is carried out in ANSYS software. Deformation due to torsional moment and angle of twist is studied for various angle of wrapping. The deformation diagrams are shown below.

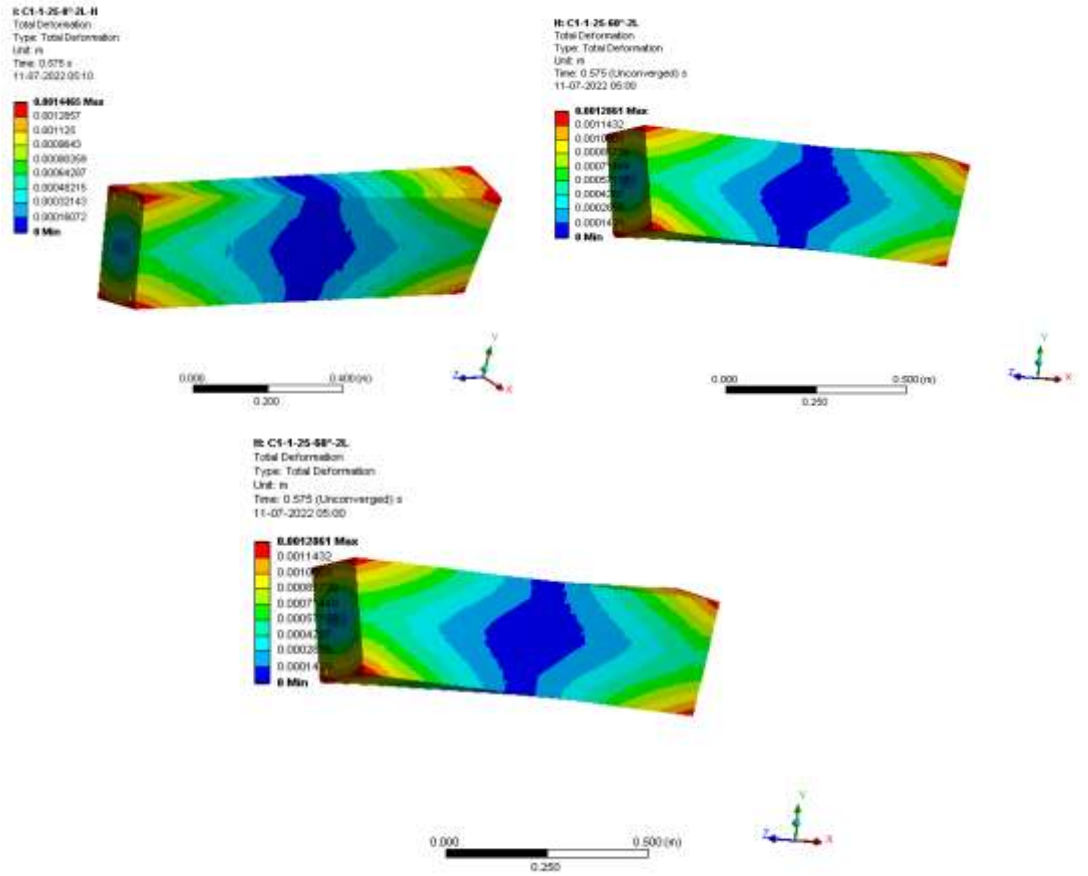

Fig. 6.2 Total deformation of RC Beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

6.3 Results and Discussions

The result obtained from the Nonlinear static structural analysis of reinforced concrete beams wrapped with half number two layer of aramid fiber strips in 0˚ angle, 30˚ angle and 60˚ angle is compared on the basis of total moment carrying capacity. For that deformation curve is taken for each model. The highest moment carrying capacity and angle of twist obtained are compared. The Table 6.6 shows the highest torsional moment and rotation of the 3 beams by changing the angle of AFRP wrapping and Fig.6.3 show comparison of Torsional moment and angle of twist. Highest moment carrying capacity shown by C1-1-25-30°-2L-H.

Table 6.6 Result comparison of Angle of Twist and Moment of RC Beam

Beam Name	Rotation (rad)	Moment (kNm)	Moment (Nm)
C1-1-25-0°-2L-H	0.02	10.92	10920
C1-1-25-30°-2L-H	0.0115	11.4	11396
C1-1-25-60°-2L-H	0.0072	10.31	10310

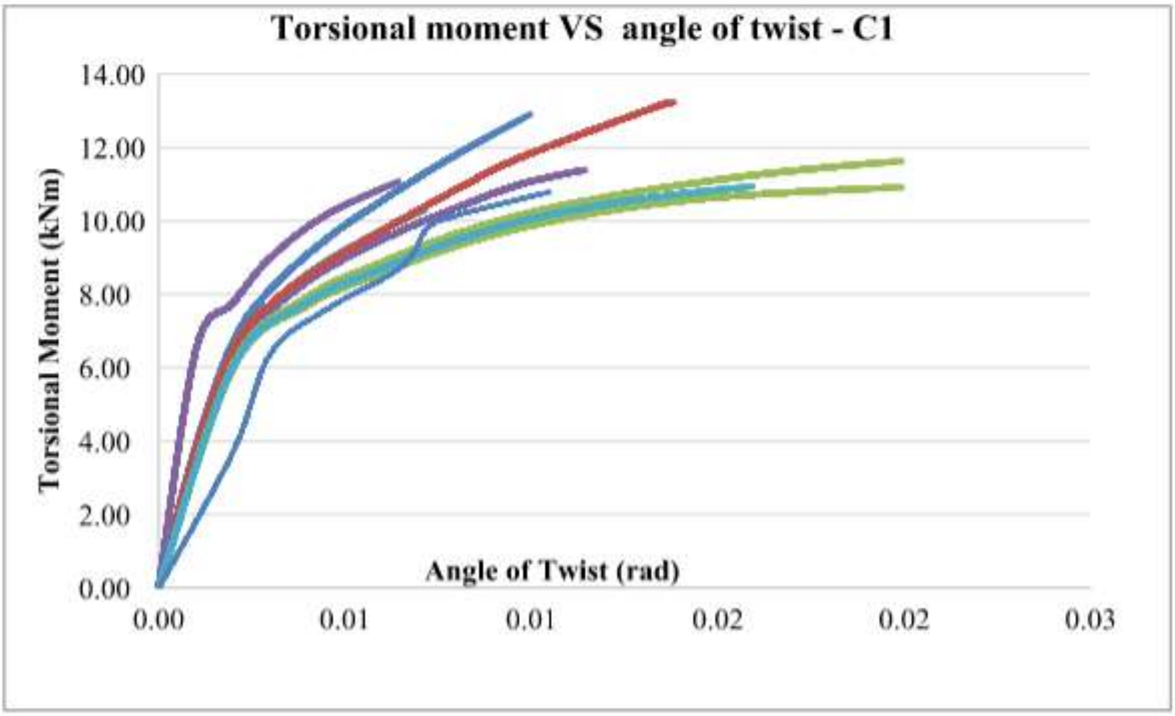

Fig. 6.3 Graph of Torsional moment VS angle of twist

VII. ANALYSIS OF RC BEAM WITH SINGLE LAYER OF ARAMID FIBER WRAPING IN OPPOSITE ANGLES

Two models are created using ANSYS software with two different angle profile for aramid fiber strips. The different angles used for wrapping are 30˚, 60˚ and -30˚, -60˚. The concrete type used is M30 Grade Concrete.

7.1 Meshing and loading

Reinforced concrete beam is modelled using rectangular mesh which is a 4-noded mesh, having mesh size of 50 mm and in hexahedron shape. Two models where created, 30˚, 60˚ angles with same mesh properties.

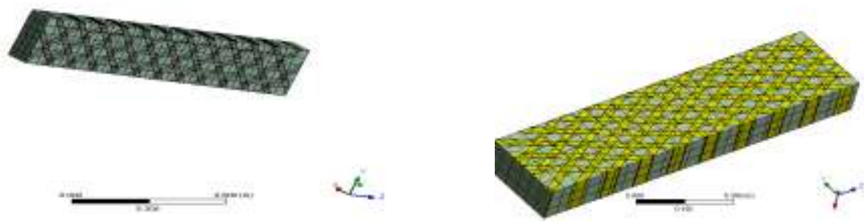

Fig. 7.1 Meshing of RC beam with 0˚, 30˚ and 60˚ angle of FRP wrapping

7.2 Analysis

Analysis is carried out to study the torsional moment carrying capacity of reinforced concrete beams wrapped with single layer of aramid fiber strips in opposite angles. Nonlinear static structural analysis is carried out in ANSYS software. Deformation due to torsional moment and angle of twist is studied for both angles of wrapping. The deformation diagrams are shown in Fig.8.60 to8.61.

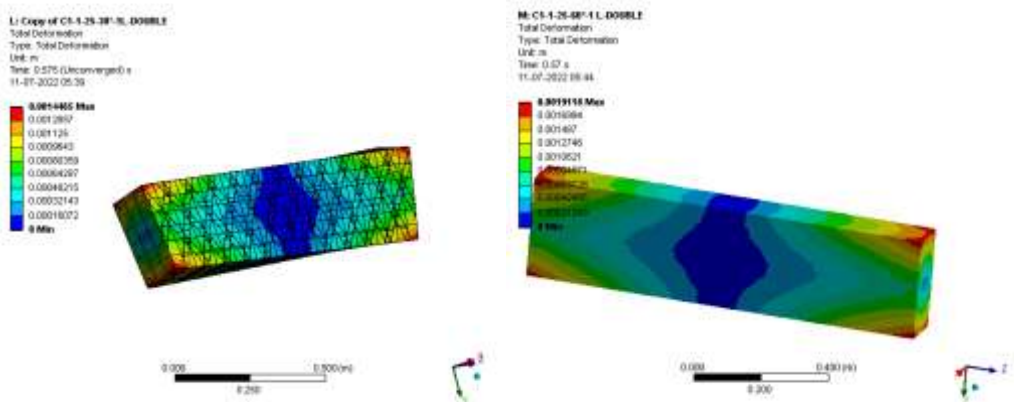

Fig. 7.2 Total deformation of RC Beam with 30˚ and 60˚ angle of FRP wrapping

7.3 Results and Discussions

The result obtained from the Nonlinear static structural analysis of reinforced concrete beams wrapped with single layer of aramid fiber strips in 30˚ and 60˚ in opposite angle of orientation is compared on the basis of total moment carrying capacity. For that deformation curve is taken for each model. The highest moment carrying capacity and angle of twist obtained are compared. The Table 8.29 shows the highest torsional moment and rotation of the 3 beams by changing the angle of AFRP wrapping and Fig.6.39 show comparison of Torsional moment and angle of twist. Highest moment carrying capacity shown by C1-1-25-30°-1L-DOUBLE.

Table 7.7 Result comparison of Angle of Twist and Moment of RC Beam

Beam Name	Rotation(rad)	Moment (kNm)	Moment (Nm)
C1-1-25-30°-1L -DOUBLE	0.0113	10.52	10516
C1-1-25-60°-1L -DOUBLE	0.057	12.23	12228

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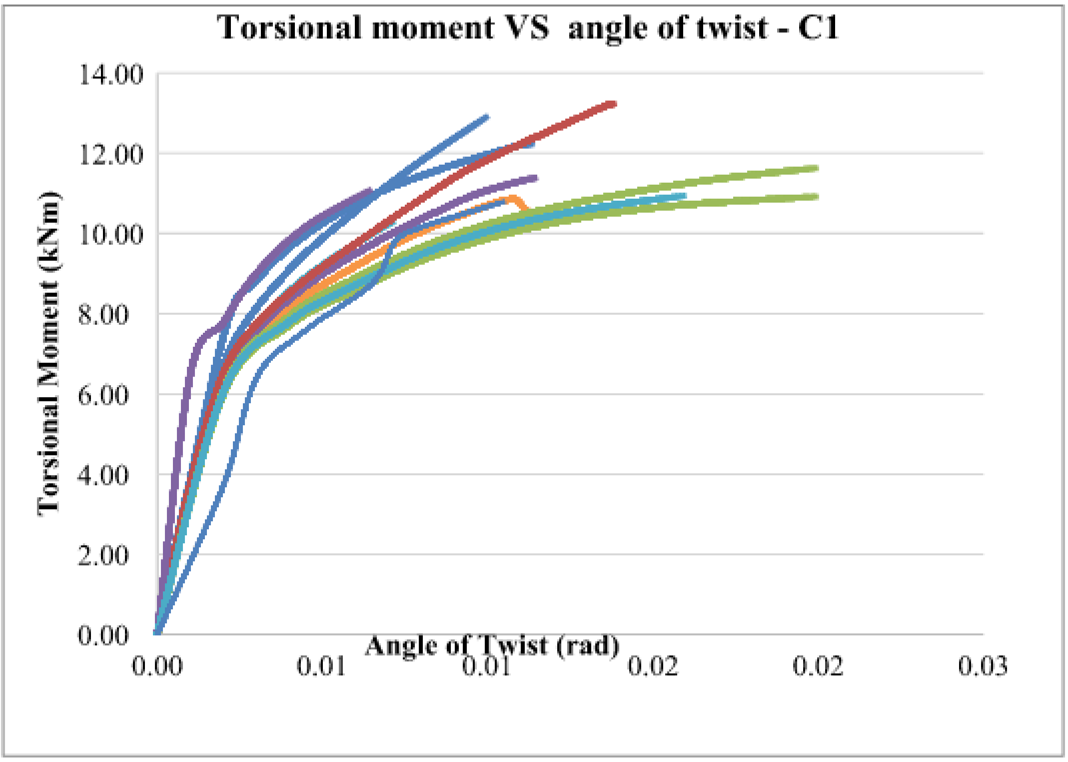

Fig. 7.3 Graph of Torsional moment VS angle of twist

VIII. RESULTS COMPARISON

When comparing four categories of beam with aramid fiber wrapping, that is wrapping in single layer, Two-layer, Two layer by half number of AFRP strips, Single layer in opposite angle. The moment carrying capacity for beams wrapped with aramid fiber strips in 30˚ angle shows highest value in four categories. Whereas, the beam wrapped with two layers of AFRP in 30˚ angle shows high torsional capacity than others.

Percentage decrease in moment carrying capacity of AFRP wrapped beam when compared with moment carrying capacity of normal beam is studied and it shows heavy increase in torsional capacity.

Table 8.8 Result comparison with percentage decrease in moment

	Rotation (rad)	Torsional Moment (kNm)	% Increase in Moment
Controlled beam	0.0044	3.30	1
C1-1-25-30°	0.0200	11.54	249.6969697
C1-1-25-0°	0.0200	11.22	239.9090909
C1-1-25-60°	0.0065	11.10	236.4545455
C1-1-25-0°-2L	0.0200	11.64	252.6060606
C1-1-25-30°-2L	0.0139	13.25	301.4545455
C1-1-25-60°-2L	0.0100	12.94	292.0606061
C1-1-25- 0°-2L-H	0.0200	10.92	230.9090909
C1-1-25- 30°-2L-H	0.0115	11.40	245.3333333
C1-1-25- 60°-2L-H	0.0072	10.31	212.4242424
C1-1-25- 30°-1L-DOUBLE	0.0113	10.52	218.6666667
C1-1-25- 60°-1L-DOUBLE	0.0114	12.23	270.5454545

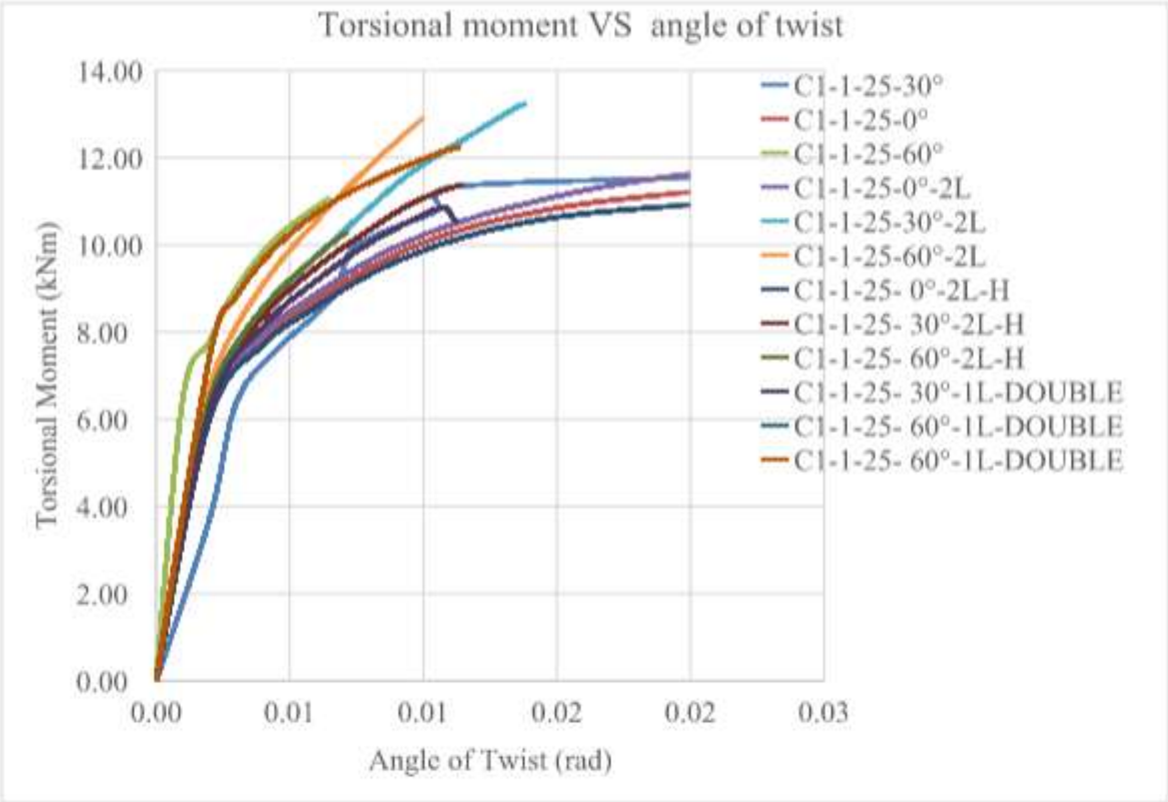

Fig. 8.1 Comparison graph of Torsional moment VS angle of twist

IX. CONCLUSIONS

From the analytical study the following conclusions are drawn. They are summarized as follows:

- Single layer of aramid fiber strips wrapped in 0˚ angle shows highest moment carrying capacity whereas angle of twist is highest in 60˚ wrapping
- When compared with single layer FRP, double layer wrapping shows more torsional capacity that is about 13.25 kNm in 30˚ angle
- Torsional capacity in RC beams wrapped with half number of FRP strips, shows highest value of 11.40 kNm in 30˚ wrapping
- RC beams wrapped with single layer of aramid fiber strips in 60˚ double angle (60˚and -60˚) shows high moment carrying capacity, that is 12.23 kNm
- When comparing all categories, highest torsional capacity shows when FRP wrapped in 30˚ angle
- From result analysis C1-1-25-30°-2L have high moment carrying capacity 13.25 kNm when compared with all other models and having 0.0139 rad angle of twist
- C1-1-25-30°-2L shows 300% increase in moment carrying capacity when compared with the normal controlled beam.

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