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Experimental Study on the Effect of Basalt Fiber Reinforced Concrete in Concrete Filled Steel Tube Columns

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Abstract - *Concrete Filled Steel Tube (CFST) columns are nowadays becoming a common structural element in bridges, tall buildings, transmission towers etc. Various structural properties of CFST members were investigated from 1970's by Furlong, Knowels, Han and Schneider. CFST attained its importance over normal RC structures and Hollow Structural Section (HSS) structures because of its astonishing structural properties like high axial strength, good fire resistance, enhanced ductility, and constructional ease and economy. In this paper, an elemental level study on the comparison of the behaviour of circular CFST columns and HST columns under uniaxial compression is studied. Also, the effect of basalt fiber reinforced concrete as filling in steel tube columns is studied. A total of sixteen specimens were tested in order to analyze the behaviour CFST columns. The effect of D/t ratio and L/D ratio on the behaviour of CFST columns, ductility and failure modes were experimentally investigated.*

***Key Words*: CFST columns, HST columns, Basalt fiber, Compressive strength.**

1. INTRODUCTION

Concrete Filled Steel Tubes (CFST) are composite members made up of circular, square or rectangular cross section of steel tube and filled inside with concrete. A CFST member utilizes the advantages of both steel tube and concrete through the composite action. Concrete Filled Steel Tubular columns are found to be used widely nowadays as a common structural element in bridges, multi-storeyed buildings, diagrid structures, transmission towers etc. The composite action of concrete core and steel tube enhances the structural properties of CFST columns when compared over steel and reinforced concrete columns. Outer steel tube provides confinement effect to the concrete core and the inner concrete core delays the local buckling of outer steel tube. Thus, the interactive behaviour of CFST columns can be effectively enabled in seismic prone areas and in high rise buildings. The outer steel tube act as a form work for casting the concrete, as a result the overall construction time can be saved, and the construction cost can be reduced. Introduction of basalt reinforced concrete in concrete filled steel tubes to achieve the use of material most effectively it has to be provided along the perimeter of the element and thus provides the highest contribution of the steel to the moment of inertia of the section and higher flexural resistance capacity.

1.1 Basalt Fiber

Basalt fiber is a material made from extremely fine fibers of basalt composed of the minerals pyroxene, plagioclase and olivine. It is similar to fiberglass, having better physic mechanical properties than fiberglass and is cheaper than carbon fiber.

2. MATERIALS USED

The materials used for the preparation of CFST specimens are hollow steel tubes, M-Sand as fine aggregate, 12.5mm crushed stones as coarse aggregate, Portland Pozzolana Cement as the cementitious material. The properties of materials and their details are as follows.

2.1 Hollow Steel Tubes

Mild steel hollow tubes with yield strength of 250 MPa were used in the experiment. The dimension of steel tubes is given in Table-1.

Table -1: Dimensions of the steel tube

Diameter (mm)	Thickness (mm)	Length (mm)	D/t	L/D
75	4	600	18.75	8
60	4	600	15	10
75	4	1200	18.75	16
60	4	1200	15	20

2.2 Basalt Fiber

Basalt fiber is made from a single material, crushed basalt from a carefully chosen quarry source. Melting of Basalt rock at about 1400 degree Celsius is done next extrusion of molten rock through small nozzle to produce continuous filaments of basalt fibers are done. The filament diameter obtained will be between 9-13 micro meters.

2.3 Cement

The Portland Pozzolana Cement (PPC) of 53 grade and confirming to IS 1489 (Part 1):1991 was used for the preparation of CFST and its properties are given in the Table-2. It is seen that all the test results satisfy the specifications as per Indian standards.

Table -2: Properties of PPC

Property of cement	PPC	Requirement as per IS 1489 (Part 1):1991
Standard consistency	32%	-
Specific gravity	3.15	-
Initial setting time	3.5 hrs.	> 30 minutes
Final setting time	6 hrs.	<600 minutes
Fineness of cement	3%	<10%

2.4 Fine Aggregate

Fine aggregate used was M-Sand which confirms to Table 4 of IS 383-1970 (Reaffirmed 2002). The properties of M-Sand are shown in the Table-3.

2.5 Coarse Aggregate

Coarse aggregate confirming to Table 2 of IS 383-1970 (Reaffirmed 2002) was used for the project. It consists of cubically shaped granite type aggregate having maximum size of 12.5mm. The properties of 12.5 mm aggregates are shown in the Table-3.

Table -3: Properties of aggregates

Property of aggregate	M-Sand	12 mm aggregate
Specific gravity	2.402	2.78
Water absorption (%)	3.24	1.645
Bulk density	1.847	1.653
Loose density	1.617	1.52
Percentage of voids (%)	30.59	37.99
Fineness modulus	2.79	6.79
Zone	II	

2.6 Water

Water used for mixing and curing should be fresh, clean and potable. It should be free from impurities like clay, loam, soluble salts.

3. CONCRETE MIX DESIGN

M20 concrete mix was proportioned according to the properties of the materials determined and the mix design was based on Indian Standard Concrete Mix Proportion Guidelines (IS 10262-2009). M20 mix was designed for a water cement ratio of 0.5. Workability of the mix designed was found by the slump test. The slump obtained was 75mm and thus confirms to medium degree of workability as per IS 456: 2000.

4. COLUMN SPECIMEN

4.1 Specimen Details

The behaviour of column subjected to concentric axial load is to be studied. The dimensions of specimens used are detailed in Table 3.5. The parameters varied in the study are diameter and length of the steel tube. The experiment is carried out for two diameters (60mm and 75mm) and two lengths (600mm and 1200mm). Hence experiments are carried out for two D/t ratios- 15 and 18.75. Effect of L/D ratio is studied by conducting experiments for four L/D ratios (8, 10, 16 and 20). As a result, HST1a, CFST1a, HST2a and CFST2a fall into the category of short columns and HST1b, CFST1b, HST2b and CFST2b fall into the category of slender columns. Hollow steel tube and CFST column elements are designated as HST and CFST respectively. The abbreviations are followed by one number and one alphabet. The number denotes the diameter of the tube (**1** for 75mm, **2** for 60mm) and the alphabet denotes the length of steel tube (**a** for 600mm, **b** for 1200mm).

Table -4: Details of test specimen

Designation	Diameter (mm)	Thickness (mm)	Length (mm)	D/t	L/D
HST1a	75	4	600	18.75	8
CFST1a	75	4	600	18.75	8
BCFST1a	75	4	600	18.75	8
HST2a	60	4	600	15	10
CFST2a	60	4	600	15	10
BCFST2a	60	4	600	15	10

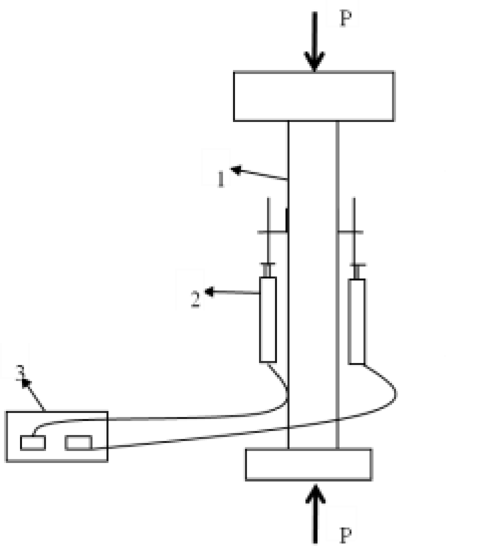
HST1b	75	4	1200	18.75	16
CFST1b	75	4	1200	18.75	16
BCFST1b	75	4	1200	18.75	16
HST2b	60	4	1200	15	20
CFST2b	60	4	1200	15	20
BCFST2b	60	4	1200	15	20

4.2 Casting and Curing of Test Specimen

The concrete for casting was prepared by machine mixing. All the materials except water was added and dry mixing was done for about 2 minutes. Then water was added slowly and mixed for 5 minutes. The machine mixed concrete was poured into the steel tube and table vibrator was used for vibrating concrete in the mould. The concrete was filled in three layers. Then the top surface was levelled to have a smooth finish and kept for setting. After 24 hrs, curing of the concrete was done. The infill concrete was cured for 28 days before testing.

4.3 Test Setup

The column elements were tested in a Universal Testing Machine of 300 tons capacity. The test setup is shown in Fig-1. At every 1-ton load increment, axial strain at mid height was measured using two LVDTs (Linear Variable Differential Transducer) and the ultimate loads were recorded. The LVDTs were calibrated using the calibration jig and screw gauge.



1- Specimen, 2- LVDT, 3- Display monitor

Fig -1: Test Setup

Fig -2: LVDT fixed on the specimen for measuring vertical strain

5. RESULTS

5.1 Compressive strength

The compressive strengths are obtained, and results are presented in Table -5 and Table -6.

Table -5: Compressive strength of basalt fiber specimens (7 days)

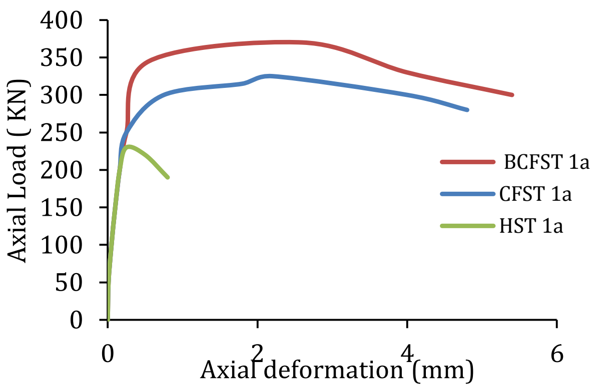
Specimen (concrete reinforced with basalt fiber)	Slump (mm)	Age	
		7 days	
		Compressive strength (MPa)	Increase in strength w.r.t A (%)
A (0% fiber)	97	15.30	-
B (0.5%)	86	17.50	14.37
C (1%)	76	17.89	16.93
D (1.05%)	69	18.30	19.60

Table -6: Compressive strength of basalt fiber specimens (28 days)

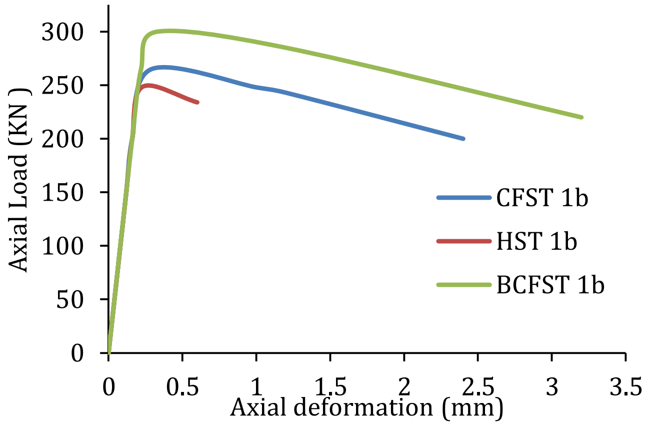
Specimen (concrete reinforced with basalt fiber)	Slump (mm)	Age	
		28 days	
		Compressive strength (MPa)	Increase in strength w.r.t A (%)
A (0% fibe)	97	21.10	-
B (0.5%)	86	24.55	16.35
C (1%)	76	25.35	20.01
D (1.05%)	69	26.30	24.64

5.2 Load deformation curve

The behaviour of hollow steel tube CFST and Basalt fibre reinforced concrete filled steel tube (BCFST) can be observed by plotting the load deformation curve. The comparison of performance of 75mm specimen for short and long column is shown in Fig-3(a) and 3(b). It can be observed that the ultimate load carrying capacity increased in case of the CFST specimen. It can also be noted that the deformation of the CFST specimen after the yield load is much more compared to the hollow steel specimen.



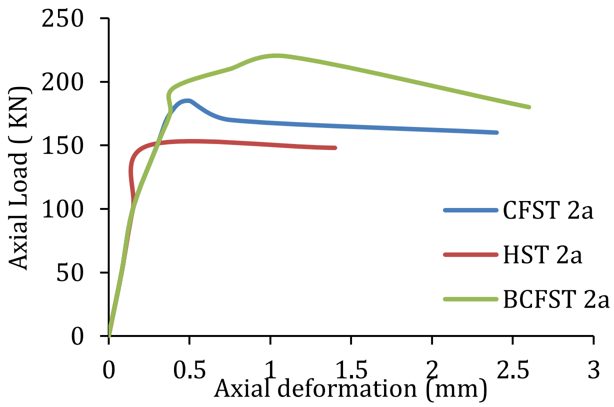
(a)



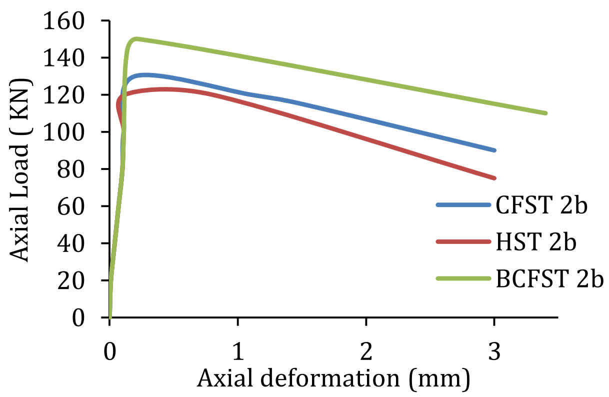
(b)

Fig -3.: Load deformation curve of 75mm dia CFST specimen (a) Short column (b) Long column

The comparison of performance of 60mm specimen for short and long column is shown in Fig-4(a) and 4(b). It can be observed that the ultimate load carrying capacity and ductility increased in case of the CFST specimen.



(a)

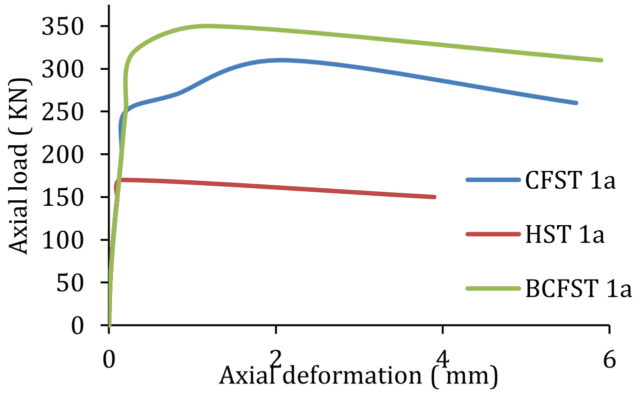


(b)

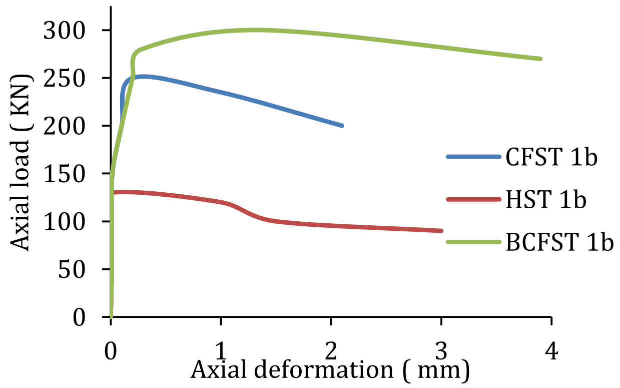
Fig -4: Load deformation curve of 60mm dia CFST specimen (a) Short column (b) Long column

5.3 Comparison based on D/t ratio

The experiment is conducted for two *D/t* ratios (15 and 18.75). Load deformation curve of CFST with different *D/t* ratio for short and long column is plotted and compared in Fig-5 (a) and 5(b). It can be observed that as *D/t* ratio increases the ductility of the column increases.



(a)



(b)

Fig -5: Load deformation curve of 60mm dia CFST specimen (a) Short column (b) Long column

5.3 Ductility index

It is an important parameter to assess the ductility of columns, it is an index which helps in estimating the seismic behaviour of CFST column. It can be found by

$$\mu = \frac{D_u}{D_y}$$

where D_u - Ultimate deformation

D_y – Deformation corresponding to yield strength i.e. yield deformation

Load-deformation curve is an important profile which shows the behaviour of material under load. Since Load-deformation curve for CFST columns doesn't have well define yield point it can be obtained by drawing a tangent to initial straight portion of curve and tangent to peak point the deformation at intersection point of two tangents gives yield deformation as shown in Fig-6.

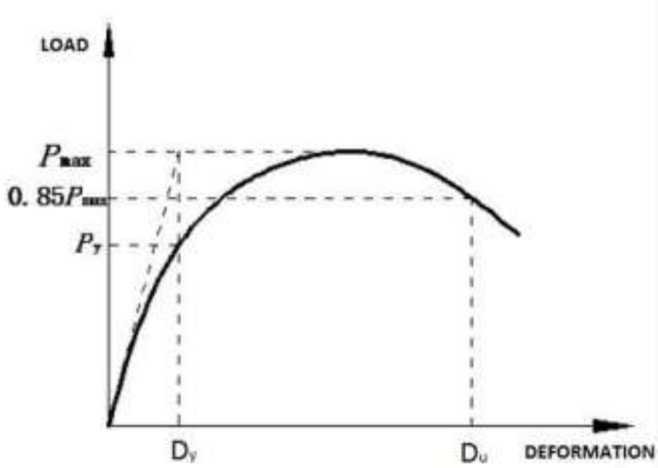


Fig-6: Load deformation curve of CFST

Table -7: Ductility index

Designation	Ductility Index
CFST1a	15.4
HST1a	4
BCFST1a	16.5
CFST2a	10.1
HST2a	6.8
BCFST2a	11.1
CFST1b	12.45
HST1b	4
BCFST1b	13.1
CFST2b	8.6
HST2b	5
BCFST2b	9.5

6. CONCLUSIONS

With reference to the experimental study carried out throughout the work, certain conclusions are drawn. They are summarized as follows:

- Basalt fibre reinforced concrete was found to have a higher compressive strength compared to plain concrete. Addition of 0.5 % to 1.05% of Basalt fibre enhanced the compressive strength by 15% to 25%

- Load deformation curve of BCFST columns clearly indicated improved ductility when compared to HST columns. Short columns were found to fail by crushing of concrete accompanied by the yielding of steel and long columns failed due to overall flexural buckling. When the BCFST short columns are loaded axially, formation of bulges was observed at the top of the specimen which was observed to be a trait in short column alone.
- From the experimental studies, it can be seen that the ductility index increases as the D/t ratio increases. Favourable range of D/t ratio was fixed based on the ductility index value for a fixed L/D ratio. Based on the experimental results the D/t ratio shall not be less than 15.

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