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Original article

Torsional behaviour of reinforced concrete beam wrapped with aramid fiber

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A B S T R A C T

بتن مسلح

Present study gives the torsional behaviour of Reinforced Concrete (RC) beam of M30 grade of concrete strengthened with aramid fiber. The aramid fiber as an externally bonded reinforcement used for increasing flexural strength, an attempt is made to use it for improving torsional behaviour of RC beam. Torsional failure mostly occurs in seismic affected areas subjected to sudden failure. Torsional failure is brittle type failure occurs due to undesirable loading.

RC beam strengthened with aramid fiber tested for torsional moment using lever arms subjected to equal static loading which transfer equal torsional moment to the beam. The cross section of beam is 150 mm × 300 mm and of 1 m in length. In that three beams were designed for torsional reinforcement and nine as conventional beams. Beam is designed for torsion as per IS456-2000. Building designed earlier using the codes were insufficient to cater for torsional reinforcement. This research investigates behaviour of such conventional beams for torsion when wrapped with aramid fiber. Torsional moments of such strengthened beams are compared with torsionally designed beams which are designed as per new design codes. The study is restricted to aramid fiber fully wrapped and wrapped in strips at width 100 mm of U shape on three faces of beam by using epoxy resin.

Experimental result includes ultimate loads & first cracking loads, angle of twist and twisted shape of the beam. Result shows that fully wrapped RC beam gives more torsional strength as compared to controlled beam and there is significant improvement in torsional strength of beams wrapped in strips. After first crack, beam shows tendency to carry load with increase in angle of twist. Thus it is easy method for strengthening of RC beams.

1. Introduction

مقدمه

ساخت

Fiber reinforced composites have been used for construction and aerospace industries. Reinforced concrete is among the most widely used building materials in the construction industry, but it faces potential problems, including damage from seismic hazards, and cracking due to shrinkage and expansion. This damage permits moisture attack resulting corrosion and expansion of steel reinforcement and resulting eventually in loss of structural strength. In many cases, damaged structures can be repaired. They also can be strengthened to accommodate changes in load variation or code revisions. Aramid fiber composites play a major role in improving strength of structure and do so at significantly lower cost than the cost required to construct new structure. Deifalla and Ghobarah (2007) developed an analytical model for the case of the RC beams strengthened in torsion. Chalioris (2008) present experimental study deals with the torsional strengthening of concrete beams without stirrups using externally bonded carbon fiber sheets and strips as an external reinforcement. Alabdulhady et al. (2017) carried investigation on the improvement of the torsional resistance of reinforced concrete beams using PBO-FRCM composite. Jariwalaa et al. (2013) studied the combined effect of Torsion and Bending with GFRP composites on RC beams. In case of torsion, the cracks follow a spiral pattern, propagating in opposite directions on the opposite sides of the beam (Deifalla and Ghobarah, 2014). Behera et al. (2016) done the experimental investigation on torsional behaviour of reinforced concrete beams with

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ferrocement U-jacketing. Thus externally wrapped fiber sheet can be used to increase the torsional strength of rectangular reinforced concrete beams.

1.1. Aramid fiber

Aramid fiber is having highest weight to strength ratio compared with any commercially available fiber reinforcement. Aramid Fiber is also known as keveler fiber. It is the first organic fiber with high enough tensile modulus and strength to be used as reinforcement in advanced composite (Jassal and Ghosh, 2002). Aramids share a high degree of orientation with other fibers such as ultra-high-molecular-weight polyethylene, a characteristic that dominates their properties.

Aramid fiber is also having high tensile strength, tough and highly oriented organic fiber manufactured from polyamide (Abdel-Jaber et al., 2007). This fiber had good abrasive resistance and under cyclic loading, they can abrade against each other by weakening the sheets. Aramid fiber is formed from synthetic products characterized by strength five times stronger than steel on an equal weight basis and heat-resistance. Fibers manufactured by Hindoostan Technical Fabrics Limited are used in the experimental program. Physical properties of Aramid Fiber are given in Table 1.1.

2. Experimental program

Total twelve numbers of reinforced concrete rectangular beams were cast for the experimental study. Here 3 beams are designed as controlled beams (with normal reinforcement) and other 3 beams are designed with torsional reinforcement as per IS 456-2000 as shown in Fig. 2.1. Remaining six samples are with normal reinforcement and are divided in to 3 with full wrapping and other 3 wrapped with 100 mm aramid fiber strips at spacing 200 mm center to center as shown in Table 2.1.

2.1. Beam Specimen for testing

The experimental program consists of a twelve rectangular beams designed as under reinforced section. The reinforcement details of beam used for experiment has illustrated in the Fig. 2.1. The beams were cast by using M30 grade of concrete. The mix proportion for M30 grade of concrete is given in Table 2.2.

Table 1.1
Aramid fiber properties.

	Description	Specification
Property	Weave style plain	Plain
	Areal weight of fabric (g/m^2)	300
	Standard width (mm)	1000
	Dry fabric thickness(mm)	0.25
Mechanical Properties of fiber	Tensile strength (Mpa)	2400–3600
	Tensile modulus (Gpa)	60–120
	Elongation percentage (%)	2.2–4.4

Table 2.1
Beam designations.

Set No.	Type of beam	Beam designation	No. of specimen
I	Controlled beam	C	3
II	Design for torsion	T	3
III	Fully wrapped beam	F	3
IV	Wrapped with strip	S	3

2.2. Preparation of test specimen

The dust is removed from the surface of beam and cleaned using polish paper. Each of these beam were wrapped with aramid fibers by using epoxy resin at the all faces of the beam as per the procedure given by the manufacturer.

2.3. Test setup

The controlled and strengthened beams were tested using the torsion test setup shown in Fig. 2.2. A bracket is formed by attaching channel section back to back and attached around the concrete beams to act as lever arms to apply the torsional moment. These lever arms were 1.12 m long and were bolted around the beam. A long steel wide flange I-beam was diagonally laid down resting on hinged end supports on top of the lever arms. The advantage of the test setup is that, by applying a single vertical load, the middle part of the reinforced concrete beam is subjected to pure torsion. The specimen is placed over the two steel roller bearings leaving 50 mm gap from the ends of the beam as shown in Fig. 2.3. The load was applied by using Universal Testing Machine of capacity 1000 kN. During testing, from the applied load twisting moment is calculated. By using dial gauge having a least count of 0.02 mm, corresponding angle of twist is measured at both the lever arm with every load increment. Cracks formed on the surface of beam were observed and marked.

2.4. Failure pattern

The torsional crack develops in spiral direction at torsional loading in controlled beam as shown in Fig. 2.4. Vertical crack develops in beam which is designed for torsion. Same vertical cracks are seen in beam wrapped with aramid fiber strip as shown in Fig. 2.5.

3. Result and discussion

All strengthened specimens show limited deformation and cracks before failure of concrete. The first cracks were appears

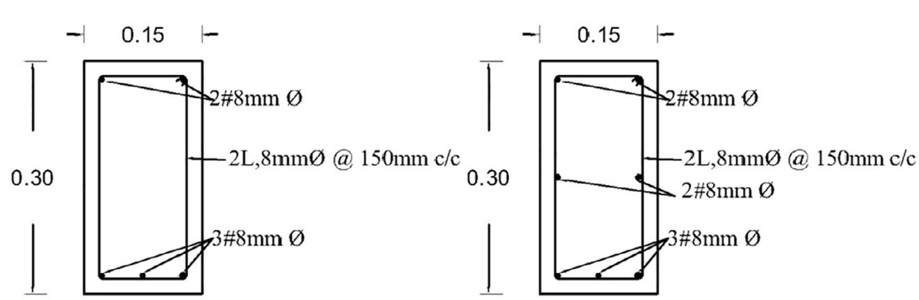

Fig. 2.1. Reinforcement detailing of controlled beam and beam designed for torsion.

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Table 2.2
Design mix proportions.

Description	Cement	Fine aggregate	Coarse aggregate	Water
Mix proportion (by weight)	1	2.14	3.54	0.45
Quantities of materials (kg/m^3)	350	769.75	1240	0.45

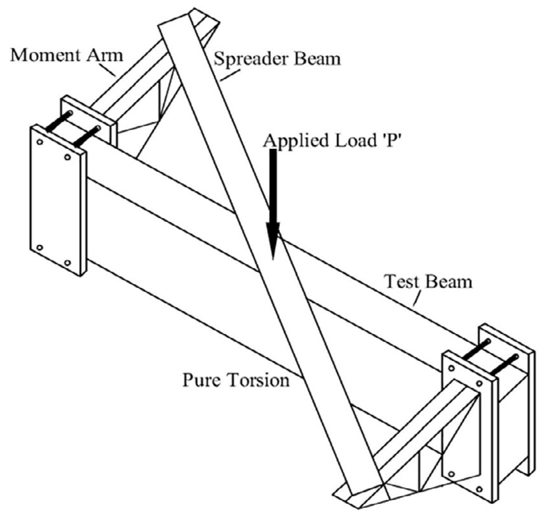

Fig. 2.2. Schematic of torsion test setup.

Fig. 2.3. Test setup.

Fig. 2.4. Crack pattern of controlled specimen.

vertically in strengthened beam. Strengthened beams shows tendency to carry more load with increase in angle of twist.

All the beams are compared for torsional moment at first crack as shown in Fig. 3.7. Comparisons are also made at ultimate torsional moment as per Fig. 3.8. It was noted that the behavior of the normally reinforced beams strengthened with aramid fiber are better than the controlled beams and are equivalent to beam designed for torsion. The use of aramid fiber had effect in delaying the growth of crack formation. Due to this angle of twist of beam with torsional reinforcement and wrapped beam are same or even less in some cases as shown in Fig. 3.1, 3.2, 3.3 and 3.4. It is found that, the experimental behaviour of beam is nearly same when compared with the beam modeled in ANSYS software as per Fig. 3.5 and 3.6.

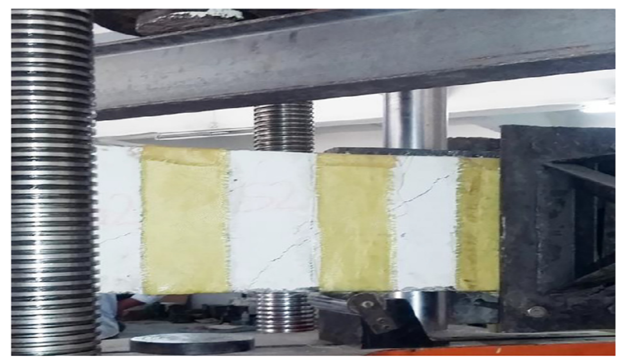

Fig. 2.5. Vertical crack in beam wrapped with strip.

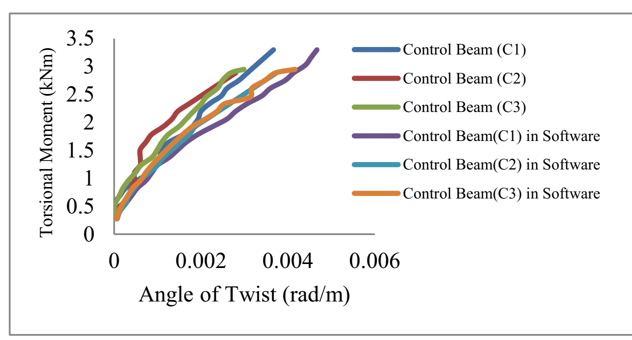

Fig. 3.1. Torsional moment Vs angle of twist for control specimen.

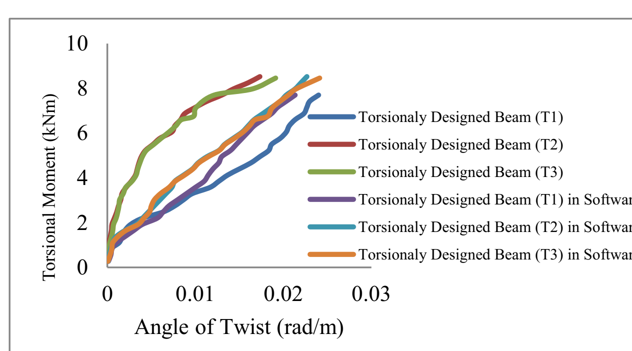

Fig. 3.2. Torsional moment Vs angle of twist for torsionally designed specimen.

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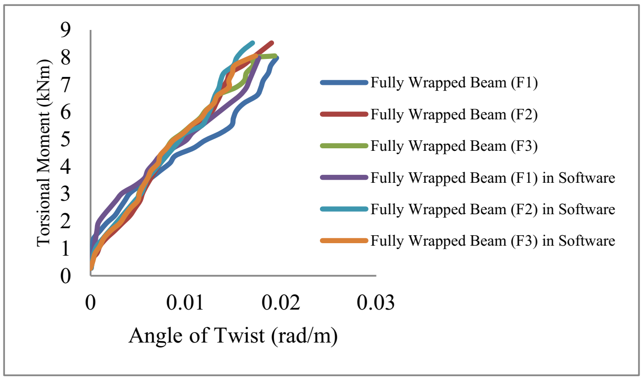

Fig. 3.3. Torsional moment Vs angle of twist for fully wrapped specimen.

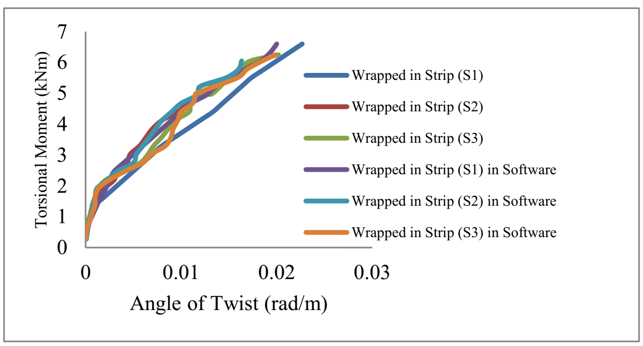

Fig. 3.4. Torsional moment Vs angle of twist for specimen wrapped in strip.

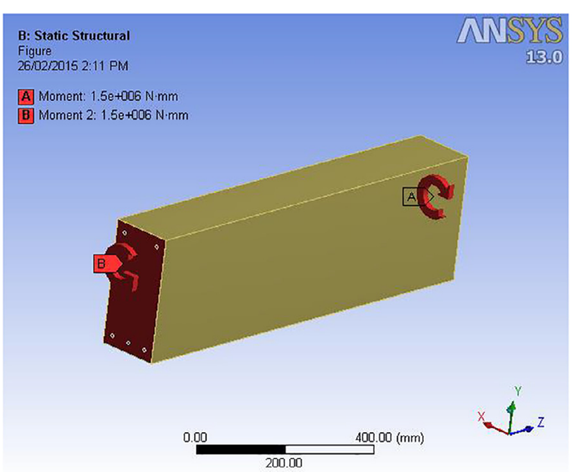

Fig. 3.5. Beam model in ANSYS for fully wrapped.

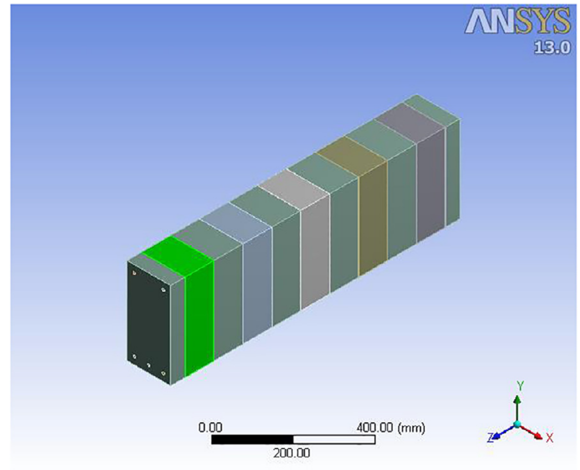

Fig. 3.6. Beam model in ANSYS for wrapped with strip.

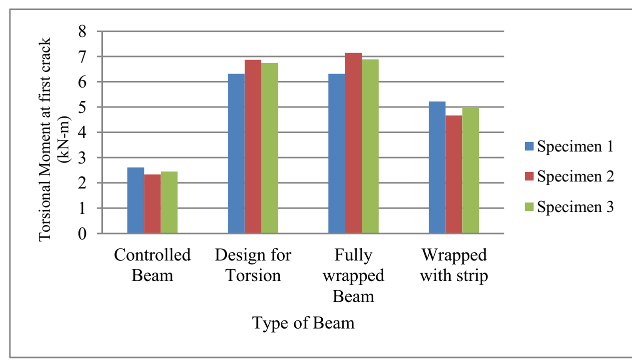

Fig. 3.7. Comparison of torsional moment at first crack in beam specimen.

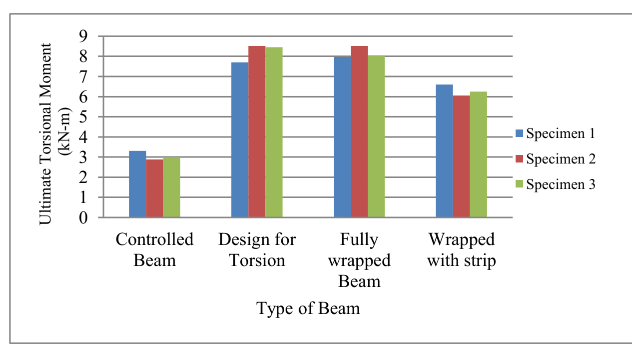

Fig. 3.8. Comparison of ultimate torsional moment in beam specimen.

For analytical modeling in ANSYS mesh size used is 1 mm with standard deviation of 0.17 mm. As the beam is in pure torsion two equal and opposite torques are applied at both ends. At end A and B the displacements (d_x, d_y and d_z) are not allowed and rotations (θ_x, θ_y and θ_z) are allowed with simple support at ends. The beam is having six degree of freedom. When wrapped with Aramid fiber it creates bonded joint interface. The properties of material are tabulated in Table 3.1. As the experimental investigation is up to yield, ultimate or breaking point, therefore bilinear stress strain relationship (elasto-plastic) is considered in the study.

Normally reinforced beam when wrapped with Aramid Fiber shows the torsional moment and angle of twist nearly equal to the beam designed for torsion. It indicates that wrapping is functioning like a torsional reinforcement enhancing properties of beam against torsional failure as shown in Fig. 3.9.

Fig. 3.1 shows that controlled beam (normal reinforcement) fails at an angle of twist 0.0028 to 0.0046 rad/m. When a beam is designed for torsion, it fails at an angle of twist 0.017 to 0.024 rad/m as per Fig. 3.2. Normally reinforced beam fully wrapped with aramid fiber fails at angle of twist of 0.017 to 0.019 rad/m whereas

Table 3.1
Material properties and elements used in the modeling.

Materials	Density (kg/m^3)	Elastic modulus (MPa)	Poison's ratio	fck (MPa)	fy (MPa)	Element used
Concrete	2400	19,364	0.17	15	–	SOLID65
Reinforcing steel	7850	210,000	0.27	–	415	BEAM188
Aramid fiber	1450	90,000	0.36	–	3000	SHELL91

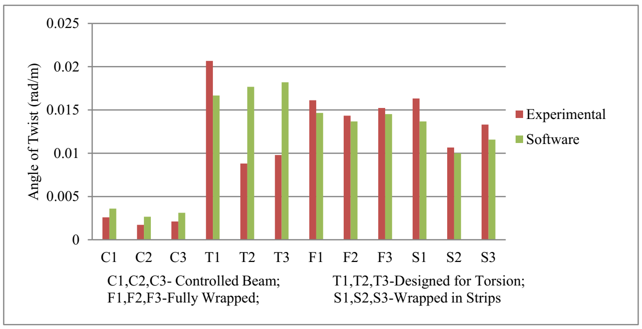

Fig. 3.9. Comparison of angle of twist by experimental and ANSYS software results.

when wrapped in strips angle of twist was 0.16 to 0.22 rad/m as shown in Fig. 3.3 and 3.4 respectively. Controlled beam fails very early thereby angle of twist is very small.

4. Conclusions

Based on the above results following conclusions are drawn.

1. The torsional capacity of strengthened beams was enhanced as compared to the controlled beam.
2. Initial cracks appear for higher loads in case of strengthened beams. The moment carrying capacity of the strengthened beam fully wrapped with aramid fiber was found to be maximum compare to all the beams.
3. Reinforced concrete beams strengthened with fully wrapped aramid fiber has taken 140% more moment at first crack as well as ultimate torsional moment, when compared with controlled beam.
4. Reinforced concrete beams strengthened with aramid fiber strips of 100 mm width taken 80% more moment at first crack and ultimate torsional moment, when compared with controlled beam.
5. Reinforced concrete beams strengthened with aramid fiber strips has taken 25% less torsional moment than the beam designed for torsional steel.

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