A Study on the Strength Behaviour of Circular Stiffened Concrete-Filled Aluminium Alloy Tube (CFAT) Columns

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Abstract - *Aluminium alloy is used as a building material in curtain walls, bridges and many other structural applications due to its high strength-to-weight ratio, excellent corrosion resistance, ease of extrusion into complex cross sections etc. The concrete filled in aluminium alloy hollow sections could effectively delay inward and outward local buckling failure of aluminium alloy members and greatly enhance load carrying capacity of structural components. However, little research has been carried out on concrete-filled aluminium alloy tube composite columns. Hence, there is a need to investigate the structural performance of concrete-filled aluminum alloy tube (CFAT) columns. CFAT members sometimes fail due to detachment of aluminium alloy tube from inside concrete surface. This bond breakage can be reduced by providing stiffeners which enhances bond strength, load-bearing capacity, ductility, buckling of aluminium alloy tube reduced which indicate better bond performance and increase confining effect from aluminium alloy tube to concrete. This paper focuses on experimentally determining the axial load carrying capacity of circular stiffened CFAT columns by varying number and layers of stiffeners and determine the best arrangement of stiffeners for circular CFAT columns. This paper also focuses on experimentally determining the energy absorption, ductility and failure patterns of circular CFAT columns with and without stiffeners.*

***Key Words*: Local buckling, Load carrying capacity, Concrete-filled aluminium alloy tube, Stiffeners, Ductility, Energy absorption, Failure patterns.**

1. INTRODUCTION

Aluminium alloy is used as building material in curtain walls, bridges and many other structural applications due to its high strength-to-weight ratio, excellent corrosion resistance, ease of extrusion into complex cross sections, ease of production etc. Furthermore, aluminum alloy tubes surrounding concrete eliminate permanent formwork, has high strength and high stiffness, and as such, construction time can be reduced [3,4,5]. Light-weight aluminum tubular members are used for structural applications, especially in space structures, claddings and curtain walls [3]. The concrete filled in aluminium alloy hollow sections could effectively delay inward and outward local buckling failure of aluminium alloy members and greatly enhance load carrying capacity of structural components [1,2]. The aluminum alloy tubular members are normally manufactured by heat-treated aluminum alloys, because heat-treated alloys have notably higher yield stress than non-heat-treated alloys. However, when heat-treated aluminum alloys are welded, the heat generated from the welding reduces the material strength significantly in a localized region, and this is known as the heat-affected zone (HAZ) softening [4].

1.1 Need of Stiffeners

CFAT members sometimes fail due to detachment of aluminium alloy tube from inside concrete surface. This bond breakage can be reduced by providing stiffeners which enhances bond strength, load-bearing capacity, ductility in compression of CFAT members, buckling of aluminium alloy tubes reduced which indicate better bond performance and increase confining effect from aluminium alloy tubes to concrete. The best arrangement of stiffeners for circular CFAT column is T-shaped stiffeners, ie., welding shear studs on internal tube surfaces, which enhances behavior of CFAT columns in terms of strength and ductility. Fig -1 shows T-shaped stiffener arrangement in CFAT column.

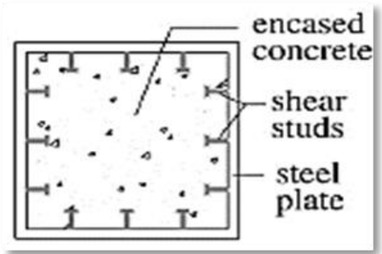


Fig -1: T-shaped stiffener arrangement in CFAT column [Source: www.researchgate.com]

The paper consists of an experimental investigation on the ultimate axial load carrying capacity, energy absorption, ductility and failure patterns of CFAT column specimens with and without stiffeners having difference in arrangement of stiffeners.

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 inorder 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 produced by BASF Incorporation was 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	Compressive strength (N/mm^2)	
	Cement	Fine aggregate	Coarse aggregate			7th day	28th day
M25	1	2.43	2.13	0.42	0.20%	20.35	32.4

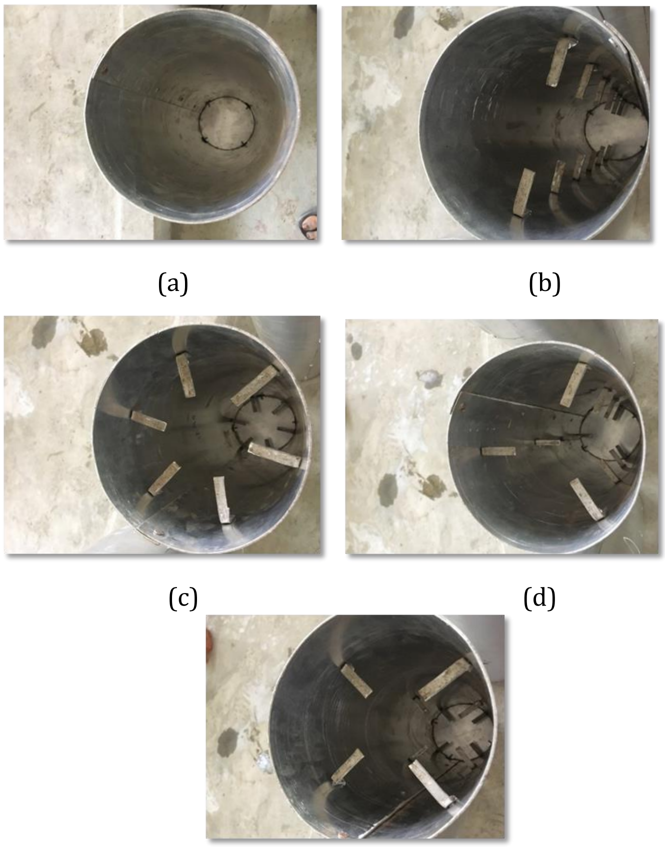
2.2 Details of CFAT specimens

A total of five column specimens were casted. The required aluminum alloy was 6061-T6 heat treated aluminium alloy (f_y= 270 N/mm^2) purchased from the local market to fabricate the column. The aluminium alloy sheet was riveted by overlapping the aluminium sheet and henceforth spot welded to obtain a tube shape. Each five CFAT column specimen includes one CFAT column without stiffener and four CFAT columns with different arrangement in number and layers of stiffeners. All the columns were 600 mm long with a diameter of 150 mm and a thickness of 1.5 mm. Stiffeners were provided at a 50 mm from top and bottom ends of the tubes having a total of 12 numbers in each tube with a length, breadth and thickness of 35 mm, 3 mm and 1.5 mm respectively. Stiffeners having equal area were provided throughout the height for all the columns. The bottom surface of CFAT was covered with a plate of 1.5 mm thick. All columns had the same geometrical dimensions and they are tested to failure. The columns are indicated by the label A1, A2, A3, A4, A5 for CFAT specimens where 'A' represents aluminium alloy and 1,2,3,4 and 5 represents different arrangement of stiffeners in terms of number and layers. The further details of specimens are as shown in table-2.

Table -2: Details of specimens

Label	Specimen Description
A2	CFAT column specimen with 2 numbers of stiffeners in 6 layers
A3	CFAT column specimen with 6 numbers of stiffeners in 2 layers
A4	CFAT column specimen with 3 numbers of stiffeners in 4 layers
A5	CFAT column specimen with 4 numbers of stiffeners in 3 layers

The different arrangement of stiffeners in Aluminium alloy Tubes are shown in Fig -2.



(a) (b) (c) (d) (e)

Fig -2: Different arrangement of stiffeners in Aluminium alloy Tubes: (a) A1 (b) A2 (c) A3 (d) A4 (e) A5

2.3 Casting of CFAT Column Specimens

For conducting experiment, the proportion of 1:2.43:2.13 was taken for cement, fine aggregate and coarse aggregate. Initially, the concrete floor of the laboratory was properly cleaned to avoid the undulations which was created by the small particles during the column casting. The machine mixed concrete was batched in the laboratory, poured into the aluminium alloy moulds and compacted using tamping rod. After compacting, the surface of concrete was levelled and finished. From the next day, the columns were cured for 28 days in curing tank.

2.4 Experimental setup

The CFAT specimens were tested in Universal Testing Machine (UTM) having load carrying capacity of 1000kN. The columns were tested under axial loading. Deflection of the column specimens were measured using a dial gauge (deflectometer) of least count 0.01 mm. Load was applied axially on the top surface of the CFAT column specimens at a uniform rate till the ultimate failure occurred. For each load of 10 kN, the deflection were recorded. All specimens were subjected to load up till failure. Testing procedure for all the column specimens were same. Thus load carrying capacity of each column specimen would be calculated by applying load. The load was applied gradually up to an ultimate load and deflections were measured at various load stages. The experimental test setup of column specimens is shown in Fig -3.

Fig -3: Experimental test setup of column specimens

3. RESULTS AND DISCUSSIONS

3.1 Effect of Number and Layers of Stiffeners in CFAT Column Specimens

A summary of test results for ultimate load carrying capacity and deflection of all CFAT column specimens are shown in table -3.

Table -3: Observed test results of CFAT column specimens

Sl.No.	Specimen name	Ultimate load (kN)	Ultimate axial deflection (mm)
1.	A1	520	5.00
2.	A2	695	6.53
3.	A3	586	5.52
4.	A4	760	10.50
5.	A5	644	6.00

The chart -1 shows variation of ultimate loads (kN) for CFAT column specimens.

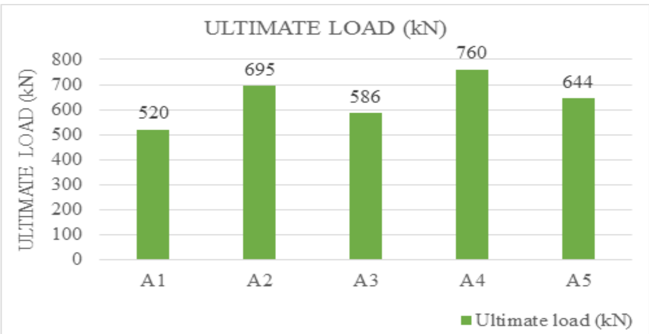


Chart -1: Variation of Ultimate loads (kN) for CFAT column specimens

The influence of number and layers of stiffeners in different arrangements of CFAT column specimens are discussed and compared with CFAT column specimens without stiffeners. The load vs deflection curve for the column specimens without stiffeners (A1) and with stiffeners of different arrangement (A2,A3,A4,A5) were shown in chart -2.

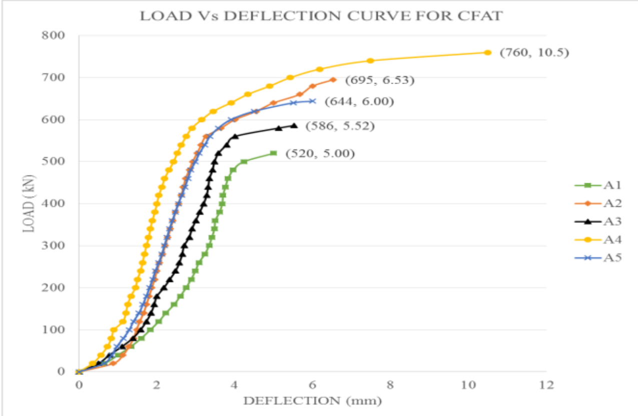


Chart -2: Load vs deflection curve for CFAT column specimens with and without stiffeners

3.2 Ultimate Load Carrying Capacity and Axial deflection

The ultimate load of CFAT column specimens with stiffeners (A2, A3, A4, A5) were increased when compared to A1 (without stiffeners). The increasing trends and the percentage increase in the ultimate load were shown in chart -1 and Table -4 respectively.

Table -4: Comparison of percentage increase in ultimate load for CFAT column specimens with and without stiffeners

Specimens	Percentage increase in ultimate load carrying capacity (%)
A2 w.r.t A1	33.65
A3 w.r.t A1	12.69
A4 w.r.t A1	46.15
A5 w.r.t A1	23.85

The measured ultimate load carrying capacity of stiffened CFAT column specimens is larger when compared to CFAT column specimens without stiffeners. This increase is due to the increase in bond strength between aluminium alloy tube and in-filled concrete in stiffened CFAT and due to larger effect of confining pressure provided by the stiffeners to the aluminium alloy tube and the in-filled concrete. The improvement in percentage increase in ultimate load bearing capacity is about 46.15%.

The best arrangement of stiffeners in CFAT is A4 (3 numbers of stiffeners in 4 layers) with an ultimate load of 760 kN. The ultimate load carrying capacity of stiffened CFAT increases as both the number of stiffeners in each layer and layer of stiffeners increases due to increase in bond strength between aluminium alloy tube and concrete in-fill. The table -5 shows axial deflection of CFAT column specimens corresponding to ultimate load of 520 kN.

Table -5: Axial deflection of CFAT column specimens corresponding to ultimate load of 520 kN

Sl.No.	Specimen name	Axial deflection (mm)
1.	A1	5.00
2.	A2	3.03
3.	A3	3.58
4.	A4	2.52
5.	A5	3.09

The chart -3 shows variation of axial deflection of CFAT column specimens corresponding to ultimate load of 520 kN.

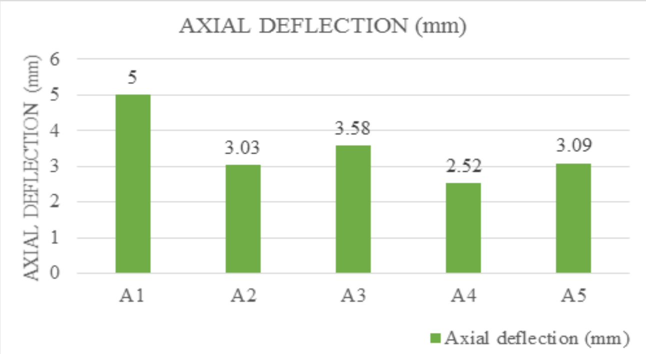


Chart -3: Variation of Axial deflection of CFAT column specimens corresponding to ultimate load of 520 kN

From chart -3, we can conclude that axial deflection is higher for CFAT column specimens without stiffeners (A1) compared to CFAT column specimens with stiffeners (A2,A3,A4,A5). From table -5, it is clear that the axial deflection for A1 is 5.00 mm. The best value of axial deflection is observed for A4 ie., 2.52 mm.

3.3 Deflection ductility index (DI)

The Table -6 represents the deflection ductility index and ratios of CFAT column specimens.

Table -6: Deflection Ductility index and ratios of CFAT column specimens

Specimen name	Max deflection (mm)	Yield deflection (mm)	Deflection Ductility Index (DI)	Deflection Ductility Ratio
A1	5.00	4.23	1.182	1
A2	6.53	3.36	1.943	1.644
A3	5.52	4.13	1.337	1.131
A4	10.5	3.15	3.333	2.82
A5	6.00	4.05	1.481	1.253

The chart -4 shows bar chart for variation of deflection ductility index (DI) for CFAT column specimens.

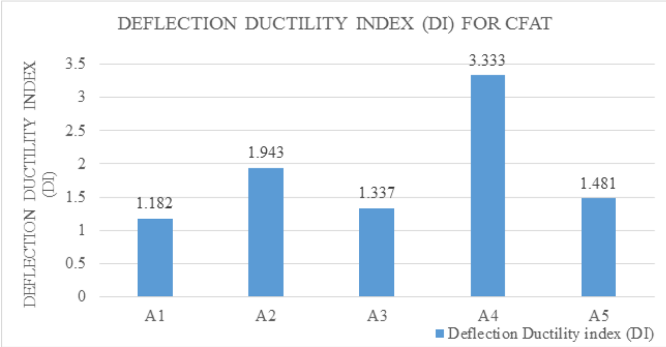


Chart -4: Variation of deflection ductility index (DI) for CFAT column specimens

A ductile reinforced concrete structure may take care of overloading, load reversals, impact and secondary stresses due to differential settlement of foundation. It gives the occupant sufficient time to vacate the structure by showing large deformation before its final collapse. Accordingly, the loss of life is minimised with the provision of sufficient ductility. IS 1893 (Part-1): 2002 states that, ductility of a structure or its members is the capacity to undergo large inelastic deformations without significant loss of strength or stiffness. The displacement ductility index, is defined as the ratio of deflection at ultimate load to the deflection at the yield load. The displacement ductility ratios of stiffened CFAT column specimens are obtained by dividing their respective deflection ductility indices with the deflection ductility index of CFAT column specimens without stiffeners. The deflection ductility indices is greater for stiffened CFAT column specimens than CFAT column specimen without stiffeners due to increase in load carrying capacity, confining effect and bond strength in stiffened CFAT column specimens. From chart -4, we can conclude that deflection ductility index (DI) is higher for A4 compared to other CFAT column specimens. From table -6, it is clear that the deflection ductility ratio for CFAT specimen with stiffeners is 1.131 to 2.82 times greater than that of specimen without stiffener.

3.4 Energy Absorption

The area under the load-deflection curve up to the ultimate load is taken as the energy absorbed by the CFAT column specimens with and without stiffeners. The Table -7 shows the energy absorbed by the CFAT column specimens.

Table -7: Energy absorbed by the CFAT column specimens

Specimen name	Energy absorbed by the specimen (J)	Energy Absorption Ratio	Percentage increase in absorbed energy w.r.t A1 (%)
A1	1473.2	1	------
A2	1820.575	1.236	23.58

A3	1496	1.015	1.548
A4	1865.8	1.266	26.649
A5	1503.85	1.021	2.081

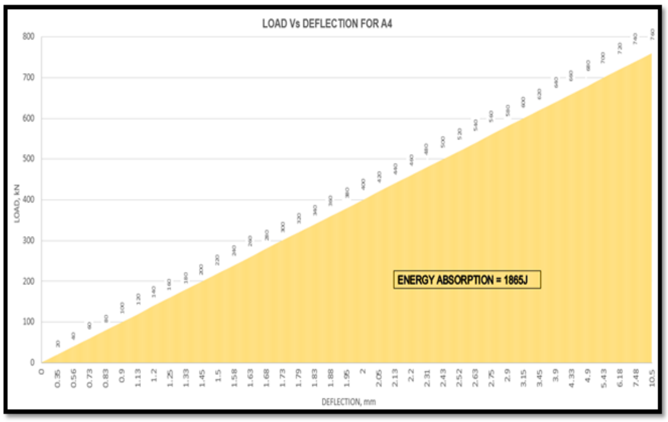


Chart -5: Energy absorption for A4 column specimen

In the seismic design of structures, a high energy absorption capacity is expected to ensure the safety of the structure. More the energy absorption capacity of the column, more is its resistance towards seismic loads. The energy absorption ratios of stiffened CFAT column specimens are obtained by dividing their respective energy absorbed with the energy absorbed by the CFAT column specimen without stiffener. The chart -5 shows energy absorption for A4 column specimen. From the table -7, we can conclude that, there is a 26.649% increase in energy absorption of A4 compared to that of A1. From the table -7, we can derive that, the energy absorption of stiffened CFAT is 1.015 to 1.266 times that of the unstiffened CFAT. The columns with stiffeners has increased energy absorption compared to the columns without stiffeners. However, increasing both the number of stiffeners in each layer and layer of stiffeners in CFAT has improved the energy absorption due to the increased load carrying capacity of the same.

3.5 Failure Pattern of CFAT Columns

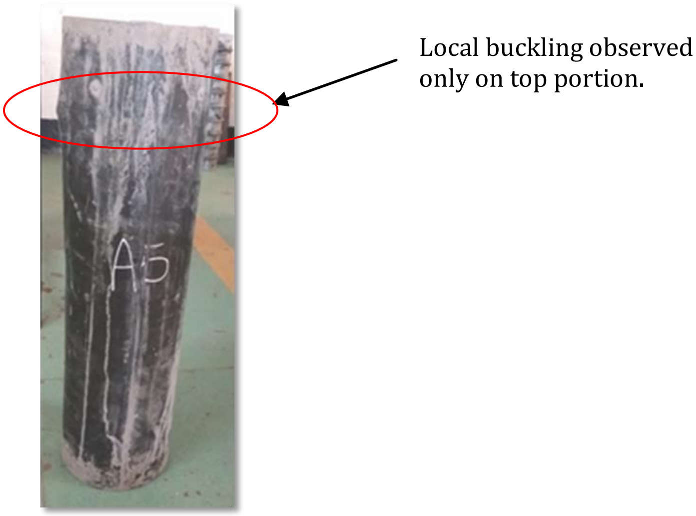
The local buckling of the aluminium alloy tube was visible in all the specimens. In most of the CFAT specimens, local buckling was observed near the top portion (one fourth height of column) of the aluminium alloy tube column specimens. The failure mode obtained for the stiffened and unstiffened CFAT columns are shown below.

(a) A1

(b) A2

(c) A3

(d) A4



(e) A5

Fig -4: Failure patterns observed for CFAT column specimens

4. CONCLUSIONS

The major conclusions derived from the experimental investigations carried out on the stiffened and unstiffened CFAT column specimens are as follows:

- The ultimate load carrying capacity of the stiffened CFAT (A4) were increased by 46.15% when compared to A1, ie., CFAT without stiffeners.

- From the results it is observed that the ultimate load carrying capacity increases as both the number of stiffeners in each layer and layer of stiffeners increases. Therefore, the best arrangement of stiffeners in CFAT is A4 with an ultimate load of 760 kN.

- The axial deflection is higher for CFAT column specimens without stiffeners (A1) when compared to CFAT column specimens with stiffeners (A2,A3,A4,A5). The axial deflection for A1 is 5.00 mm. The best value of axial deflection is observed for A4 ie., 2.52 mm.

- The deflection ductility indices increases for stiffened CFAT than CFAT without stiffeners. From the results, we can conclude that deflection ductility index (DI) is higher for A4 compared to other CFAT column specimens. The deflection ductility ratio for CFAT specimen with stiffeners is 1.131 to 2.82 times greater than that of specimen without stiffener.

- The energy absorption of A4 is 26.649% greater than A1. The energy absorption of stiffened CFAT is 1.015 to 1.266 times that of unstiffened CFAT. Thus proving the CFAT column to be effective in earthquake prone areas.

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