Behaviour of hybrid fibre reinforced concrete-filled steel tubular beams and columns

Comportamento de fibra híbrida reforçada vigas tubulares aço e colunas tubulares aço cheias de concreto

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ABSTRACT

This paper presents the flexural performance of newly developed hybrid fiber reinforced concrete-filled steel tubular sections. The test parametres are fiber volume fraction and fiber hybridation ratio. Initially mechanical properties studied for 10 mono fiber reinforced concrete mixes using steel and Polypropylene fibres with 0.5%, 1.0%, 1.5%, 2.0% and 2.5% volume fraction. Based on the performance optimum fiber dosage was determined in each fiber, with the same volume fraction three different fiber hybridation was developed. Developed hybrid fiber reinforcement concrete, conventional concrete and optimum mono fiber reinforced concrete was used in the concrete-filled steel tubular beams and columns to determine the structural performance. The test results shows that, fiber reinforced concrete-filled steel tubular beams display significant improvement in the flexural performance.

Keywords: CFST, hybrid, fiber reinforcement concrete, flexural behavior, moment-curvature.

RESUMO

Este artigo apresenta o desempenho de flexão de seções tubulares de aço recobertas com concreto reforçado com fibras híbridas recentemente desenvolvidas. Os parâmetros de teste são fração de volume de fibra e taxa de hibridação de fibra. Inicialmente foram estudadas as propriedades mecânicas para 10 misturas de concreto mono-fibras reforçadas utilizando fibras de aço e polipropileno com frações volumétricas de 0,5%, 1,0%, 1,5%, 2,0% e 2,5%. Com base no desempenho, determinou-se a dosagem ideal de fibras em cada fibra, com a mesma fração volumétrica foram desenvolvidas três diferentes híbridas de fibra. Desenvolveu-se concreto reforçado de fibra híbrida, concreto convencional e concreto reforçado com fibra monofásica ideal nas vigas tubulares de aço preenchidas com concreto para determinar o desempenho de flexão. Os resultados do teste mostram que, os feixes tubulares de aço reforçados com concreto reforçado com fibra exibem uma melhora significativa no desempenho de flexão.

Palavras-chave: CFST, híbrido, concreto de reforço de fibra, comportamento à flexão, momento-curvatura.

1. INTRODUCTION

Concrete is a construction material which consists of fine aggregate, course aggregate, cement and water which hardens over a period of time[1]. It is most extensively used construction materials which have high strength in compression[2]. One of the major disadvantages in the concrete is the brittle fracture in tension with low tensile strength and ductility. The lack of structural ductility is due to brittle nature of concrete in tension which may lead to structural integrity[3]. Steel has high tensile strength which are used in concrete as reinforcement[4]. The bond between the concrete and steel makes the structure to achieve high strength in compression, tension and flexural properties[5]. Inorder to make the construction cost as economical and to reduce the cost of formwork, a special type of composite tubes known as Concrete-filled Steel Tubes (CFST) are introduced [6]. CFST are composite members consisting of an steel tube infilled with concrete to increase

the stabillity of the member. The CFST structural member have more advantages over steel reinforced concrete member. The strength and stiffness of the section increases with the orientation of steel and concrete in correct proportion [7]. It may appear unconventional, but the design, fabrication and construction process are simple and familiar to design and construction professionals [8]. The steel in the outer perimeter increases the performance of structural member and also resists the bending moment. The steel has high modulus of elasticity than concrete, hence it enhances the stiffness of the CFST. The concrete is the ideal core to withstand the compressive load and it prevents local buckling of the steel. Numerous testes have illustrated the increase in cyclic strength, ductility and damping by filling hallow tube with concrete[9]. Recent applications have also introduced the use of high strength concrete as filling material in the CFST combined with fiber has become much success[8]. There are some additional benefits from the use of CFST, in which tube serves as formwork in construction which reduces the labour and material costs. In conventional to high rise buildings can ascend more quickly than comparable reinforced concrete structures. CFST structural member behavior depends on concrete confinement, bond, residual stress, creep, shrinkage and type of loading. However, researches are ongoing about the study to impove CFST member in local buckling, concrete confinement, effect of bond, scale effect, and fire on CFST member strength, load transfer mechanisms so as to facilitate the development of performance based seismic design provisions.

For this study, twelve mix combinations like conventional concrete of M30 grade,Polypropylenefiber of volume fraction 0.5%, 1%, 1.5%,2%. 2.5% and steel fiber of volume fraction 0.5%, 1%, 1.5%, 2%, 2.5% was used. Another three mixes like Polypropylenefiber of volume fraction 1% was hybridized with steelfiberof volume fraction 0.5% and Polypropylene fiber of volume fraction 0.75% was hybridized with steel fiberof volume fraction 0.75% and Polypropylene fiber of volume fraction 0.5% was hybridized with steel fiberof volume fraction 1%. The mechanical properties were found to obtain the optimum mixes in Polypropylene fiber, steel fiber and hybridized combination. After obtaining the optimum mixes, the structural properties were foundout for that mixes.

2. MATERIALS AND METHODS

2.1 Materials

In this study, Ordinary Portland Cement (OPC) of 53 grade as per IS: 2269-2013 [10] was used and their chemical compositions are shown in Table 1.The commercially obtainable sand from river bed is used as a fine aggregate for this investigation. Fine aggregates used for concreting was clean, free from clay, chemically static and they contain sharp grains with angular alignment and used sand has been made to pass through 4.75 mm sieve and retained on 150 micron sieve. Fine aggregate is tested as per IS: 2386-1963 [11]. Specific gravity and fineness modulus of sand was 2.66 and 2.85 respectively.Crushed rock from quarry was used as a coarse aggregate of maximum size 20 mm with angular shape. Specific gravity and water absorption of coarse aggrgate was 2.6 and 0.3% respectively.

Table 1: Chemical composition of cement (% of ingredients)

	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	SO_3 (%)	Alkalines (%)
Cement	63.71	22.3	4.51	3.39	1.77	2.59	1.73

In this study, low modulus polypropylene fiber (PP) and high modulus steel fiber were the two different fibers were used for experimental investigationThe length, Diameter, Mechanical Properties of the fiber, are shown in Table 2.Figure 1. shows the polypropylene fiber and steel fibers used in this investigation.

Table 2: Physical and mechanical properties of different fibers

Fibre	Diameter [µm]	Length [mm]	l/d ratio	Density (g/cm³)	Nominal tensile strength [MPa]	Elongation at break [%]	Young's modulus [MPa]
PP	37	10	270	0.91	400	23	2.5
Steel	300	12	40	7.9	2000	4.5	175
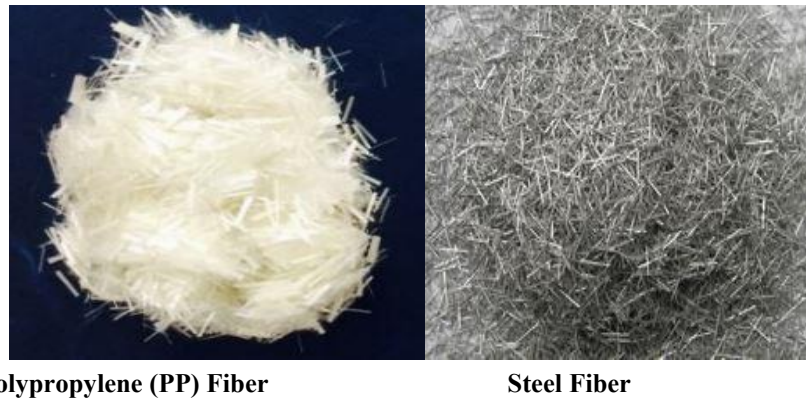
Polypropylene (PP) Fiber   **Steel Fiber**

Figure 1: Twotypes of fibers used for this study

As per Indian Standard concrete with 30 MPa is termed as M30 in which 'M' indicates the mix proportion and '30' indicates the compressive strength of concrete after 28 days curing. In this study, M30 grade concrete is used as a conventional concrete with 'M1' mix identification. The M2, M3, M4, M5, M6 mixes are M30 concrete with addition of polypropylene fiber of volume fraction 0.5%, 1%, 1.5%, 2%, 2.5% respectively and M7, M8, M9, M10, M11 mixes are M30 concrete with addition of steel fiber of volume fraction 0.5%, 1%, 1.5%, 2%, 2.5% respectively. To improve the strain hardening capacity[12], M12 mix with PP fiber and steel fiber of volume fraction 1% and 0.5% respectively was added and in M13 mix, PP fiber and steel fiber of volume fraction 0.75% and 0.75% was added respectively and in M14 mix, PP fiber and steel fiber of volume fraction 0.5% and 1% respectively is added. The mix proportions details are shown in Table3.

Table 3: Mix proportion of ECC

Mix ID	Ce-ment	Coarse Aggregate		Steel Slag		Wa-ter/Bin-der ratio	Sand	Silica Fume	Super Plasti--cizer	Fiber	
		10 mm	20 mm	10 mm	20 mm				[%]	PP	Steel
M 1	415	308.4	462	205.6	308	0.5	653	83	1.2	--	--
M 2	415	308.4	462	205.6	308	0.5	653	83	1.2	0.5	--
M 3	415	308.4	462	205.6	308	0.5	653	83	1.2	1	--
M 4	415	308.4	462	205.6	308	0.5	653	83	1.2	1.5	--
M 5	415	308.4	462	205.6	308	0.5	653	83	1.2	2	--
M 6	415	308.4	462	205.6	308	0.5	653	83	1.2	2.5	--
M 7	415	308.4	462	205.6	308	0.5	653	83	1.2	--	0.5
M 8	415	308.4	462	205.6	308	0.5	653	83	1.2	--	1
M 9	415	308.4	462	205.6	308	0.5	653	83	1.2	--	1.5
M 10	415	308.4	462	205.6	308	0.5	653	83	1.2	--	2
M 11	415	308.4	462	205.6	308	0.5	653	83	1.2	--	2.5
M 12	415	308.4	462	205.6	308	0.5	653	83	1.2	1	0.5
M 13	415	308.4	462	205.6	308	0.5	653	83	1.2	1	1

| M 14 | 415 | 308.4 | 462 | 205.6 | 308 | 0.5 | 653 | 83 | 1.2 | 0.5 | 1 |

2.2 Specimen Preparation

The specimen are prepared by mixingcement, fine aggregate, silica fume, steel slag and coarse aggregate were for 5 minutes. Now the fiberswere mixed with the concrete mix slowlyuntil fibers were mixed evenly. To reduce the effect of thixotropy, the mixing time of the concrete mix need to be extended (maximum15minutes)[13-18].The mixing time of concrete wasincreased inorder to reduce the balling effect. Now the prepared concrete mix was placed in their respective moulds and was vibrated to reduce the voids in concrete. Inorder to prepare CFST member, the concrete is filled inside the steel tubular section. Specimens were kept atroom temperature for 24 hours. Later the specimens weredemoulded and then cured for 28 days. After 28 days,all the tests were performed on the respective specimens. Table.4 shows the specimen details used for this investigation.

Table. 4: Specimen details

Test type	Specimen dimension (mm)	Tested after curing	Total specimen cast
Compression strength	150 x 150 x 150	28 days	36
Tensile strength	150 mm diameter x 300 mm height	28 days	36
Modulus of rupture	100 x 100 x 500	28 days	36
Flexural strength	115 x 115 x 1500	28 days	5

2.3 Test Methods

2.3.1 Compression Strength Test

To determine the compressive strength, the concrete cube of size 150x150x150 mm was tested at 28 days as percode IS 516-1959[19]. The cube specimen was placed in the compressive testing machine and theload was applied on the cube specimen until the cube specimen fails.The ultimate load at which the cubefails is known as compressive load.

2.3.2 Split Tensile Strength Test

To determine the split tensile strength, the cylindrical specimen of size 150 mm dia and 300 mm height was tested after28 days curing. The cylindrical specimen was placed in the testing machine and the load was applied until the specimen fails as per code IS 5816-1999 [20].

2.3.3 Modulus of Rupture

Inorder to determine the Modulus of rupture, the prism specimen of size 100x100x500 mm was used and test was carried out as per IS 516-1959 [19].The prism specimen was placed on two parallel supporting pinsandthe loading force was applied in the middle by means of deflection control machine. The loading was applied continuously until the specimen fails.

2.3.4 Flexural Performance of CFST Beam

To findthe flexural performance of CFST beam, hollow rectangular steel beam of size 110x110x1500 mm was casted and concrete mix is poured into the hollow beam andfour point load was applied on the beam specimen [21]. The beam is tested by usimg UTM machine. The load is applied gradually on the beam at the rate of 10kN and the deflection for every 10kN is measured by using dial gauge located below mid span. The load is applied until the beam specimen fails. Figure.2 shows the flexural load setup of steel tubular beam.

2.3.5 Performance of CFST Column under Axial Load

Short circular steel tubular section of inner diameter 105 mm, length 750 mm and 5 mm thick of tubular section was taken in to study. Figure.3 shows the test setup of column under axial load in a loading frame. Hydraulic Jack of 200Ton capacity was used to apply the axial load on the column and load cell is placed between jack and column to measure the applied load. Linear Variable Differential Transformer (LVDT) is used to measure the deformation in the column, Figure.3 shows the position of LVDT in the column, two LVDTs placed at the

center of the column to measure the lateral deformation and another is placed at the top to measure the axial deformation. Readings is measured with help of data acquisition system and values are stored in the computer and same is used for comparison of results.

Figure 2: Flexural Load Setup of CFST Beam.

Figure 3: Axial Load Setup of CFST Column.

3. RESULTS

3.1 Compressive Strength

The Compressive strength of all mixes are shown in Figure 4. From the results, it is found that compressive strength of conventional concrete M1 is found to be 53.1 MPa. On adding polypropylene fiber in different proportion, it was found that M5 has the maximum strength of 56.03 MPa which is 5.37% greater than conventional concrete M1. On other hand, while adding Steel fiber in different proportion it is found that M10 has higher strength of 55.62 MPa which is 4.64% higher than conventional concrete M1. While both polypropylene and Steelfibers were hybridized, it was found that M13 has higher strength of 57.2MPa which is 7.43% higher than conventional concrete.
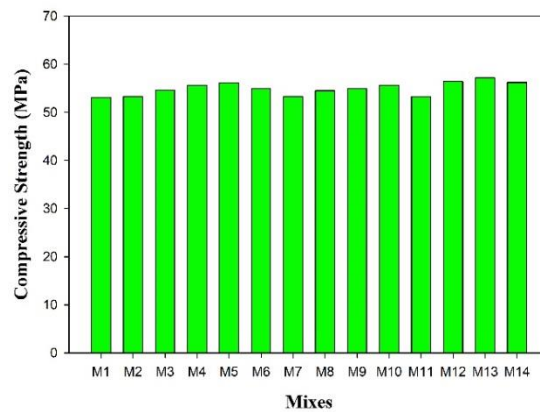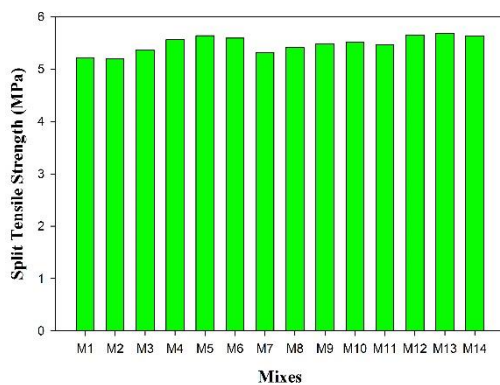

Figure 4: Compressive Strength of Various Mixes.

3.2 Split Tensile Strength

The split tensile strength of all mixes are shown in Figure 5. From the results, it was found that split tensile strength of conventional concrete M1 is found to be 5.21MPa. On adding polypropylene fiber in different proportion, it was found that M5 has the maximum strength of 5.64MPa which is 7.92% greater than conventional concrete M1. On other hand, while adding Steel fiber in different proportion it was found that M10 has higher strength of 5.52 MPa which is 5.78% higher than conventional concrete M1. While both polypropylene and Steelfibers were hybridized, it was found that M13 has higher strength of 5.68MPa which is 8.63% higher than conventional concrete. The regression analysis is carried out to predict the theoretical value of split tensile strength with respect to the compressive strength value [22]. From the regression analysis it was found that experimental values are almost close to the theoretical values. The regression analysis for split tensile strength is shown in Figure 6.
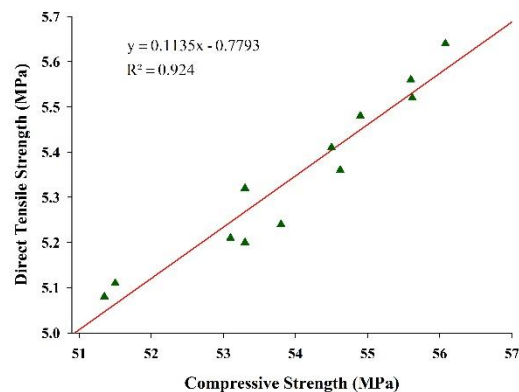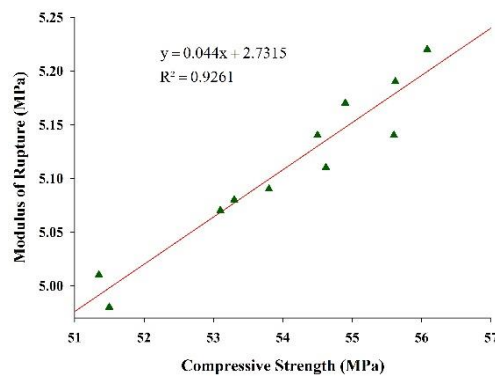
Figure 5: Split Tensile Strength of Various Mixes   **Figure 6:** Regression Analysis between Split Tensile vs Compressive Strength

3.3 Modulus of Rupture

The modulus of rupture of all mixes are shown in Figure 7. From the results, it was found that modulus of rupture of conventional concrete M1 is found to be 5.07MPa. On adding polypropylene fiber in different proportion, it was found that M5 has the maximum strength of 5.22MPa which is 2.91% greater than conventional concrete M1. On other hand, while adding Steel fiber in different proportion it was found that M10 has higher strength of 5.19 MPa which is 2.34% higher than conventional concrete M1. While both polypropylene and Steelfibers were hybridized, it was found that M13 has higher strength of 5.26MPa which is 3.67% higher than conventional concrete. The regression analysis is done to predict the theoretical value of modulus of rupture with respect to the compressive strength value[22]. From the regression anlaysis it was found that experimental values are almost close to the theoretical values. The regression analysis for modulus of rupture is shown in Figure 8.


$$y = 0.044x + 2.7315$$
$$R^2 = 0.9261$$
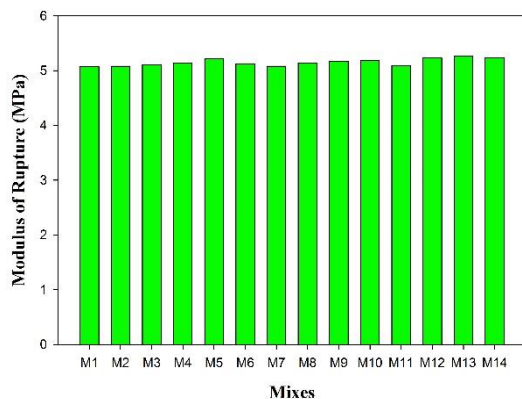
Figure 7: Flexural Strength of Various Mixes   **Figure 8:** Regression Analysis between Flexural vs Compressive Strength

3.4 Flexural Performance of Composite Beam

In this experiment, the flexural performance of conventional M1 and CFST beams of mixes M5, M10, M13 and also empty steel tubular beam were studied by applying four point load on the beam by using universal testing machine. Figure 9 and Figure 10 shows the moment vs curvature and load vs deflection curve of concrete filled steel tubular beams. For comparison purpose steel tubular section without concrete filled is used for the investigation. Empty steel tubular beam exhibit maximum flexural load of 182.5 kN and deflection of 19.6 mm under ultimate flexural load. Similarly the steel tubular filled with conventional concrete mix (M1 mix) exhibit ultimate load of 253 kN with deflection of 33.89 mm in mid span. Ultimate load carried by Mixes M5, M10 and M13 are 252.25 kN, 269.3 kN and 263 kN respectively, from this results it was observed that presence of PP fiber in the concrete does not improve the load carrying performance and which is nearly equal to the strength of convention concrete steel tubular section. However the deflection of M3 mix is 43.8 mm which is 22.6% higher than the M1 mix CFST beam. Deflection under ultimate load is 37.9 mm and 41.3 mm for M10 and M13 mixes respectively. The energy absorption of conventional mix beam M1 was 6217 kN mm and CFST beams of mixes M5, M10, M13 and empty steel tubular beam were found to be 8362 kN mm, 6969 kN mm, 7969 kN mm, 2350 kN mm respectively. From results, it was found that CFST beam with 2% steel fiber volume fraction carries the maximum load with notable deflection due to high modulus of rigidity of fiber [23]. However, the energy absorption capacity of CFST beam with 2% of polypropylene fiber is high when compare with other beams because the polypropylene fiber is a low modulus fiber and which exhibits high elongation with minimum load carrying capacity [24]. Mix M10 and M13 absorb notable load than the M5 mix, but it fails to perform in the deformation. Hence M5 mix CFST beam perform better than the hybrid fiber CFST beam. Which Presence of low modulus polypropylene fibers in the CFST improves the performance of the CFST section against load and deflection. Figure 11 shows the typical failure of CFST beam under flexural load.
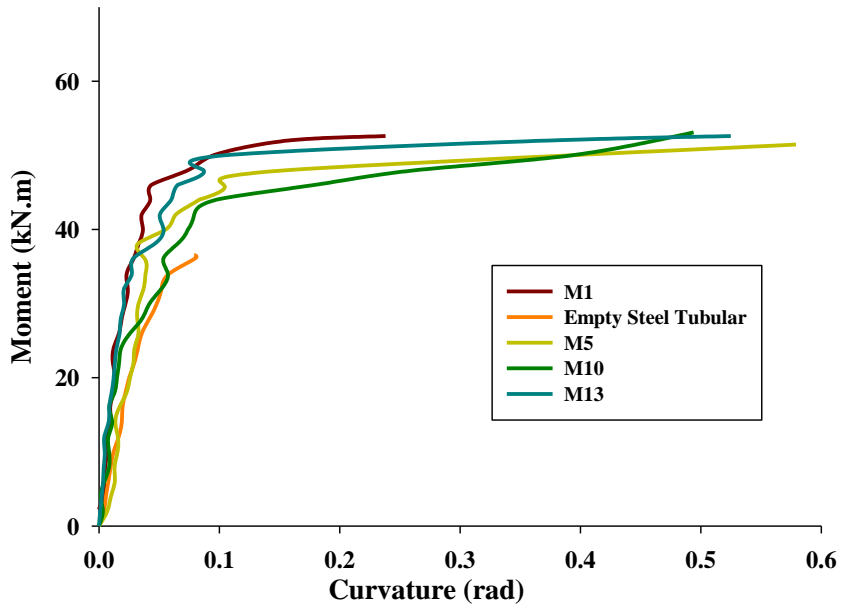
Figure 9: Moment vs Curvature curve for CFST beams.
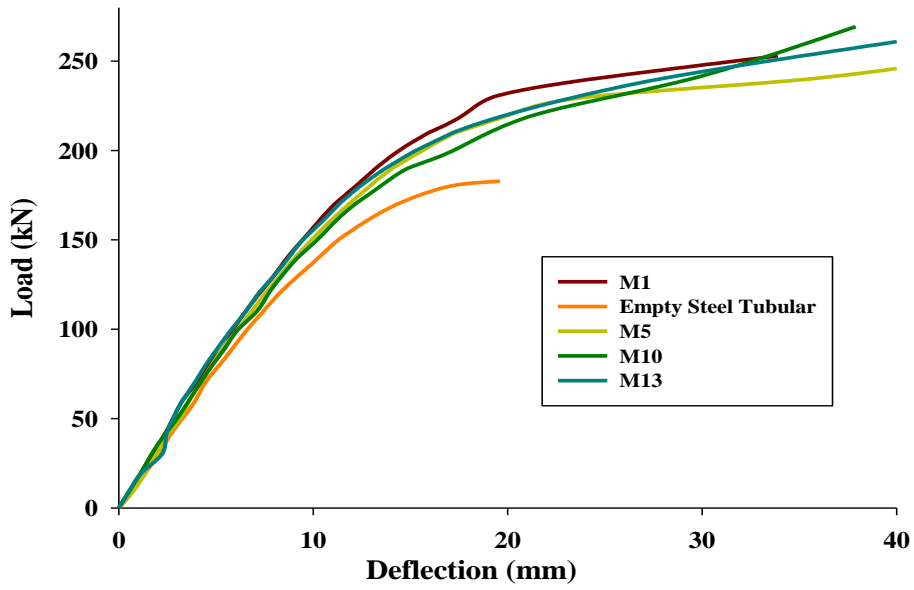
Figure 10: Load vs Deflection of CFST Beams.

Figure 11: Typical Flexural behavior of CFST beam under flexural Loading.

3.5 Performance of CFST Column under Axial load

To study the performance of CFST circular column mixes M5, M10 and M13 are used and in addition to that empty steel tubular beam was also used for the investigation for comparison purpose under axial load by using loading frame. LVDT is used to measure the axial and lateral deformation in the CFST circular columns. Figure 12 and Figure 13 shows the axial load and its corresponding axial deformation and axial load and its lateral deformation respectively of CFST column. CFST with maximum steel fiber reinforcement carries the maximum load of 725.9 kN, which is 5.81%, 4.35%, 2.84% and 43.24%, higher than the CFST column with Mixes M1, M5, M13 and empty steel tubular section respectively. Presence of fiber in the concrete mix improves the load carrying capacity of CFST column significantly due to the improvement in the stiffness of the mix under axial load [25]. However, empty hollow steel tubular section carried very minimum load of 412 kN due to its profile and very stiffness of the column to resist the axial load. In axial deformation aspect presence of fiber in CFST column does not create any impact.

Figure 13 shows the behavior of the CFST column after ultimate load, from this figure it was observed that the load applied face was crossed changed and look like elephant foot, this was happen after the specimen crossed the yield load and upto the ultimate load this process continues. From the figure 12 it was also observed that the Mix M5 subject to maximum deformation parallel to the load applied direction, which exhibit deformation of 19.52 mm in axial load direction. 15.12 mm, 13.9 mm, 18.5 mm and 18.9 mm are the axial deformation in the M1, empty steel tubular, M10 and M13 respectively. Similarly results is replicated in the r lateral deformation of CFST column, in which following deformation encountered in the CFST concrete column of 4.15 mm, 4.01 mm, 6.3 mm, 5.53 mm and 5.71 mm for mixes M1, empty steel tubular, M5, M10 and M13 respectively. Presence of PP fiber improves the performance of the columns after the yield load and also increases the energy absorption capacity of the column and similarly steel fiber reinforced composites also exhibit more load and noteworthy deflection in axial and lateral deformation [26]. In the fiber reinforced concrete CFST column display notable achievement in the load carrying capacity and also in the deformation along lateral direction.
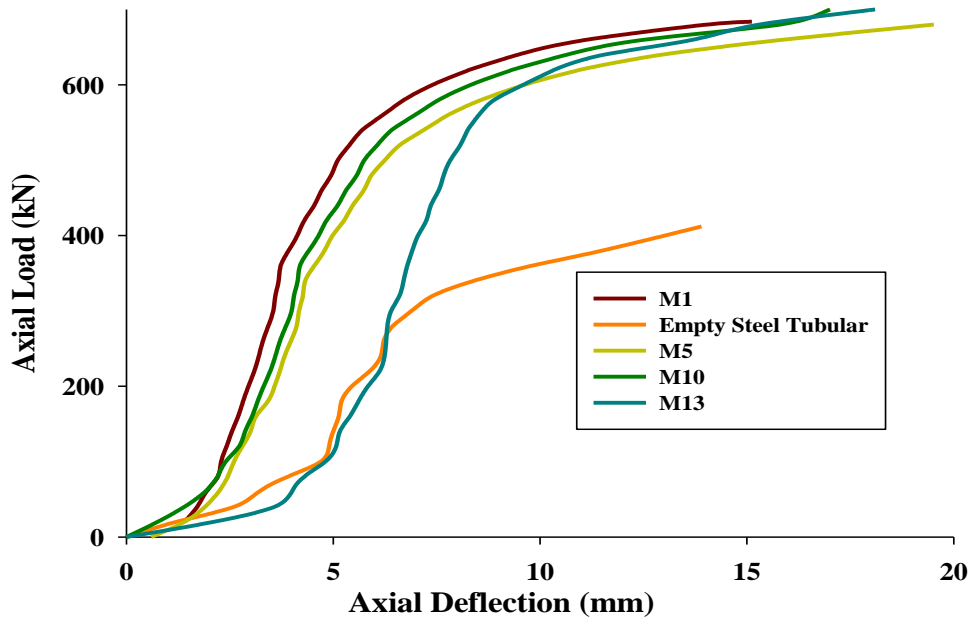
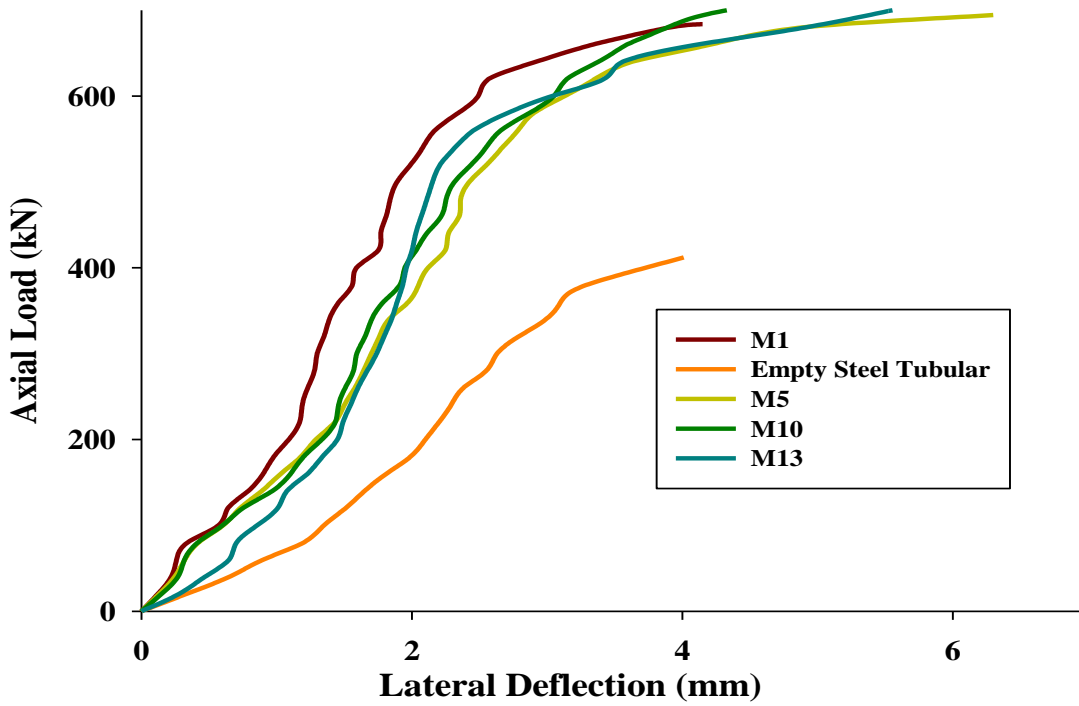**Figure 12:** Axial Load vs Axial Deflection of CFST Columns.

Figure 13: Axial Load vs Lateral Deflection of CFST Columns.

Figure 14: Behavior of CFST Column after Axial Load.

4. CONCLUSION

From the experimental investigations on CFST structural members like beams and columns the following conclusions were derived. From the mechanical properties, it was found that fibers with 2% volume fraction have higher properties when compared with conventional concrete. On analyzing the flexural performance, CFST beams with steel fiber of 2% volume fraction have higher load and with notable deflection in both beam and column. However CFST beams with PP fiber shows good results under ductility. Hybridation of fibers in the CST beams does not create any impact on the flexural performance than the mono fiber mix. Ductility of CFST beams increases with increase in ductility of concrete used to fill. In case of CFST column under axial load, presence of fiber does not create much impact in the load carrying capacity of column, improvement of axial load and respective deflection in mono and hybrid fiber is not more than 5% conventional concrete CFST column. On the other hand, lateral deformation of CFST column with PP fiber exhibit notable. Hybridation of low modulus and high modulus fiber does not create any impact in the flexural performance of beams and axial load on column. Presence of fiber in the CFST column under axial load shows less impact than the conventional CFST.

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