

Experimental investigations on steel-concrete composite columns for varying parameters

V Aparna¹, D Vivek¹, Kancharla Neelima² and B Karthikeyan^{3*}

¹KPR Institute of Engineering and Technology, Arasur, Coimbatore-614407, India.

²NVLN Constructions Pvt. Ltd., Hyderabad, India

³ School of Civil Engineering, SASTRA University, Thanjavur-613401, India.

*Email: karthikeyan@civil.sastra.edu

Abstract. In this study, the experimental investigations on steel tubes filled with different types of concrete are presented. Steel tubes filled with fibre reinforced concrete using lathe waste and steel tube with concerned confined with steel mesh were investigated. The combinations were compared with steel tubes with conventional concrete. A total of 4 concrete filled steel tube (CFST) combinations were made with tubes of diameter 100 mm with wall thickness 1.6 mm and a height of 300 mm. Axial compression test to examine the resisting capacity of the columns and push-out test for noting the bond strength were performed. Coupon tests were also conducted to determine the mechanical properties of steel. The structural behaviour of the composite columns was evaluated from on the test results. It was observed that steel tube filled fibre reinforced possessed better bond strength and resistance to axial load.

Keywords: CFST, lathe waste, steel mesh, steel fibre, push-out test

1. Introduction

Studies on steel-concrete composite sections and encased columns have extensively been made over recent years and have also been implemented in many new constructions. Due to the benefits such as increased strength, better ductility and lower construction costs as form works are not required and they are preferred in the construction field [1]. Many research works have already shown the advantages of using concrete filled tubular columns under various categories. Works from various researchers explain about performing axial loading tests on concrete filled tubular columns [2-7]. Few research works discussed about strength and state of art research on non-linear analysis of concrete filled tubular columns [8-10]. Research work of Varma et al discusses the behaviour of steel- concrete columns under seismic load conditions [11]. Azizinamini and Schneider discussed about connection of circular CFST columns [12]. In addition to using steel tubes filled with concrete many researches were done using FRP tubes, confining steel tube with FRP [13-17]. Ehab Ellobody and Marian did an experimental investigation of eccentrically loaded fibre reinforced concrete-filled stainless steel tubular columns [18]. Though many works were done as mentioned in previous literatures using CFST, FRP tubes, confining concrete filled tubes (CFT) with FRP still a lot more space is available in this area for further improvement and implementation of new techniques in that field and this study helps to identify such innovations and improvement that can be made in this fixed composite structures.



1.1 Objective

The major objective of this experimental research work is to study the mechanical properties of CFT columns when the concrete is mixed with fibres and mesh. Since no form work is required for structural elements made with concrete filled tubes, it is difficult to check whether the concrete has occupied the tubular section fully or it has dumped over the aggregates leaving a hole in between. Use of fibres can help the concrete arresting the propagation of cracks also improving its tensile and impact strength. Instead of choosing steel fibres or any costly fibres, lathe waste was added as a fibre to the concrete mixture. In addition to that steel mesh was also used as a fibre and the behaviour was studied. The main objective of the present work is to study the structural performance of the fibre reinforced CFST columns with lathe waste and steel mesh used as fibres and to compare them against those with the normal concrete mixes.

2. Materials

2.1 Cement

OPC 43 grade cement from the local market was used and the physical properties of the cement were tested as specified in IS: 4031(1988) [19] and IS: 12269 (1987) [20]. The specific gravity of cement is 3.15.

2.2 Aggregate

For fine Aggregate River sand was used and aggregates passing through 16 mm sieve and retained on 12.5 mm sieve were used as coarse aggregate in the concrete mix. The basic properties such as specific gravity, bulk density, and gradation and fineness modulus are tested as specified in IS: 2386 Part 1 (1963) [21]. The specific gravity of fine aggregate is 2.6.

2.3 Steel sheets

Mild steel hot rolled sheets of 1.6 mm thickness were used for our study. Steel sheets were shaped into the desired shape with the use of welding.

2.4 Lathe waste

In this research the lathe waste which otherwise would be dumped as a waste was tried using as a fiber in the concrete filled tubes and the parameters were studied. Steel fibers balance the force by transmitting tensile forces to the steel fibers which run along the cracks, as the result flexural toughness and flexural strength increases to great amount. Steel scrap fibers from lathe machines of random dimensions are used, usually of length 20-30 mm, width 1.5-2 mm and 0.3-0.6 mm thick, are used to reinforce the concrete cubes. It is a normal practice to add steel Fibers in concrete in fewer dosages to reduce cracking. Though steel bars are used in tension zone of concrete they can improve the tensile strength in one particular direction only and steel fibers can act as multidirectional reinforcement. Steel scraps obtained from the wastes of lathe machine are generally known as lathe waste. Fig.1 shows the Lathe waste used for the research work and the properties are listed out in Table 1. Since lathe fibers are actually obtained from waste, they do not have a well defined material property. So, we tried to fix its properties with reference to a commercially available steel fiber. A crimped steel fiber of length 12.5 mm and diameter 0.3 mm was taken as a reference and the lathe waste fibers were made into pieces, matching the dimensions of the crimped steel fiber. Though the fibers were a little curly, they were cut and made approximately straight.

Table 1. Properties of lathe waste

Cross section	Length (mm)	Diameter	Aspect ratio
Straight	25	0.3	83.33

2.5 Steel mesh

Steel mesh of 1mm thickness is used as a minimal reinforcement for the columns to check its behavior. Fig. 2 shows the steel mesh and its position before pouring concrete. It is a common practice to provide a lean reinforcement in the tubular section before pouring concrete though it is not necessary as the outer steel tube is sufficient and can act both as longitudinal and lateral reinforcement. Here instead of providing reinforcement with steel bars we tried with steel mesh.



Figure 1. Lathe waste used as fibre



Figure 2. CFSTM before pouring concrete

3. Testing methods

In the present study, a total of 14 specimens were considered for two separate tests viz, Test I and Test II. Test I was for finding the maximum axial load bearing capability by axial compression test and the test II for finding the bond stress of the specimen by performing push out test. All the specimens were chosen according to Euro Standards [22] provided for the selection of CFST column dimensions.

The circular models having diameter 100 mm and of wall thickness of 1.6 mm (i.e. D/t proportion with 62.5) were utilized, the exact sizes were chosen from previous research works [23]. For performing axial compression empty steel tubes (HT), Concrete Filled Steel Tubes with normal concrete (CFST), with lathe waste fibre reinforced (CFSTF), and with steel mesh (CFSTM) were examined. In case of push out test, Concrete Filled Steel Tubes, Concrete filled steel tube with fibre reinforced concrete and Concrete Filled Steel Tubes with Steel mesh were considered.

3.1 Concrete mix proportions

A normal concrete mix of M25 is adopted for this work. 4 combinations were made for the present research work namely HT, CFST, CFSTF and CFSTM, where HT is a hollow tubular section, CFST representing specimens with normal concrete, CFSTF concrete with lathe waste in which the lathe waste fibre was added in 1.5% to the total volume of the concrete and CFSTM is the one with steel fibre mesh used along with concrete.

3.2 Specimen details

Steel sheets of thickness 1.6 mm thickness were cut to 300 mm length and were welded such that tubes of inner diameter 100 mm were made. The yield strength and ultimate strength of the steel tube were obtained from coupon tests. After cutting the sheets for the desired length and before making them as tubes, grooves were made inside them to enhance the gripping property of the steel tube. The specimens were subjected to curing by wetting the top and bottom concrete portions with water. The ends of the specimens were later covered with steel plates and welded to induce the condition both

ends fixed while testing it for compressive strength. All the tubes were of same size and material and the difference in behaviour due to the use of various concrete mixtures were studied.

3.3 Coupon test

The test was done by placing the specimen in the Universal Testing Machine (UTM) between the two chucks after marking the gauge lengths and extending it slowly till it fails. The elongation of the gauge section was noted later. The computerized UTM recorded the percentage of elongation; ultimate tensile strength, yield strength of the material and stress vs. strain graph were arrived.

3.4 Push out test

The steel specimens were cut for the obliged L/D ratio, and the edges were flattened well to obtain a level surface for uniform loading. In the course of preparation of the test specimens, the specimens were kept in upright position and the compaction was carried out in layers for maintaining a strategic distance from air voids in concrete. And also for performing push out test for finding bond stress, before the casting of specimens a gap of 50 mm left not filled at the top for enabling the movement of concrete within the outer shell at load. The specimens were kept inverted and load was applied on the concrete alone using a circular steel solid less than the diameter of the specimen and the 50 mm gap at the bottom got collapsed, the slip was noted up to the failure load after it attained the peak load. Fig.3 illustrates the push out test being conducted.



Figure 3. Setup for push out test

3.5 Axial compression test

The sections were fixed ended at the closures with the help of steel plates of 5mm thickness welded to the top and bottom of the tubes and the load applied exactly on the centroid of the section. A circular steel collar plates were given at the closures of specimens to exchange the concentric action with no slip. The specimens mounted with dial gauge at the compression side of the tube in order to record the amount of axial shortening for the given load at regular intervals of deflection. The tests were carried out through a 1000 kN capacity universal testing machine. In order to perform axial compression test, steel plates were made for required dimensions with a small groove exactly at the middle of the plate and steel ball of required dimensions were placed at the centre point of the two plates.

4. Results and discussion

4.1 Push out test

Push out test is conducted to find out the bond stress at the steel concrete interface. For all specimens the failure load and its corresponding axial displacement were observed, the bond strength of the specimens was shown in the Table.2. For determining the bond stress of the specimens from the failure load equation (1) was used

$$\text{Bond Stress} = \frac{P}{\pi DL} \quad (1)$$

Where P was the failure load, D was the inside diameter of the steel tube and L was the length of the concrete steel interface. According to the test results, it can be noticed that the strength of the concrete and load conveying limit of the specimen increases with the provision of mesh in CFST. A sound can be perceptible once the failure load reaches. Then solid body motion of the concrete in relation with steel tube starts with increasing displacements. The failure loads of the specimens are shown in the Table 2 .The bond failure state of the specimen is shown in Fig. 10. It is observed that the higher bond stress is found in tube with fibres mixed, since fibre is provided, bond between steel and concrete was really high as the fibres actually stitched the aggregates with concrete.

Table 2. Results of push out test

Specimen	Average ultimate compression load (kN)	Average bond-stress (N/mm ²)
CFST	50.2	0.532
CFSTF	62.8	2.09
CFSTM	55.2	1.85

4.2 Axial compression test

Graph was plotted between axially applied load and the axial deformation for the CFST segments. The axial load was noted from the universal testing machine while the axial shortening was noted from dial gauge. It was observed that for the specimens with normal concrete, at first, the axial load increased as the axial shortening increased. As the shortening increased further, the micro-cracks in the central solid concrete grew quickly and consequently the Poisson's ratio of concrete increased alarmingly and its value was more than that of steel tube. The load bearing capability of CFSTF is 16.7% more than that of CFST. The axial shortening significantly reduced in CFSTF and its value was 10.5 mm as against the value of 14.4 mm for CFST at failure loading.

4.3 Failure modes of columns

The various modes of crushing of concrete were observed in the specimens for different parameters. They are discussed as below.

4.4 Hollow tube without infill concrete (HT)

The maximum load that the HT specimens resisted was 59.5 kN and it failed shortly at an axially displacement of 4.6 mm. Deflection occurred earlier in this column than other specimens and the load deflection behavior is depicted in Fig. 4. The empty hollow tubular sections (HT) experienced local failure mechanism which can be noted from the dents made in the outer core. Fig 5 shows the failure of hollow tubular column.

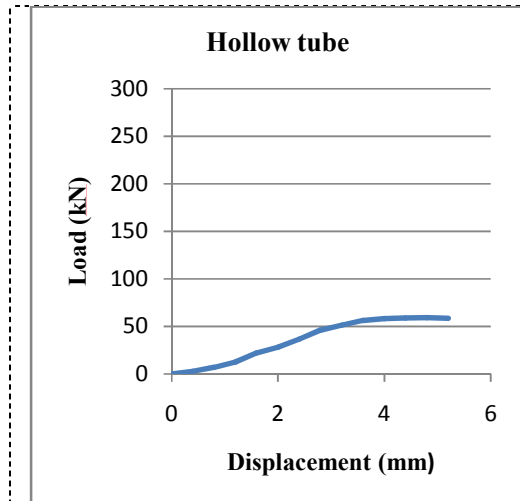


Figure 4. Load displacement curve of HT



Figure 5. Crushing failure of HT

4.5 Concrete filled steel tube (CFST)

In this tubular column, concrete of grade M25 was filled in the steel tube. Fig.6 shows the load deflection curve. On observing the results a drastic increase in strength from 59.35 kN to 245 kN can be noticed. The concrete core which is good at taking up compression load has resisted well up to 245 kN until reaching an axial displacement of 14.4 mm. The failure was mainly due to crushing of the concrete. Concrete got crushed at many local points under compression and it can be noted from the outer surface of the steel tube, many dents have formed on the steel tube section which are due to the concrete pieces disintegrated during crushing and getting dumped at certain locations which can be observed from Fig.7. Though they behaved better compared to the hollow tube, it is observed that they can offer more resistance when mixed and used with other mineral admixtures.

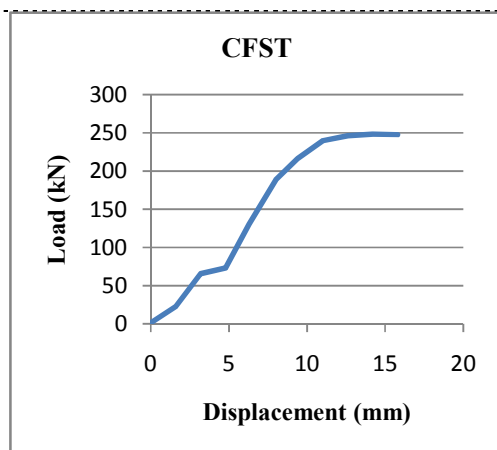


Figure 6. Load displacement curve of CFST

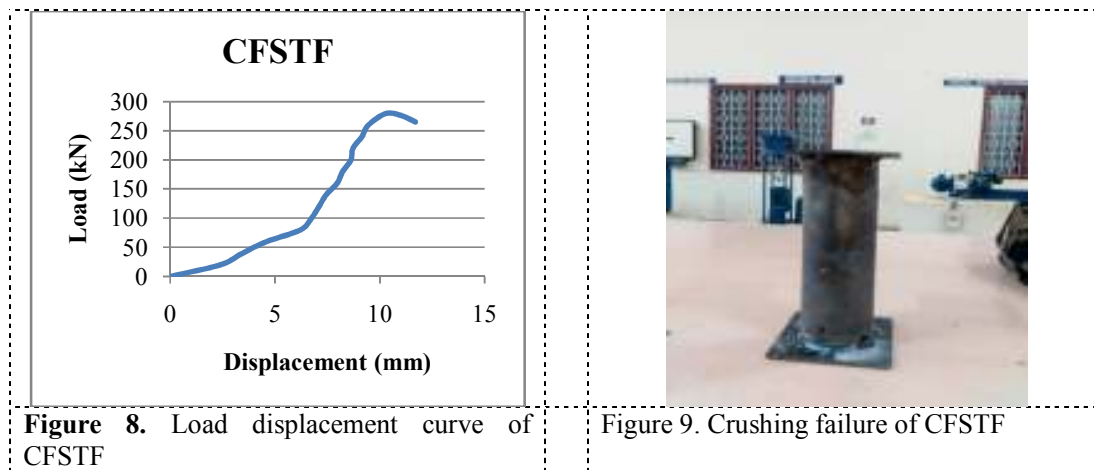


Figure 7. Crushing failure of CFST

4.6 Concrete filled steel tubes with fibre reinforced concrete (CFSTF)

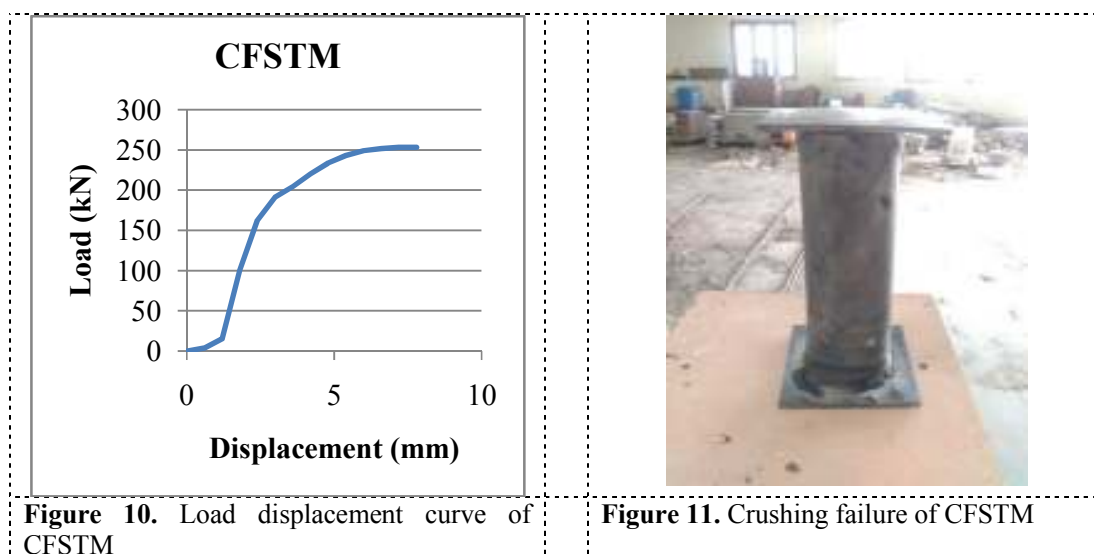
This column failed at 284.5 kN. From the results it is clear that column strength capacity has been improved on adding steel fibres to concrete. Also, the ductile properties of CFSTF columns are also

better which can be understood from the high degree of deformation capacity. Crushing of concrete at many places was reduced due to the presence of fibres as the presence of lathe waste fibres, stitched the pores, and prevented the crack propagation in the concrete core, thereby leading to an increased compressive strength. Figures 8 and 9 show load displacement curve and the crushing failure state of CFSTF.



4.7 Concrete filled steel tube with mesh reinforcement (CFSTM)

This column showed a moderate load carrying of 253.5 kN, which is better than the specimens cast only with concrete. Fig. 10 shows the deflection characteristics. Steel mesh was provided as minimum reinforcement for the column instead of steel bars. One of the main advantages of providing mesh is that it reduces the weight of the column. CFT with mesh reinforcement behaves well compared to all other because of the stiffer bond between the steel the concrete as a core. On observing the profile of the specimen after failure, it can be noted that the local failure point due to the crushing of concrete pieces were less. Generally the crushed concrete particles will create pores inside the concrete core and the disintegrated pieces will blocked somewhere inside creating dents on the steel section when load is applied. Such, effects were limited due to the provision of mesh and crushing of concrete was observed only in the cover regions. It can be noticed from Fig. 11.



5. Conclusions

On the basis of the results, the following conclusions were arrived.

- ❖ There were significant enhancements in the physical performance of CFSTF in reference to ultimate load bearing capacity, stiffness and ductility.
- ❖ The consequences from push out tests specified that bond strength of CFSTF specimens were found to be superior to the other CFSTs specimens.
From load versus deflection curve, the proportional increase in load carrying capability of CFSTF increased in the range of 16.6%, when compared with CFST columns.
- ❖ Though, there was no drastic improvement in load carrying capacity of the axial loaded CFSTF columns, it offers more ductility than the CFST columns.
- ❖ Hence, it is once again proved that addition of fibers in concrete will have effect not only in normal, high strength, high performance concrete but can also add strength to structures with concrete filled tubular section.

References

- [1] Guoqiang Li 2007 Experimental study of hybrid composite cylinders *Compos. Struct.* **78**, 170-81
- [2] Schneider S P 1998 Axially loaded concrete-filled steel tubes *J. Struct. Eng. ASCE* **124**(10) 1125-38
- [3] Han L H 2002 Tests on stub columns of concrete-filled RHS sections *J. Constr. steel Res.* **58**(3) 353-72
- [4] Han L H, Yao G H and Zhao X L 2005 Tests and calculations of hollow structural steel (HSS) stub columns filled with self-consolidating concrete (SCC). *J. Constr. Steel Res.* **60**(9) 1241-69
- [5] Giakoumelis G and Lam D 2004 Axial capacity of circular concrete-filled tube columns. *J. Constr. Steel Res.* **60**(7) 1049-68
- [6] Lam D, Young B and Ellobody E 2009 Behaviour of normal high-strength concrete-filled compact steel tube circular stub columns. *J. Constr. Steel Res.* **62**(7) 706-15
- [7] Liang QQ and Fragomeni S 2009 Nonlinear analysis of circular concrete-filled steel tubular short columns under axial loading. *J. Constr. Steel Res.* **65**(12), 2186-96
- [8] Knowles RB and Park R 1969 Strength of concrete filled steel tubular columns. *J. Struct. Eng. ASCE* **95** 2565-87
- [9] Hajjar J F and Goorley B C 1996 Representation of concrete-filled steel tube cross-section strength. *J. Struct. Eng. ASCE* **122**(11) 1327-36
- [10] Spacone E and El-Tawil S 2004 Nonlinear analysis of steel-concrete composite structures: State of the art. *J. Struct. Eng. ASCE* **130**(2) 159-68
- [11] Varma A H Ricles J M Sause R and Lu L W 2004 Seismic behavior and design of high-strength square concrete-filled steel tube beam columns. *J. Struct. Eng. ASCE* **130**(2) 169-79
- [12] Azizinamini A and Schneider S P 2004 Moment connections to circular concrete-filled steel tube columns. *J. Struct. Eng. ASCE* **130**(2) 213-22
- [13] Mirmiran A and Shahawy M 1996 A new concrete-filled hollow FRP composite column. *Compos Part-B: Engineering* **27B** 263-8
- [14] Li G, Torres S, Alaywan W and Abadie C 2005 Experimental study of FRP tube-encased concrete columns. *J. Compos. Mater.* **39**(13) 1131-45
- [15] Fam A Z, Flisak B and Rizkalla S 2003 Experimental and analytical modelling of concrete-filled fiber reinforced polymer tubes subjected to combined bending and axial loads. *ACI Struct. J.* **100** 499-509
- [16] Mirmiran A, Shahawy M, El Khoury C and Naguib W 2000 Large beam-column tests on concrete filled composite tubes. *ACI Struct. J.* **97** 268-76

- [17] Fam A and Rizakalla S 2003 Large scale testing and analysis of hybrid concrete/composite tubes for circular beam-column applications *Constr. Build. Mater.* **17** 507-16.
- [18] Ehab Ellobody and Mariam F 2007 Experimental investigation of eccentrically loaded fibre reinforced concrete-Filled stainless steel tubular columns. *J. Constr. Steel Res.* **76** 167-76
- [19] IS: 4031–1988, Methods of physical tests for hydraulic cement. *Bureau of Indian Standards*.
- [20] IS: 12269-1987, Specification for 53 grade ordinary Portland. *Bureau of Indian Standards*.
- [21] IS 2386(Part 1):1963 Methods of test for aggregates for concrete: Part 1 Particle size and shape. *Bureau of Indian Standards*.
- [22] Euro code 4- *Design of composite steel concrete structures*.
- [23] Brian Uya Zhong Taoa and Lin-Hai Han 2011 Behaviour of short and slender concrete-filled stainless steel tubular columns *J Constr steel res* 360-378.