Behavior of Hybrid CRRP-Concrete-Steel Double Skin Tubular Column under Axial Load

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Abstract

Hybrid double skin tubular members (DSTMs) are composite section of three material FRP tube outside, steel tube inside and concrete sandwiches in between. The current study investigated the behavior of fourteen circular DSTCs under axial load. Every specimen is average of a pair of samples, the key parameters are the layers of outer carbon FRP tube, the compressive strength of concrete and the types of columns include (DSTC) and concrete filled FRP tube (CFFT). The test results show that the concrete has effected constrained between two tubes, that's leads to increases strength and ductility of column, the most effective parameters has the number of layers of outer FRP tube the stress-strain relationship shows high ductile behavior of under compression test and the CFFT is superior in ultimate load compared with DSTC.

Keywords: Double skin tubular columns, Concrete filled FRP tube, Carbon fiber reinforced polymer tube**.**

1. Introduction

Fiber reinforced polymer (FRP) composites are using in wide application in engineering construction to achieve high performance member, such as concrete filled fiber tube and excessive research on CFFT leads to proposed a new hybrid double skin tubular column consist of outer FRP tube-concrete- steel tube [1, 2, 3], to achieve advantages of these materials in one member, like; increase strength of columns as concrete is confine by two tubes; inner steel tube and outer FRP tube, get a better ductile behavior of column, hybrid DSTCs prevent corrosion and buckling of inner steel tube because of concrete restrained steel tube absolutely that has increase rigidity of steel tube, prevent concrete from being crushed (steel tube benefit), protect columns from fire by warp column by outer FRP tube so that saving fire protection cost, vii. Higher capacity to support loading [4, 5, 6, 7]. **Vincent et. al. (2013)** [8], investigated the effect of confinement method on concrete specimens under axial compression load. Confinement method has no considerable influence on axial stress-strain behavior of FRP confined concrete and performance of FRP-wrapped concrete specimens have similar to CFFTs. **Ozbakkaloglu el. at. 2014** [9], investigated seismic behavior of DSTC. This investigating leads to the concrete filled inner steel tube of DSTC improve high capacity of lateral drift, while the CFFT with hollow steel

tube is less, DSTC may present an fascinating alternative open CFFT column in the earthquake-resistant of the building columns. **Fanggi et. al. (2015)**[10], presented the influence of inner steel tube cross section on square DSTC compressive behavior with or without concrete filled in steel tube. The DSTCs with circular hollow steel tube gave larger value of ultimate axial stress and strain compared with square hollow steel tube. Influence of the concrete inside steel tube as shown improves behavior of square DSTCs and similar in behavior of normal and high strength concrete filled inside steel tube and circular inner steel tube with same level of performance.

Ozbakkaloglu et. al. 2015 [11], investigated the DSTCs system with different grades of concrete, where filled concrete in between two tubes (FRP tube and steel tube) and inside steel tube, the study was leads to superior compression behavior of DSTCs, and behave very high load –deformation capacity. **Farahi et. al. (2016)** [12], presented the numerically on compressive behavior of steel tubular double skin filled with concrete, three generally types geometrically of cross-sections have conducted in this study, behavior of columns with concrete filled steel DSTC for given sections   were generally like short column behavior. While much research has been conducted on the DSTCs with diameter 150 mm and height 300 mm, the present study was aimed to investigating the compressive behavior of DST columns with dimension 100 mm and 310 mm to achieve properties of columns according to **Building Code Requirements for Structural Concrete (ACI 318-05)** [13]. The results of the experimental program are presented and followed by a discussions on the effect of the key parameters on the behavior of DSTCs and carbon FRP external tubes

2. Experimental Program

All 14 DSTCs have 100 mm in diameter and 310 mm in height, the outer FRP tubes have made by embedded carbon fiber sheet on polymer resin Table (1) illustrates details of specimens. The first letter of specimens name (D) refers to DSTC and (F) refers to CFFT.

The letter (C) refer to concrete compressive strength of cubic fcu (70mm* 70mm) C60, C55, C50 and C45 MPa. The letters (ds) refer to diameter of inner steel tube diameter 48mm ds48. The letters (ts) refer to thickness of inner steel tube thickness 1.5mm ts1.5. The roman numeral (I) refer to number of carbon fiber reinforced polymer layers I: one layers.

Table (1) Details of specimens

Specimens Designation	Cubic Compressive Strength of Concrete (MPa)	Diameter of Inner Steel Tube (mm)	Thickness of Inner Steel Tube (mm)	Number of Layers of FRP Tube
DC60ds48ts1.5I	60	48	1.5	1
DC60ds48ts1.5II	60	48	1.5	2
DC60ds48ts1.5III	60	48	1.5	3
DC55ds48ts1.5I	55	48	1.5	1
DC50ds48ts1.5I	50	48	1.5	1
DC45ds48ts1.5I	45	48	1.5	1
FC60I	60	Non	Non	1

3. Material of DSTC

3.1. Concrete material

The specimens have poured with high strength self-compact concrete (mortar) with four compressive strength and cement: sand 1:1.5 as shown details of mixes in Table

Table 2. Mortar mixes proportion

Mixes Designation	Water /Cementatious	Cement :Sand	Silica fume %from weight of cement	S.P. % from weight of cement	Cubic compressive strength (fcu) MPa	Cylinder compressive strength (fć) MPa
C45	0.37	1:1.5	8	1.00	45	30
C50	0.36	1:1.5	10	1.36	50	35
C55	0.36	1:1.5	12	1.78	55	45
C60	0.35	1:1.5	15	2.17	60	50

3.2 Fiber Reinforced Polymer (FRP)

Carbon fiber reinforced polymer tube (CFRP) was used in this work consists of two components, unidirectional carbon fiber sheet and epoxy resin. Table 3. illustrate the properties of carbon fiber sheet from data sheet. The carbon sheet has cut into three pieces, two small with 50 mm width and third pieces with 310 mm width, with overlapping zone 100mm, that pieces embedded with epoxy .

Table 3. Properties of carbon fiber

Nominal thickness t f (mm-ply)	Tensile strength ff (MPa)(nominal)	Ultimate tensile strain,6 ε f (%)	Elastic modulus Ef (GPa)(nominal)
0.12	4100	1.7	231000

*from data sheet of carbon fiber.

3.3 Steel Tubes

Hollow steel tube (HST) is used in this study with ds 48 mm and ts 1.5 mm, three specimens are tested under axial load to get properties steel tube, as show in Table 4..

Table 4. Properties of steel tube

Specimens	Peak Load (kN)	Yield Load (kN)	yieling Stress (MPa)	Axial Strain (mm/mm)	lateral Strain (mm/mm)	Modes Failure
HSTds48ts1.5	75	60	327	-1.550	2.034	global buckling, elephant footing & rippling

* From compression test of steel tube in Diyala university, structural engineering lap.

3.4 Instrumentation and Testing

All specimens have tested under axial compression load until failure, the test conducted in university of Diyala,

engineering college, structural lap. The testing machine with load capacity 2000 kN, the load increment was 1kN/sec, Figure 1. Shows set up of testing.

Fig 1. Set up of testing.

4. Test Results and Discussion

4.1 Ultimate Load

It can be seen that, better confinement by (two and three) layers of outer FRP tube in DSTCs which caused an increase in Pu by (15% and 63%), respectively, compared with DSTC with one layer of FRP. When increased the compressive strength of concrete in DSTCs (50, 55 and 60) MPa caused increasing in value of Pu by

(5%, 19% and 32%), respectively compared with DSTC of compressive strength of (45) MPa. While The Pu was increased in CFFT by (15%) compared with DSTC. To evaluate the percentage between (Pu) to assemblage of (Pc) and (Ps) ratio as called Load enhancement ratio (LE) as illustrated in eq. 1, (**Yu, 2007** [14] **and Ozbakkaloglu, 2013** [15**]** and ultimate load capacity of unconfined concrete (Pc) has get from multiplying ultimate stress of unconfined concrete (fć) by cross section of concrete in side DSTC, and ultimate load of steel test (Ps) was

ultimate load of steel tube get from compression test of steel tubes, (consider that ultimate load of DSTCs ignore effect of FRP confinement and combined part doesn't interact), the load enhancement ratio was given below:

$$LE= \frac{Pu}{Pc+Ps} \qquad (1)$$

Load enhancement ratio gave a good indication of higher ultimate load with (15% and 63%) in DSTCs with two and three layers, respectively compared with DSTCs with one layers of FRP tube, consider exactly the same increasing in ultimate load and load enhancement ratio, that's because effective restrained concrete by two tubes, FRP tube outside and steel tube inside. In addition to number of outer FRP layers that provide more restriction.

Table 4. Summery of test result of specimens

Specimens Designation	Ultimate Load Pu (kN)	Service Shortening Δs (mm)	Ultimate Shortening Δu (mm)	Ultimate Load of concrete Pc (kN)	Ultimate Load of steel Ps (kN)	Load Enhancement Ratio LE	Ultimate stress of Concrete f'con (MPa)	Nominal Confinement Ratio	Strength Enhancement Ratio of Concrete SE	Axial Strain εa (mm/mm) ×10⁻³	Enhancement of Axial Strain K1	Hoop Strain εh (mm/mm) × 10⁻³
DC60ds48ts1.5I	518	2.30	5.90	303.0	75	1.37	74.0	0.188	1.48	-3.50	2.14	3.20
DC60ds48ts1.5II	593	2.78	7.71	303	75	1.57	86.0	0.342	1.72	-3.65	2.23	3.30
DC60ds48ts1.5III	845	2.78	9.76	303	75	2.24	127.5	0.514	2.55	-6.11	3.74	4.85
DC55ds48ts1.5I	460	2.70	5.70	272.3	75	1.32	63.6	0.209	1.41	-3.42	2.57	3.23
DC50ds48ts1.5I	414	2.70	5.54	242.0	75	1.31	55.5	0.235	1.40	-3.41	2.64	3.50
DC45ds48ts1.5I	393	2.80	5.40	212.0	75	1.36	53.5	0.269	1.50	-3.10	3.15	3.70
FC60I	595	1.80	7.14	Non	Non	Non	76	0.188	1.50	-4.18	2.56	2.80

4.2 Load-Shortening Behavior

The load-shortening relationship of specimens, the curve has bilinear at first part, after transition point at second part the curve became nonlinear and stiffer in specimens with (two and three) layers, the CFFT and specimens with C60 and one layers of outer FRP tube. The specimens of C55, C50 and C45 behave at the first part of the curve has bilinear, at the second part the ultimate shortening was increase with load increase, after bilinear first part drop in load has occur in curve because of redistribution stress after yielding of inner steel tube, as shows in Figure 2, 3 and 4 below. From Table 4. it can be seen that the service shortening Δs (at the service stage was considered by 70% of reference ultimate load **Ibrahim et al, 2013)** [16], Δs has slightly decreased, while the ultimate shortening was increased by (24% and 54%) in DSTCs with two and three layers of outer FRP tube respectively compared with specimens DSTC with

one layers of FRP tube as shown in Figure 2., the similar observation with (**Yu et. al, 2013)** increase number of FRP layers caused increasing in the ultimate load and ultimate shortening.

The service shortening decreased by (4%, 18% and 18%), and ultimate shortening has increased by (2.6%, 5.5% and 9.2%) in DSTCs with compressive strength (50, 55 and 60) MPa, respectively, compared with DSTCs with compressive strength (45) as show in figures 3.

The service shortening was decrease by (18%), and ultimate shortening was increase by (21%) in CFFT compared with DSTC, the ultimate shortening of CFFT was more than DSTC because of CFFT restrained by outer FRP tube only, while DSTC has restrained by two tubes outer FRP tube and inner steel tube inside as shown in figure 4.
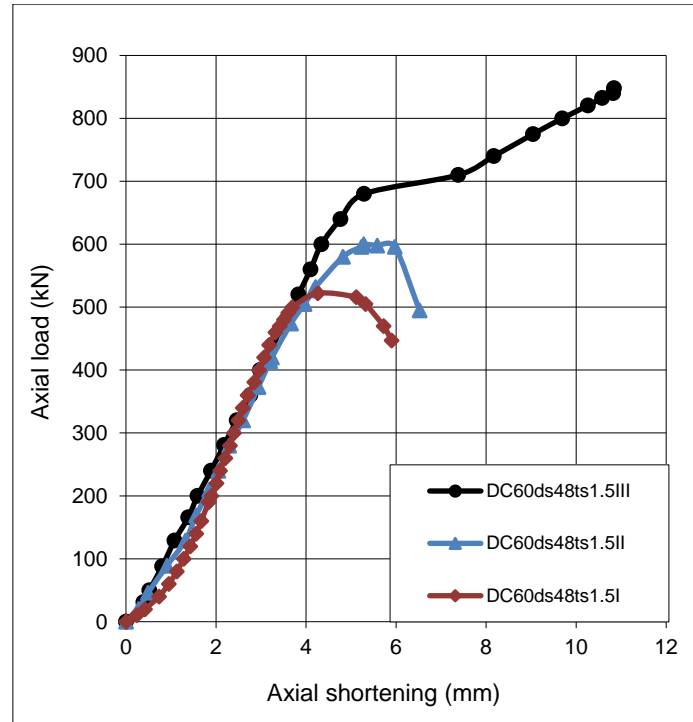
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Fig 2. Load- shortening relationship of DSTCs with (one, two and three) layers of FRP tube.
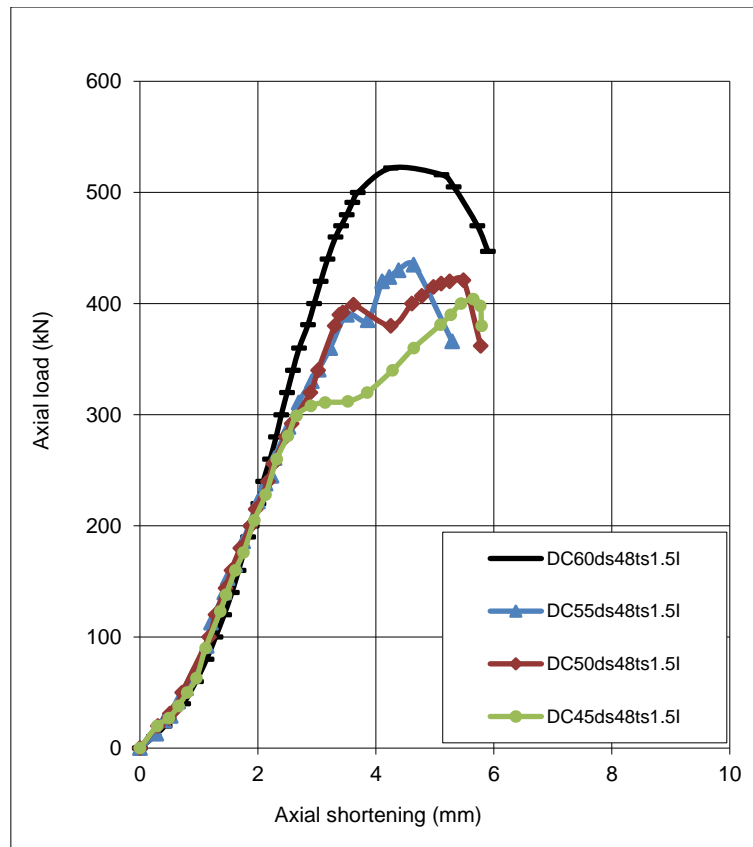

Fig 3. Load- shortening relationship of DSTCs compressive strength (45, 50, 55 and 60) MPa layers of FRP tube.
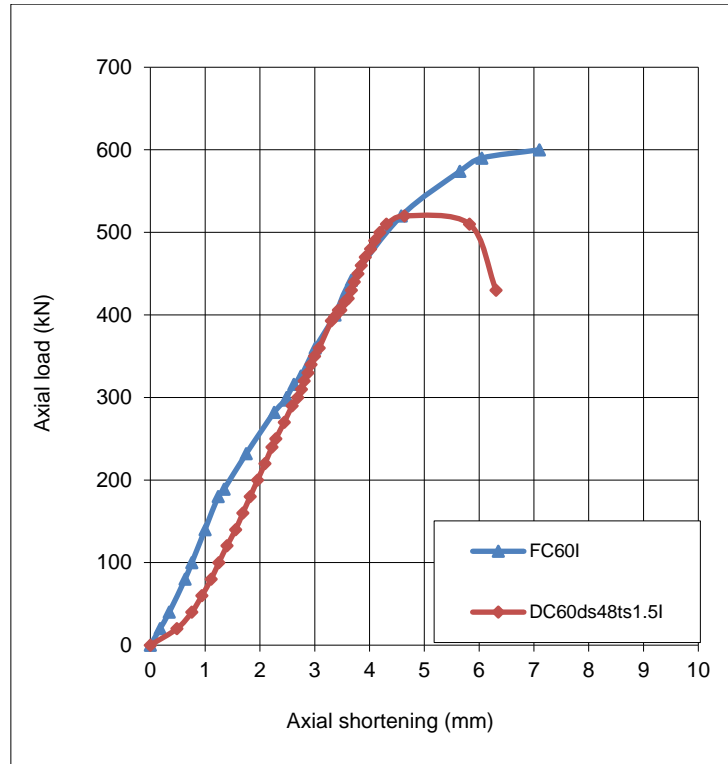
Fig 4. Load- shortening relationship of DSTCs and CFFT.

4.3 Stress- Strain Behavior

The confinement of concrete has became very necessary to increase compressive strength and protect concrete from weathering condition. Therefore; behavior of concrete in DSTC should be investigated, for the designing of outer FRP tube the nominal confinement ratio has percentage between confining pressure to concrete compressive strength, calculated from Eq. 2 to assuming a uniform confinement distribution, as the performance criterion in establishing relative confinement levels of DSTCs with different concrete strengths (**Ozbakkaloglu et. al., 2013**)

$$\frac{f_1}{f\acute{c}} = \frac{2t_f E_f \varepsilon_f}{D_f f\acute{c}} \tag{2}$$

Where :

f_1: confining pressure (MPa).

$f\acute{c}$: cylinder concrete compressive strength (MPa).

E_f: modulus of elasticity of FRP (GPa).

t_f: total nominal thickness of FRP(mm).

εf : ultimate tensile strain of the fibers (mm/mm).

D_f: internal diameter of the FRP tube (mm).

Nominal confinement ratio were increased by (82% and 172%) in DSTCs with two and three layers of outer FRP tube as illustrate in Table 4., that's increasing in nominal confinement ratio leads to more effect of FRP tube layers and increasing in axial load and ultimate shortening. The stress-strain curve of concrete inside DSTCs of specimens with one, two and three layers are illustrate in Figures 5. to 7. respectively.
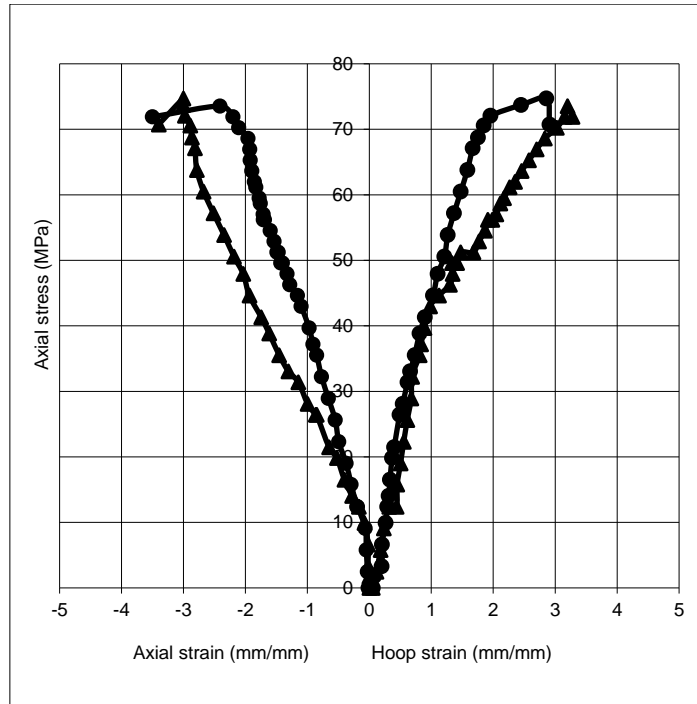
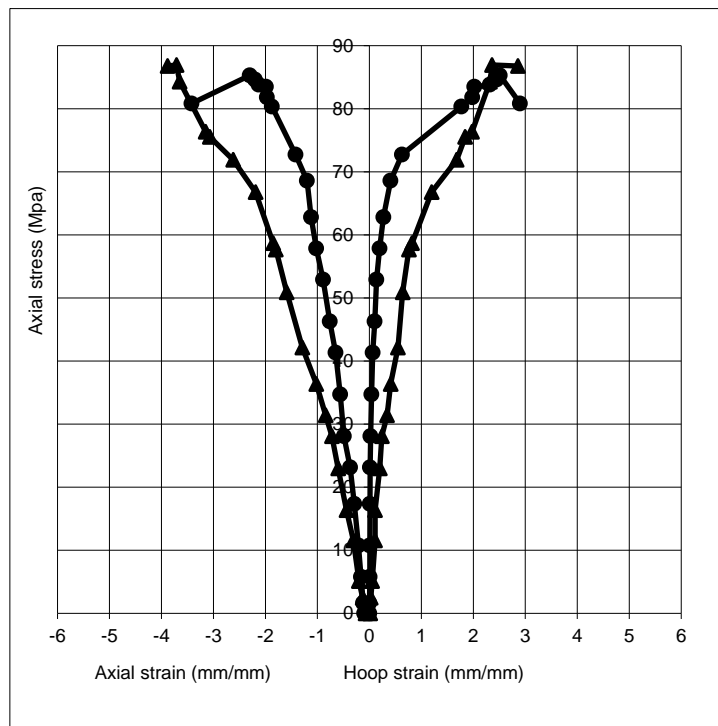**Fig 5**. Stress-strain relationship of specimen DC60ds48ts1.5I.

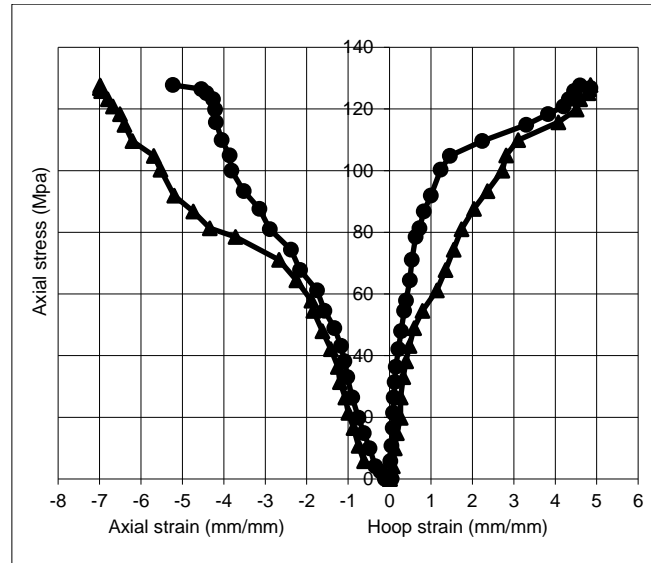**Fig 6**. Stress-strain relationship of specimen DC60ds48ts1.5II.

Fig 7. Stress-strain relationship of specimen DC60ds48ts1.5III.

The stress of concrete inside DSTC (fcon) evaluated by ultimate load of DSTC subtraction from ultimate load of steel tube test to same strain, fcon have increased by (16% and 72%) in DSTCs with two and three layers. The strength enhancement ratio of concrete inside DSTC (SE) (get from dividing the ultimate stress of confinement concrete to ultimate strength of unconfinement concrete), SE ratio has increased significantly the same increasing of concrete stress.

The axial strain of concrete in DSTC has gotten from average of two strain gauges at mid height of specimens. Enhancement of axial strain (K1) has gotten from divided axial strain of confined column (εa) to the axial strain of unconfined concrete (εco) (from cylinder 100*200 mm^2),

K1 increased by (4% and 74%) in DSTC with two and three layers of FRP, that's due to the amount of confinement leads to better ductility and strength of concrete inside DSTCs.

Nominal confinement ratio has decreased by (13%, 22% and 30%) in DSTCs with compressive strength (50, 55 and 60) MPa compared with DSTC of compressive strength of (45) MPa, that's leads to the confinement of concrete became very effective, Especially, when compressive strength of concrete has low. The stress-strain relationship of DSTCs with compressive strength (55, 50 and 45) MPa show in Figures 8, 9 and 10 respectively, it can be seen that the drop in curve occur after inner steel tube reach to yielding stage.
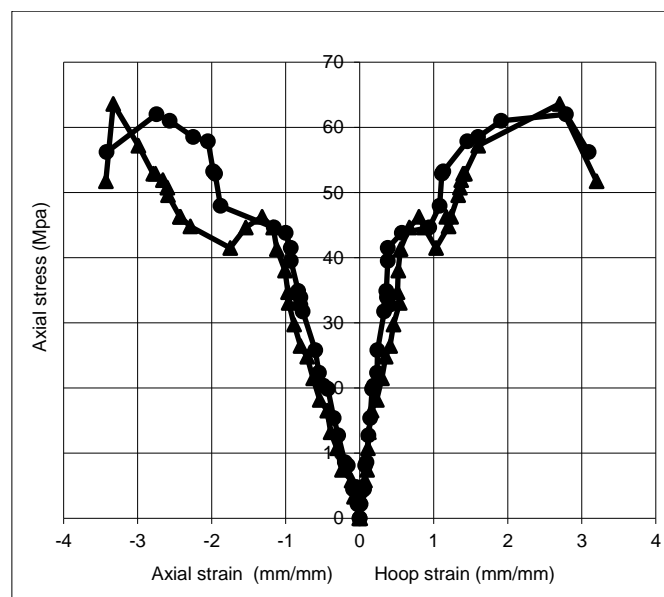

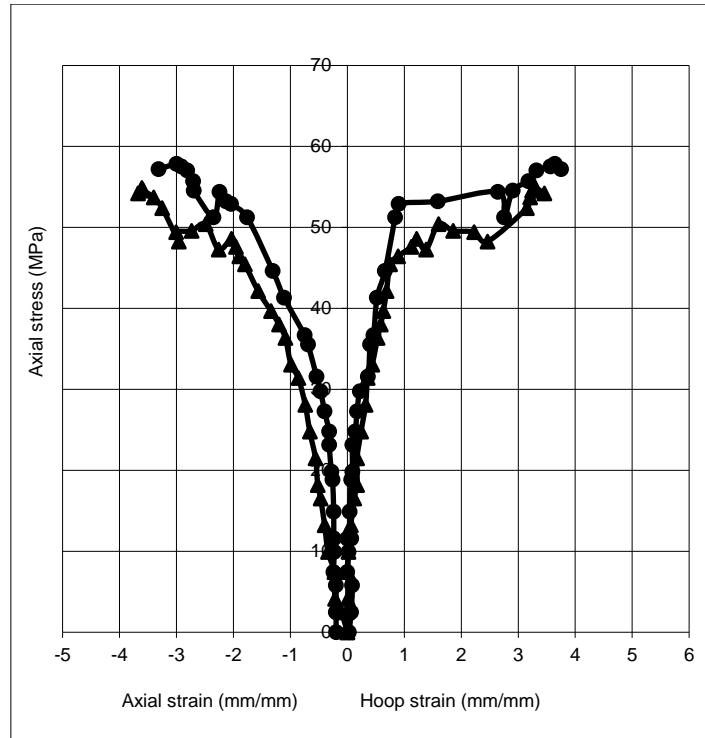**Fig8**. Stress–strain relationship of specimens DC55ds48ts1.5I.

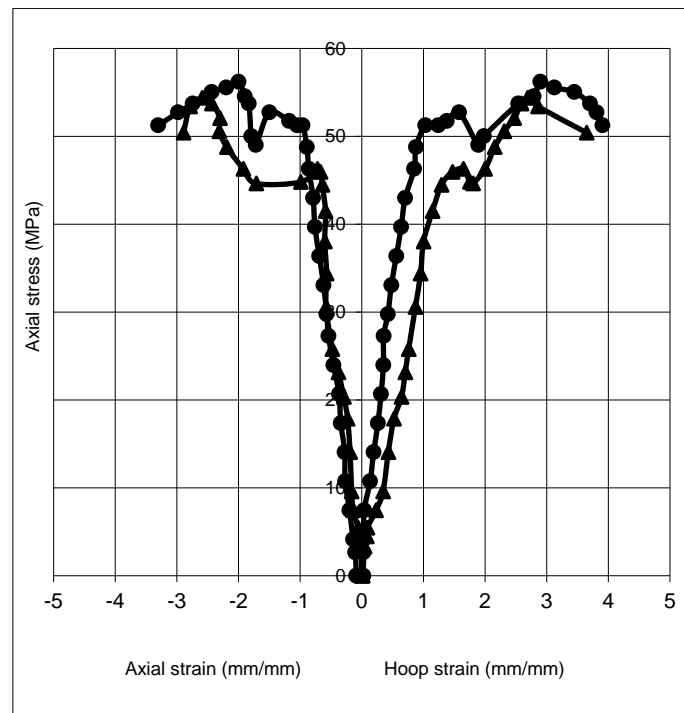**Fig 9**. Stress –strain relationship of specimens DC50ds48ts1.5I.

Fig 10. Stress –strain relationship of specimens DC45ds48ts1.5I.

Stress of concrete inside DSTCs (fcon) has increased by (5%, 19% and 38%) in specimens with compressive strength (50, 55 and 60) MPa respectively, the strength enhancement ratio has high value in DSTCs with compressive strength of concrete (45) MPa compared with the other specimens in this group   that's leads to strength of concrete did not clearly effect on SE.

The enhancement of axial strain (K1) was decrease by (16%, 18% and 32%) with increased compressive strength of concrete in DSTC (50, 55, and 60) MPa, respectively, that's because concrete inside DSTCs subjected to restrained from two tubes to raised its strength in addition to its strength. Nominal confinement ratio of CFFT and DSTC for designing outer FRP tube has the same because the ratio depends on inner diameter

of FRP tube and concrete compressive strength. The concrete filled FRP tube column was confined effectively outward and ultimate stress of concrete inside CFFT was calculated by divided ultimate load by annular area of concrete, by comparison between stress- strain relationship of DSTC and CFFT, the CFFT has superior in its behavior, both of columns had bilinear stress-strain

relationship as show in Figure 11. The strength enhancement ratio was approximately more in CFFT than DSTC as by (1.3%). The enhancement of axial strain had a large value in CFFT with value because of axial strain of CFFT more than DSTC by (19%), that's because of presence of inner steel tube.
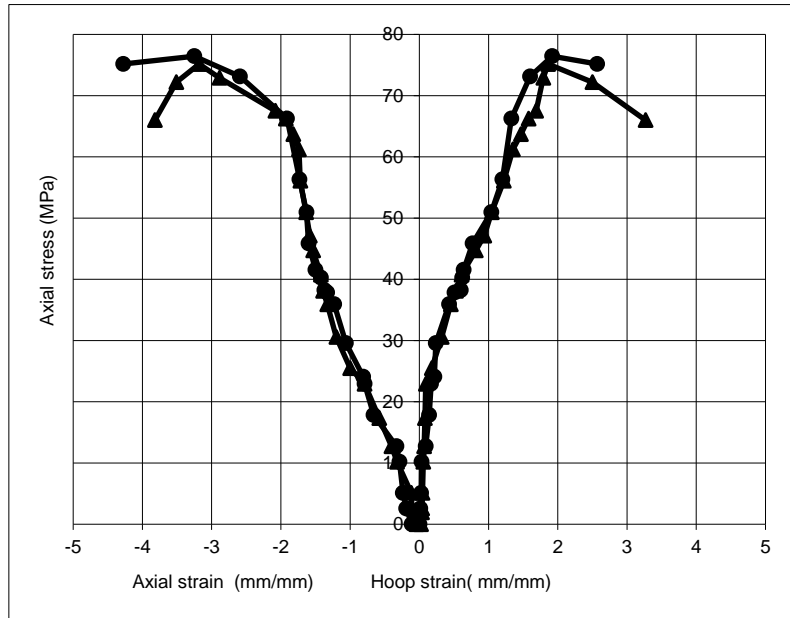

Figure 11. Stress–strain relationship of specimens FC60I.

4.4 The Hoop Strain

The hoop strain of FRP tube in DSTCs (εh) has obtained from average of three strain gauges distribution along overlap region, the εh increased by (3.1% and 51%) in DSTCs with two and three layers, respectively compared with DSTCs of one layer, as illustrate in Table 4. . The εh decreased by (5%, 13% and 14%) in DSTCs with concrete compressive strength of (50, 55 and 60) MPa, respectively compared with DSTCs of concrete compressive strength of (45) MPa.

The εh in CFFT less than DSTC because large amount of concrete confinement by FRP tube and inner steel tube.

Experimental reduction factor of hoop strain Kε ex. was calculated from (**Xie et. al., 2015**)[17] :

$$K\varepsilon\ ex. = \frac{\varepsilon h}{\varepsilon f} \qquad (3)$$

Where εf : the tensile strain of carbon fiber. And theoretical redaction factor of hoop rupture of FRP Kε th. was calculated from (**Xie el. al., 2015**) :

$$K\varepsilon\ th = 0.9 - 2.3 f\acute{c} \times 10^{-3} - 0.75 Ef \times 10^{-6}$$
$$(4)$$

Where fć unconfined concrete compressive

strength and Ef the modulus of elasticity, the

value of Kε th (0.78) less than Kε ex. (1.64%).

4.5 Modes Failure of Specimens

The specimens DC60ds48ts1.5II, DC60ds48ts1.5III have failed by rupture of outer carbon FRP tube at top height because of concrete movement as a result of higher load, while the specimens (DC60ds48ts1.5I, DC55ds48ts1.5I, DC50ds48ts1.5I and DC45ds48ts1.5I) failed by hoop rupture at mid height of outer carbon FRP tube, the specimens FC60I failed by rupture of hoop tension outer FRP tube and failure accompanied with spalling of concrete out ward and very high sound, while failure of concrete in DSTC was less spalling. As show in Figure 12.

Fig 12. Modes failure of specimens.

5. Conclusion

1- The concrete effectively confinement between two tubes FRP outward and steel tube inward, leads to increases strength and ductility of columns.

2- Outer FRP tube prevent spalling of concrete and number of FRP tube layers were most effected parameters, when increased number layers of FRP tube from (one to two and three) strength enhancement ratio increased by (16% and 72%), enhancement of axial strain increased by (4% and 74%).

3- When increased compressive strength of concrete from (45 to 50, 55 and 60) MPa, slightly effected on strength enhancement ratio, enhancement of axial strain was decrease by (16% to 32%).

4- The CFFT has more than DSTC in ultimate load, because of a large amount of concrete confinement.

Acknowledgment:

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