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Experimental investigation on Bond Behaviour of Concrete-Filled Steel Tube (CFST) Columns

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Abstract - - *Concrete Filled Steel Structures (CFST) offers wide benefits like high strength, ductility, energy absorption with the combined benefits of steels and concrete. It also reduces the time consumption in constructing since it doesn't require shuttering works hence they are frequently used. The composite actions of steel and concrete to occur there need a strong bond between steel and concrete interface. In the present study, it mainly focuses on bond behaviour of CFST columns in ambient temperatures by varying different parameters like cross section (circular and square), type of concrete (normal and expansive concrete), under normal interface condition and with shear studs and internal ring in ambient temperature and the comparison of bond strength under different cases.*

***Key Words*: Load carrying capacity, Concrete-filled steel tube, Shear stud, Internal ring, Slip, Bond stress.**

1. INTRODUCTION

1.1 General Background

Concrete Filled Steel Tubes (CFST) comprise of a steel hollow section of different shape filled with plain or reinforced concrete. CFST could make full use of the properties of steel and concrete for this it is necessary to ensure the steel and concrete materials are working together to form a composite action, which often relies on the bond in the steel-concrete interface. The strength of concrete is increased due to the confining effect provided from the steel tube, and the strength deterioration is not very severe, since the concrete spalling is prevented by tube. CFST column have a number of distinctive advantages over conventional steel – reinforced concrete members, and they are used widely for structures that requires a great applied moment and ductile deformations. Fig 1 shows typical cross sections of CFST columns

For this type of construction, it is desirable to ensure dissimilar materials to work together and develop the so-called "composite action". For achieving composite action either by relying on natural bond or with the aid of shear stud, by providing internal ring etc. is crucial methods for the increasing bond strength of CFST columns. Moreover, the interface bond of circular shaped CFST shows improved bond strength capacity than other cross sectional shapes. Despite its significance, the interface bond strength between the steel and the concrete has received relatively little attention in comparison to the structural response of CFST members.

When CFST columns are exposed to high temperature will induce the strength deterioration of both the steel tube and concrete & there occur physical and chemical changes for the steel and concrete materials. They are widely used in high-rise and multi-storey buildings as columns and beam-columns.

Tian-Yi Song *et al.* (2017) experimentally investigated the bond behaviour of CFST at elevated temperature. A total of 24 push of tests were conducted with 12 reference specimens at ambient temperature and 16 post fire specimens were tested. Different parametric studies which includes shape (circular and square), type of concrete (normal and expansive), steel type (carbon steel and stainless steel) and using shear studs, normal interface and using internal rings at temperatures of 20,200,400,600 and 800 °C with hold time periods of 45,90,135 and 180 min with applied axial load during heating. The results indicated welded ring has superior bonding compared to shear studs and normal interface. The bond strength of stainless steel specimens was lower than other reference specimens. The expansive concrete showed superior behaviour than normal concretes bond.

Zhong Tao *et al.* (2015) presented a paper regarding the bond behaviour CFST series of push out tests on circular and square CFST specimens with changing the parameters like cross sectional dimensions 120-160 mm, steel types of stainless steel and carbon steel, concrete types of normal concrete, interface with shear stud and interface with internal ring. Results indicate that stainless steel have lower bond compared to carbon steel. Bond strength decreases with increase in cross sectional dimension and concrete age. The first best method is found to using internal ring, second best method is using shear studs and then usage of expansive concrete. Tian-Yi Song *et al.* conducted and experimental investigation about the bond behaviour between steel tube and concrete with different parameters like stainless steel and carbon steel, with normal, with shear stud and internal ring, different concrete ages from 28 days to 3 years and using normal concrete and expansive concrete. It was found that the use of stainless steel leads to decrease in bond strength. Bond strength decreases with increasing in age and only welding shear studs or internal ring is recommended to enhance the bond strength.

2. EXPERIMENTAL INVESTIGATION

2.1 Concrete Mix Design Details

A concrete mix of 25 MPa was used for this study. The concrete mix design was done as per IS 456:2000 and IS 10262:2009 in order to achieve a 28th day compressive strength. The materials were tested for various properties needed for the mix design. Ordinary Portland Cement of grade 53 was used for the experiment. The coarse aggregates used were of size 10 mm and M-sand was used as fine aggregate. Admixture of type MASTER GLENIUM SKY 8433 added to increase the workability of concrete and to minimize the amount of water-cement ratio, for obtaining a desired slump range of 75 mm–125 mm for normal RCC work as per IS 456:2000, Cl.7.1. The final mix proportion adopted is as shown in the table -1.

Table -1: Concrete mix proportions

Grade	Mix Proportion			w/c ratio	Super-plasticizer
	Cement	Fine aggregate	Coarse aggregate		
M25	1	2.38	2.2	0.44	0.20%

2.2 Details of CFST specimens

Four specimens where chosen for experiment, one square cross sectional CFST column and three circular cross sectional CFST having normal interface, with shear stud and having internal ring .

A total of four CFST specimens including normal square, normal circular, circular shear stud and circular internal ring were cast. The columns were 450 mm long; with a cross section of 100 mm × 100 mm for square and 150mm diameter for circular columns with thickness of steel as 6mm. Push out testing of 4 specimens were conducted after the curing period for 28 days. At the end of curing, the columns were tested under the loading arrangement in the Universal Testing Machine. The further details of specimens are as shown in table-2.

Table -2: Details of specimens

Sl. no	Specimen designation	Height (mm)	Face dimension (mm)
1	Normal square CFST	450	100x100
2	Normal circular	450	150 dia
3	Circular with shear stud	450	150 dia
4	Circular with internal ring	450	150 dia

The different types of Steel Tubes are shown in Fig -2.

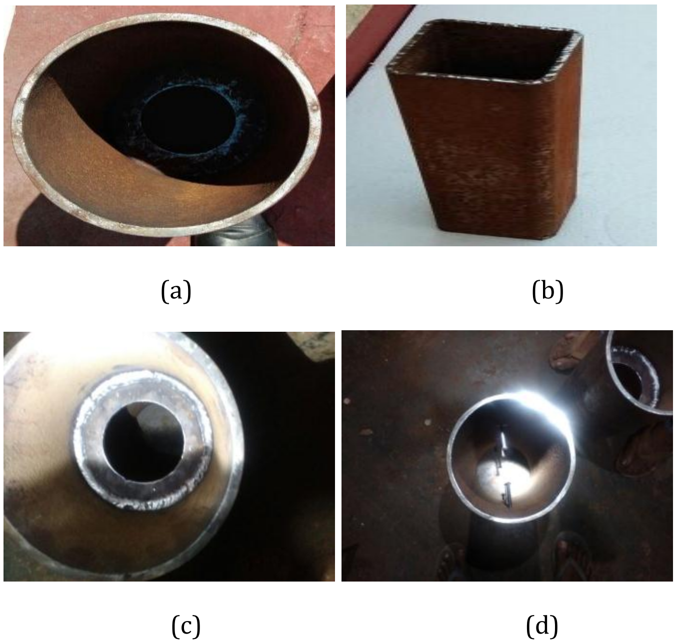

Fig -2: Different type of Steel Tubes: (a) Normal Circular CFST Column (b) Square CFST Column (c) CFST column with Internal Ring (d) CFST column with Shear Stud

The interior view of different CFST are shown in Fig -3

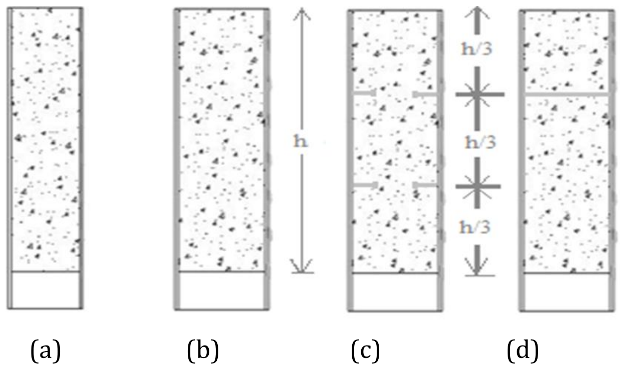

Fig -3: Different interior types of CFST Columns: (a) Square CFST column (b) Circular CFST Column (c) CFST with shear studs (d) CFST with internal ring

2.3 Casting of CFST Column Specimens

The concrete was batched, mixed manually, placed by hand in steel mould and compacted using tamping rod. A total of four CFST specimens including normal square, normal circular, circular shear stud and circular internal ring were cast. The columns were 450 mm long; with a cross section of 100 mm × 100 mm for square and 150mm diameter for circular columns with thickness of steel as 6mm. Push out testing of 4 specimens were conducted after the curing period for 28 days. At the end of curing, the columns were tested under the loading arrangement in the Universal Testing Machine.

2.4 Experimental setup

The project work consisted of an experimental investigation on bond behaviour of CFST column. Commercially available mild steel was used as steel tube. In the current process normal concrete was used for the casting of test specimens which is then cured for 28 day and tested in universal testing machine.

The test setup used to conduct the push out test which is conventionally used by many researchers. By using two steel blocks square and circle each, the load was applied to the concrete core at the top, and resisted by the steel tube alone at the bottom. For the bottom portion of CFST column, a hollow spacing of 20mm was given to allow the concrete core free to be pushed downward through the tube. The top steel block had a cross-section slightly smaller than that of the concrete core. The clearance between the top steel block and the perimeter of the tube and force applied to the concrete core only. All specimens were tested under UTM. To obtain strain readings used for the analysis of the load transfer between the steel tube and concrete, dial gauges were installed as shown in Fig-4.

(a) (b)

Fig -4: Experimental test setup of column specimens: (a) Circular Cross section CFST (b) Square Cross section CFST

3. RESULTS AND DISCUSSIONS

3.1 Slip Values

Pull out test was conducted the following table 3

Table -3: Observed slip values of CFST column specimens

Sl No.	Force (kN)	Circular CFST	Square CFST	Circular CFST with shear stud	Circular CFST with internal ring
1	0	0	0	0	0
2	10	0.5	1.15	0.5	0.3
3	20	0.7	1.92	0.68	0.48
4	30	0.86	2.31	0.83	0.58
5	40	1.03	2.63	0.95	0.69
6	50	1.2	2.88	1.03	0.78
7	60	1.35	3.8	1.08	0.86
8	70	1.45	4.27	1.15	0.93
9	80	1.6	4.51	1.2	1.03
10	90	1.7	4.72	1.25	1.1
11	100	1.8	4.94	1.3	1.15
12	110	1.9	5.16	1.35	1.22
13	120	2	5.39	1.38	1.29
14	130	3	5.69	1.43	1.34

Maximum force obtained for each CFST column specimen and their corresponding slip are shown in table -4. For comparison purpose at force equal to 100 kN different CFST columns has different slip values, Slip of internal ring is minmum with a value of 1.15mm followed by CFST welded with shear stud having a value of 1.3 mm then circular shape CFST having a slip value of 1.8 whereas sqaure CFST column has a maximum slip of 4.94mm

Table -4: Maximum load carrying capacity and slip values of CFST column specimens

Sl no	Description	Maximum force (kN)	Slip (mm)
1	Square	170	7.79
2	Circular	130	3
3	Circular with shear stud	200	1.96
4	Circular with internal ring	900	Above 7.5

The load vs slip curve for the column specimens were shown in chart -1.

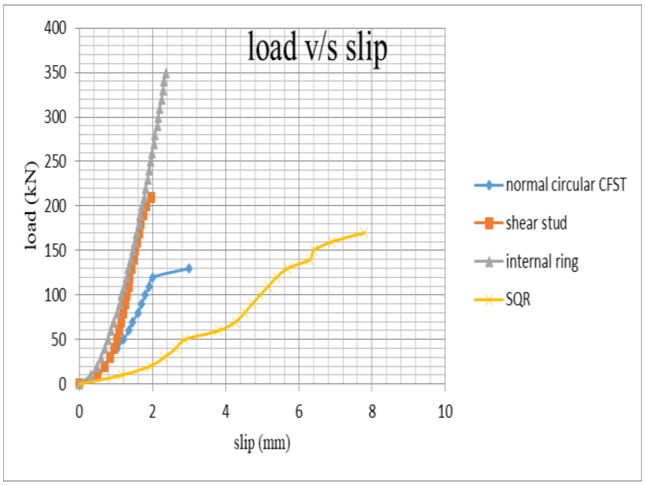

Chart -1: Load vs slip curve for CFST column specimens

From the analysis total slips were obtained. Bond stress capacity can be defined as the average interface stress associated with the initial rigid body slip of concrete core. The bond stress is used to evaluate the bond behaviour between steel tube and concrete core, bond stresses are obtained from the analysis as

$$\text{Bond stress} = \frac{Load}{area\ in\ contact\ with\ steel\ tube}$$

3.2 Slip Values with Cross Section Type

As per many studies conducted generally high bond strength is expected by circular CFST rather than square CFST since friction develop all around the perimeter of circular CFST's inner surface where as in square CFST the friction arise more at the four corners.

Chart -2: Slip of square and circular CFST column specimens

Table -5: Maximum slip values of CFST column specimens

Specimens	Ambient temperature slip (mm)
Square CFST	7.49
Circular CFST	3.19
Percentage increase	57.4 %

Above results shows the different slips values obtained from experiment in maximum load show the percentage increase in slip value, the results indicate square CFST has an increase of 134.8% than circular CFST this might be due to larger the size of tube (circular diameter of 150 mm and square of 100mm) possibility of better gaps between steel and concrete which increases the slip value.

3.3 Ultimate Load Carrying Capacity with Cross Section Type

Square column having dimensions 100x100mm and circular CFST having a diameter of 150mm has being tested under axial load in UTM on ANSYS and the results was obtained as shown in chart-3 it can be referred as the square CFST column takes more load than circular CFST this might be due to the change in type of cross section in the CFST column

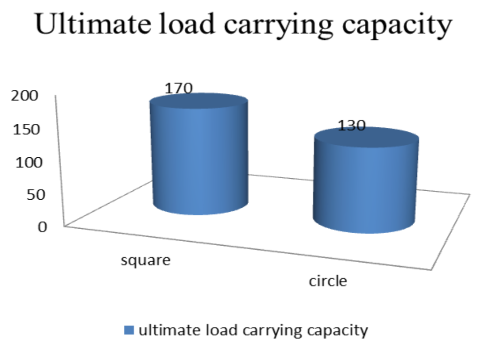

Chart -3: Ultimate load carrying capacity of square CFST column specimen and circular CFST column specimens

Table -6: Maximum load carrying capacity of CFST column specimens

Specimens	Ultimate load carrying capacity (kN)
Square CFST	170
Circular CFST	130
Percentage increase	23.53 %

It can be identified as there is a reduction in load carrying capacity of about 23.53 % for circular CFST than square CFST.

3.4 Slip with Interface Type

There are three types or interfaces selected for circular cross section as normal interface type, CFST with shear stud and CFST with welded internal ring. Circular CFST with normal interface is selected for comparison purpose as a base model. From earlier studies welding shear studs or internal ring onto the inner surface of steel tube can increase the bond strength.

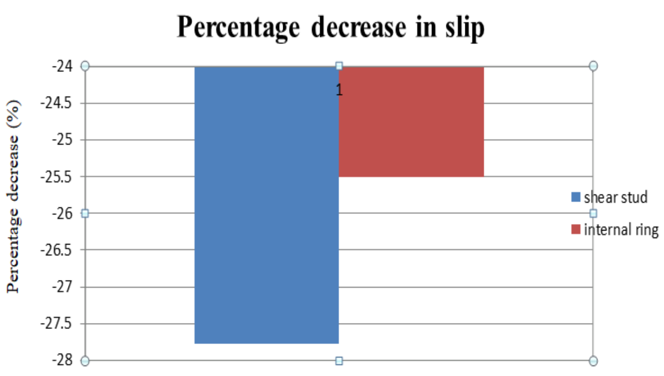

Chart -4: Percentage decrease of CFST column specimen slip values based on different interfaces of CFST column specimens

From the above chart 4 the percentage decrease in slip value with respect to normal interface, circular CFST column as a base model is more for circular column welded with shear studs compared to CFST with internal ring. The CFST with internal ring shows 36.11% decrease in slip value whereas CFST welded with shear stud shows 27.78 % reduction in slip compared to circular CFST with normal interface. Both CFST with shear stud and internal ring has less slip values compared to normal interface circular column.

3.5 Load Carrying Capacity with Interface type

The load carrying capacities of all CFST including square, circular with normal interface, circular with shear stud and circular with internal ring. CFST with internal ring shows dominant load carrying capacity.

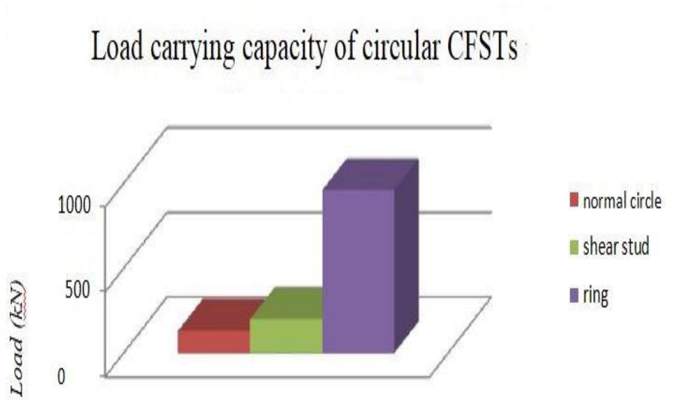

Chart -5: Load Carrying capacity of CFST column specimen based on different interfaces of CFST columns

From chart 5 we can understand that circular CFST welded with internal ring shows higher load carrying capacity consequently CFST with shear studs shows second most load carrying capacity and lastly CFST with normal interface.

3.6 Bond strength

The bond strength is the bonding capacity of steel and concrete so as they work together as a composite section. The bond stress capacity was defined as the average interface stress associated with the initial rigid body slip of the concrete core relative to the steel tube. The radial pressure resulted from the confinement of the steel tube could further enhance the frictional resistance and therefore bond stress at the top, strong composite action was formed between the outer steel tube and concrete. As the majority of the load was transferred from the concrete to the steel tube at the top, the compression was low in the concrete and high in the steel in the lower part of the column. In lower part of CFST tube bond stress is smaller than that of the top. Friction can be formed uniformly around the perimeter of circular column but for square friction is only in the vicinity of the corners.

Table -7: Maximum bond stress which each CFST can withstand before failure in MPa

Circular	Square	Internal Ring	Shear Stud
1.925	3.777	13.333	3.111

4. CONCLUSIONS

Concrete-filled steel tubes (CFST) have been widely used in engineering structures. For steel and concrete to work together as a composite action the bond between them should be strong. A study on the bond behaviour of CFST columns with various parameters like shape and interface was studied through experimental testing . For these studies, four different types of CFST columns (normal square & circle, circle with shear stud and internal ring) was considered under ambient temperature conditions. Following are the conclusions based on the parameters considered for this study:

- Maximum slip obtained for square CFST column compared to circular cross sectional CFST column was found to be an increase of 57.4% in ambient temperature condition.
- Maximum load carrying capacity and bond strength for circular CFST column when compared to square CFST column has a decrease of 27.78% and an increase of 49.03% respectively.
- Maximum slip obtained for square CFST column compared to circular cross sectional CFST column was found to be an increase of 57.4%.
- Maximum load carrying capacity and bond strength for circular CFST column when compared to square CFST column has a decrease of 27.78% and an increase of 49.03% respectively.

In general, the best method to improve bond strength of CFST columns in ambient temperature can be suggested as by providing a circular CFST column with internal ring and consequently, the second best method is of using shear stud and the last is circular shape CSFT column.

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