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An Experimental Study on Torsional Behavior of Steel Beams Infilled with Plain Cement Concrete and Fiber Reinforced Concrete

K. Perumal[1], R. Srinivasan[2]

[1] PG Student, Department of Civil Engineering, Adhiyamaan College of Engineering, Hosur, Krishnagiri, Tamilnadu, India
raviperumal33@gmail.com

[2] Professor, Department of Civil Engineering, Adhiyamaan College of Engineering, Hosur, Krishnagiri, Tamilnadu, India

Abstract

In modern construction, Concrete filled steel tubular (CFT) beam and column have better option in structural systems like buildings, bridges, caissons piers and deep foundations, because of its high compressive stiffness. These CFT members are applicable in curved bridge decks and where formwork is could not be provided. The CFT column has more stiffness and reduce local buckling failures. In present work study of torsional characteristics of steel beams, in-filled with plain cement concrete and fiber reinforced concrete. Torsional moment and angle of twist has been studied of hollow steel tubular beam, tubular beam in-filled with Plain Cement Concrete (PCC) and Steel Fiber Reinforced Concrete (SFRC) beams under torsion. The volume fraction of fiber added to concrete mix as 1.5%. The aspect ratio of steel fiber is kept as 50, crimped shaped steel fiber are used and its length 50mm. The M20 grade concrete used to infill material of steel tube. All beam specimen has been tested under two point loading on self-straining loading frame (40 ton capacity) under pure torsion. Finally, to compare the torsional behavior of hollow, PCC in-filled and SFRC in-filled steel beams.

Keywords: *Concrete filled steel tubular beam (CFT), Steel fiber, torsional strength, angle of twist, torsional moment*.

1. Introduction

The CFT structural member has a number of distinct advantages over an equivalent steel, reinforced concrete, or steel-reinforced concrete member. The orientation of the steel and concrete in the cross section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moment. Also, the stiffness of the CFT is greatly enhanced because the steel, which has a much greater modulus of elasticity than the concrete, is situated farthest from the centroid, where it makes the greatest contribution to the moment of inertia. The concrete forms an ideal core to withstand the compressive loading in typical applications, and it delays and often prevents local buckling of the steel, particularly in rectangular CFTs. Additionally, it has been shown that the steel tube confines the concrete core, which increases the compressive strength for circular CFTs, and the ductility for rectangular CFTS.

Therefore, it is most advantageous to use CFTs for the columns subjected to the large compressive loading. In contrast to reinforced concrete columns with transverse reinforcement, the steel tube also prevents spalling of the concrete and minimizes congestion of reinforcement in the connection region, particularly for seismic design. Numerous tests have illustrated the increase in cyclic strength, ductility and, damping by filling hollow tubes with concrete. Recent applications have also introduced the use of high strength concrete combined with high strength thin-walled steel tubes with much success. When high strength concrete and thin-walled steel tubes are used together, the more brittle nature of high strength concrete is partially mitigated by the confinement from the steel tube, and local buckling of the thin steel tube is delayed by the support offered by the concrete. Progress in concrete technology has made it possible to utilize concrete strengths over 15 ksi in CFT beam-columns.

The concrete-filled steel tube (CFT) column system has many advantages compared with the ordinary steel or the reinforced concrete system. The main advantages are listed below:

1) Interaction between steel tube and concrete: Local buckling of the steel tube is delayed, and the strength deterioration after the local buckling is moderated, both due to the restraining effect of the concrete. On the other hand, the strength of the concrete is increased due to the confining effect provided by the steel tube. Drying shrinkage and creep of the concrete are much smaller than in ordinary reinforced concrete.
2) Cross-sectional properties: The steel ratio in the CFT cross section is much larger than in reinforced concrete and concrete-encased steel cross sections. The steel of the CFT section is well plastified under bending because it is located most outside the section.

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3) Construction efficiency: Labor for forms and reinforcing bars is omitted, and concrete casting is done by Tremie tube or the pump-up method. This efficiency leads to a cleaner construction site and a reduction in manpower, construction cost, and project length.
4) Fire resistance: Concrete improves fire resistance so that fireproof material can be reduced or omitted.
5) Cost performance: Because of the merits listed above, better cost performance is obtained by replacing a steel structure with a CFT structure.
6) Ecology: The environmental burden can be reduced by omitting the formwork and by reusing steel tubes and using high-quality concrete with recycled aggregates.

1.1 Steel Fiber Reinforced Concrete

The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibers in the mixture. Different types of fibers, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibers help to transfer loads at the internal micro cracks. Such a concrete is called fiber-reinforced concrete (FRC), the FRC in which Steel fibers are used is called Steel fiber-reinforced concrete (SFRC).

The one of the important properties of steel fiber reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fiber composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibers are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fiber composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fiber composite and its ability to withstand repeatedly applied, shock or impact loading.

1.2 Types of Fibers

Depending upon the parent material used for manufacturing fibers can be broadly classified as;

1. Metallic fibres (e.g. low carbon steel , stainless steel, galvanized iron, aluminium)
2. Mineral fibers (carbon, glass, asbestos etc.)
3. Synthetic fibers (polypropylene, polyethylene, polyester, nylon etc.)
4. Natural fibers (bamboo, coir, jute, sisal, wood, sugarcane bagasse etc.)

1.3 Steel Fibers

Steel fibers have been used in concrete since the early 1900s. The early fibers were round, straight, and smooth with cut or chopped lengths. These fibers have not been used in recent years and replaced by modern fibers because of their intrinsic shortages of property. Modern commercial steel fibers are manufactured from drawn steel wire with either rough surface, hooked (or paddled) ends or crimped through their length. The physical dimensions of modern steel fibers vary from 0.15 to 2 mm for equivalent diameters and from 10 to 75 mm for length. The fibers aspect ratio, defined as fiber length divided by its diameter range from 20 to 100. Steel fibers have generally ductile stress-strain characteristics with the relatively higher tensile strength (0.5-2 GPa) and the high modulus of elasticity (200 GP).

Table 1: Specification of steel fibers

Cut Length	Shape	Diameter	Tensile strength
50mm	Crimped	1mm	700 MPa

Fig 1: Steel Fibers

1.4 Infilled Concrete

In modern structural constructions, concrete-filled steel tubular (CFT) columns have gradually become an option in structural systems like buildings, bridges and so forth. CFT columns have become so widespread owing to their axially compressed nature making them superior to conventional reinforced concrete and steel structural systems in terms of stiffness, strength, ductility and energy absorption capacity. The steel tube not only takes axial load, but also provides confining pressure to the concrete core, the concrete core takes axial load and prevents or delays local buckling of the steel tube. Furthermore, concrete-filled composite columns also have the advantage of requiring no formwork during construction, thus reducing construction costs.

The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed "volume fraction" (Vf). Vf typically ranges from 0.1 to 3 %. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fiber's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers that are too long tend to "ball" in the mix and create workability problems.

1.5 Torsion in CFTs

In the limited tests performed, concrete-filled steel tubes performed quite well under torsional loading. The nature of the steel tube itself is conducive to excellent torsional behavior. A closed section such as a tube has a much greater torsional resistance than a W-section with a similar area. Also, since torsional stresses increase with radial distance, the orientation of the steel (which has a much larger shear modulus, *G*, than the concrete) at the perimeter, where stresses are a maximum, idealizes the torsional resistance of the section.

Torsional failure in a CFT is not abrupt or distinct, but is characterized by a large increase in torsional rotation at a fairly constant load. The failure is due to a combination of spiral cracking in the concrete and tensile yielding of the steel.

2. Literature Review

***Pant Avinash and Suresh Parekar* (2010)** has carried out the experiment on torsional behavior of steel fiber reinforced concrete (SFRC) rectangular beams under combined torsion-bending- shear with longitudinal and web reinforcement. It is also deals the influence of web reinforcement on the ultimate torsional strength of SFRC beams under different values like torsion to moment ratio (T/M) and torsion to shear (T/V) ratios. The aspect ratio of steel fiber as 60 and volume fraction of steel fiber as 0.6 were kept constant for all beams. Finally, the test results compared with torsional strength of SFRC beam with and without reinforcement. The comparison reveals that the torsional strength is independent of longitudinal reinforcement, and it is depends upon the spacing of web reinforcements.

***Likhil L. Raut and D. B. Kulkarni* (2014)** this paper deals with study the torsional moment and angle of twist for SFRC and normal reinforced concrete (NRC) beams under pure torsion. The volume fraction of fiber added in the concrete varies from 0 to 1% and aspect ratio of steel fiber as 38, crimped shaped steel fiber are used and its length 38mm. The beam section designed as singly reinforced under reinforced section. The beam specimen tested under two point loading until failure of beam for torsion. Finally, compare the test results the torsional strength of SFRC beam increased up to 47.27%, this value very significant increases in conventional RC beam. Also fiber reinforcement increase stiffness of beam by decrease the angle of twist, compared to conventional RC beam.

***Vinayaki and Theenathayalan* (2015)** has carried out experimental study on the load carrying capacity of concrete filled GFRP box beams of size 1200x150x200mm by varying thickness of GFRP box beams as 4mm,6mm and concrete grade as M40. Flexural two point load would be applied and to find the flexural strength, load carrying capacity, deflection, load deflection relationship, load strain relationship, stiffness ratio by various thickness of GFRP box beams. The concrete filled GFRP box beam with 6mm thickness has load carrying capacity is 3 times more than conventional concrete and stiffness is 4 to 7.5 times more than conventional concrete. Finally they concluded, to increase the thickness of box beam will increase load carrying capacity and stiffness also decrease the deflection.

***Arvind and Bollineni Nithin Krishna* (2015)** has carried experimental investigation on the ultimate strength and behavior of CSCC beam (Confined steel concrete composite beam) is a concrete beam shuttered with cold formed steel sheet and shear connectors and bracings. Stud shear connectors are used to take up the bond between sheet and concrete. The passive confinement by the cold formed sheet in the sides and bottom influences the strength and ductility of the system. The thickness of steel sheet used in cold formed construction is usually 1 to 3 mm. Totally eight CSCC beams are tested under three different types loading such as pure bending, pure torsion and combined bending and torsion. The beams were tested at a rate of loading of 30kN/min. The value of flexural rigidity decreases with the increase in moment. Beams with 100 mm spacing of bracings the moment carrying capacity was found to be higher than the beams with 150mm spacing.

3. Experimental Program

The dimension of the beam specimen were kept as 50mm width x 50mm depth and 1200mm length. For applying two point load on beams, 300mm length and 6mm thick mild steel plate attached 100mm distance from both edges of beam. Steel beams in-filled with plain cement concrete (PCC) and steel fiber reinforced concrete (SFRC) beams were casted with proper fiber fraction. The fiber fraction were kept as 1.5%.

3.1 Materials

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The M 20 grade of concrete was used for the casting of PCC and SFRC beams. An Ordinary Portland Cement (OPC) of 53 MPa strength, locally available river sand as fine aggregate, crushed stone aggregate with a maximum particle size of 12.5 mm as coarse aggregate, steel fibers and potable water were used in this investigation. The mix proportion obtained from these materials is given in table below;

Water	Cement	Fine Aggregate	Coarse Aggregate
191.58	383	736	1156
0.5	1	1.92	3.02

Table 2: Mix Proportions for M20

∴ Mix Proportion is 1 : 1.92 : 3.02

3.2 Testing of Beam of Specimens

All the beams were tested in Self-Straining loading frame (40 ton capacity) under pure torsion. Totally five specimen were tested like 1 number of hollow beam, 2 numbers of PCC in-filled beam, 2 numbers of SFRC in-filled beam. All of them are rested in the torsional test arrangements as shown in fig 2, 3 and 4. The gradual increase in load were observed for calculation of torsional moment and the deformation observed in the dial gauge with the least count of 0.01mm for the calculation of angle of twist of beam. These increments in readings were taken throughout the test. The deflections were taken at two end points of the beam, and the torsional moment by angle of twist graph was plotted from the obtained results.

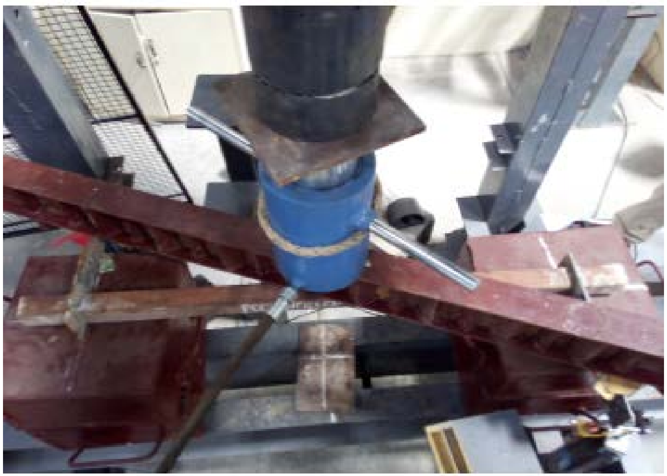
Fig 2: Experimental setup of the beam specimen
Fig 3: Top view of the beam specimen

Fig 4: Schematic test setup for end specimen

4. Results and Discussion

The obtained final results were tabulated and compared below,

Table 3: Test Results



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	Beam Specimen	Ultimate load (KN)	Torsional moment (KNm)	Angle of twist (degree)
	Hollow	36	4.050	5.73
7 Days	PCC	39	4.387	4.25
	SFRC	41	4.613	3.58
28 Days	PCC	49	5.512	3.76
	SFRC	52	5.850	3.32

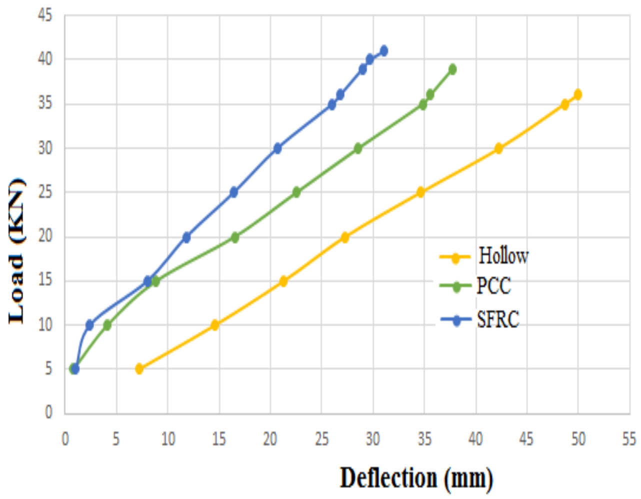

Chart 1: Load vs Deflection (7 Days specimen)

Chart -1 The hollow beam takes ultimate load of 36 KN, Plain cement concrete in-filled beam takes ultimate load of 39 KN, and Fiber reinforced concrete in-filled beam takes ultimate load of 41 KN. The above comparison of load vs deflection curve, SFRC beam gives increase ultimate load and decrease deflection.

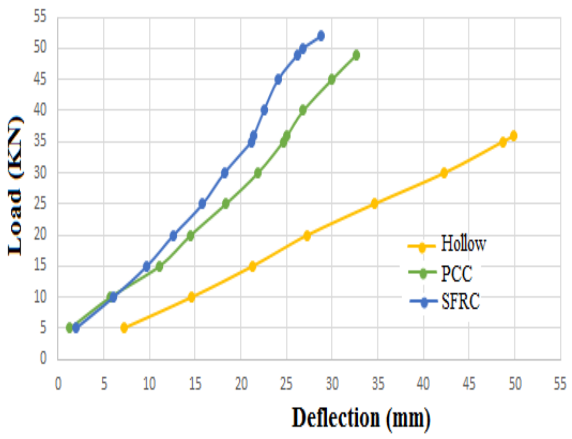

Chart 2: Load vs Deflection (28 Days specimen)

Chart -2 The hollow beam takes ultimate load of 36 KN, Plain cement concrete in-filled beam takes ultimate load of 49 KN, and Fiber reinforced concrete in-filled beam takes ultimate load of 52 KN. The above comparison of load vs deflection curve, SFRC beam gives increase ultimate load and decrease deflection.

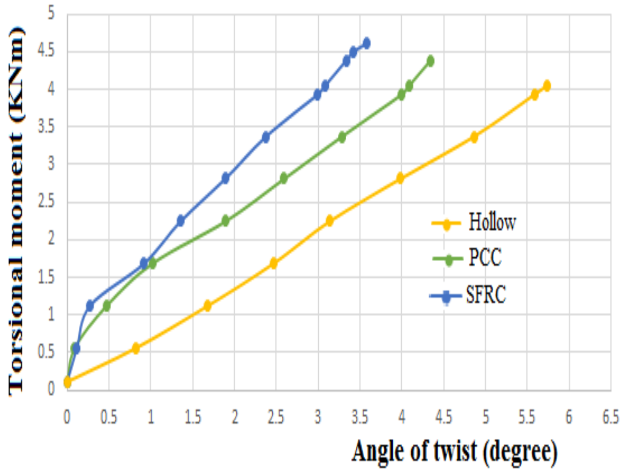

Chart -3: Torque twist response of Hollow, PCC & SFRC (7 Days specimen)

Chart -3 The torsional moment of hollow beam 4.05 KNm and its angle of twist 5.73º, torsional moment of PCC in-filled beam 4.387 KNm and its angle of twist 4.25º and torsional moment of SFRC in-filled beam 4.613 KNm and its angle of twist 3.58º. The SFRC beam has 5.5% greater than that of PCC in-filled beam.

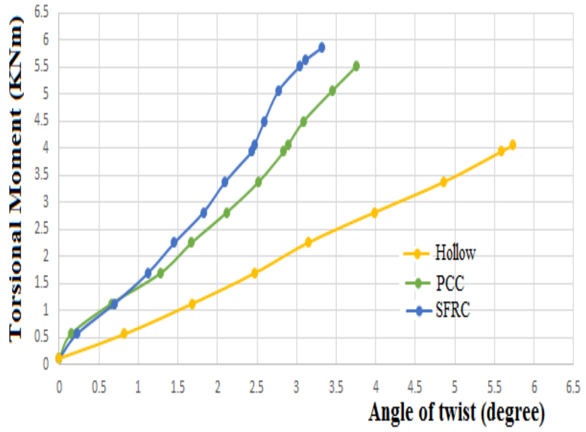

Chart -4: Torque twist response of Hollow, PCC & SFRC (28 Days specimen)

Chart -4 The torsional moment of hollow beam 4.05

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KNm and its angle of twist 5.73º, torsional moment of PCC in-filled beam 5.512 KNm and its angle of twist 3.76º and torsional moment of SFRC in-filled beam 5.85 KNm and its angle of twist 3.32º. The SFRC beam has 6.5% greater than that of PCC in-filled beam.

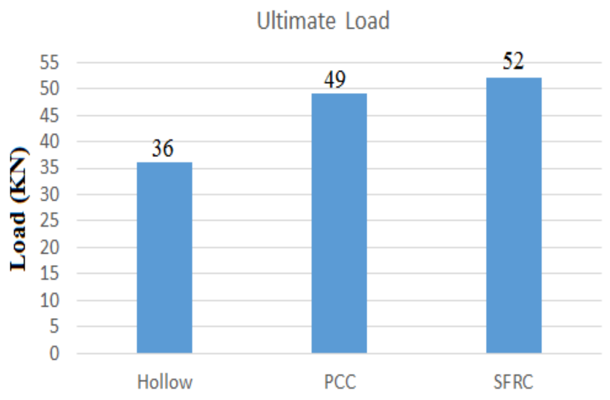

Chart -5: Variation of Ultimate load

Chart -5 shows ultimate load carrying capacity of Hollow, PCC in-filled and SFRC in-filled beams. It was observed SFRC beam having maximum load carrying capacity.

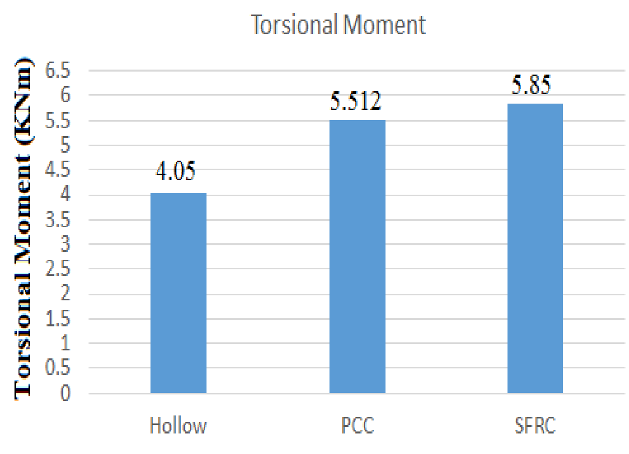

Chart -6: Variation of Torsional moment

Chart -6 shows torsional strength of Hollow, PCC in-filled and SFRC in-filled beams.

5. Conclusions

- Use of fibers, very beneficial to increase torsional strength of beam subjected to pure torsion.
- The torsional strength of SFRC beam 0.065 (or 6.5) times greater than that of PCC in-filled and hollow beam.
- The ultimate load carrying capacity of SFRC beam 6.5% greater than that of PCC in-filled and hollow beam.
- The steel fiber reinforced beam also succeeded increase stiffness of the beam by decreasing angle of twist compared PCC in-filled beam.

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