2015

Axial compressive behaviour of circular concrete filled fibre reinforced polymer tube (CFFT) columns

Qasim S. Khan
University of Wollongong, qsk991@uowmail.edu.au

M Neaz Sheikh
University of Wollongong, msheikh@uow.edu.au

Muhammad N. S Hadi
University of Wollongong, mhadi@uow.edu.au

Publication Details

Khan, Q. S., Sheikh, M. Neaz. & Hadi, M. N. S. (2015). Axial compressive behaviour of circular concrete filled fibre reinforced polymer tube (CFFT) columns. In Z. Wu, G. Wu & X. Wang (Eds.), Joint Conference of the 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-12) & the 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures (APFIS-2015) (pp. 1-6).

Axial compressive behaviour of circular concrete filled fibre reinforced polymer tube (CFFT) columns

Abstract

Concrete Filled Fibre Reinforced Polymer Tube (CFFT) technique for new reinforced concrete (RC) column construction has attracted significant research attention in recent years. The CFFT acts as a longitudinal and transverse reinforcement and serves as a formwork. The CFFT also acts as a barrier to corrosion accelerating agents and reduces the corrosion phenomenon in RC column specimens. A total of six circular CFFT specimens of 152.5 mm in diameter and 305 mm in height were cast to investigate the axial compressive behaviour of two types of circular CFFT specimens with similar nominal confinement ratios. Type-1 CFFT specimens consisted of 0.5 mm thick Carbon FRP (CFRP) tube and Type-2 CFFT specimens consisted of 1.3 mm thick Glass FRP (GFRP) tube. Test results of CFFT specimens are also compared with FRP sheet confined concrete specimens with similar nominal confinement ratios. Tested CFFT specimens failed in a brittle manner due to rupture of fibres and crushing of concrete. Experimental results showed that CFRP CFFT specimens achieved almost similar confined concrete strengths and confined concrete axial strains to that of 2.6 times thicker GFRP CFFT specimens. Tested CFFT specimens exhibited smaller confined concrete strengths and confined concrete axial strains than FRP sheet confined concrete specimens with similar nominal confinement ratios.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Khan, Q. S., Sheikh, M. Neaz. & Hadi, M. N. S. (2015). Axial compressive behaviour of circular concrete filled fibre reinforced polymer tube (CFFT) columns. In Z. Wu, G. Wu & X. Wang (Eds.), Joint Conference of the 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-12) & the 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures (APFIS-2015) (pp. 1-6).

AXIAL COMPRESSIVE BEHAVIOUR OF CIRCULAR CONCRETE FILLED FIBRE REINFORCED POLYMER TUBE (CFFT) COLUMNS

Qasim S. Khan[1], M. Neaz Sheikh[2], Muhammad N.S. Hadi[3]

[1] Ph.D. Candidate, School of Civil, Mining and Environmental Engineering, University of Wollongong, Australia
Email: qsk991@uowmail.edu.au

[2] Senior Lecturer School of Civil, Mining and Environmental Engineering, University of Wollongong, Australia
Email: msheikh@uow.edu.au

[3] Associate Professor School of Civil, Mining and Environmental Engineering, University of Wollongong, Australia
Email: mhadi@uow.edu.au

Keywords: CFFT, Confinement ratio, Strength, Axial strain

ABSTRACT

Concrete Filled Fibre Reinforced Polymer Tube (CFFT) technique for new reinforced concrete (RC) column construction has attracted significant research attention in recent years. The CFFT acts as a longitudinal and transverse reinforcement and serves as a formwork. The CFFT also acts as a barrier to corrosion accelerating agents and reduces the corrosion phenomenon in RC column specimens. A total of six circular CFFT specimens of 152.5 mm in diameter and 305 mm in height were cast to investigate the axial compressive behaviour of two types of circular CFFT specimens with similar nominal confinement ratios. Type-1 CFFT specimens consisted of 0.5 mm thick Carbon FRP (CFRP) tube and Type-2 CFFT specimens consisted of 1.3 mm thick Glass FRP (GFRP) tube. Test results of CFFT specimens are also compared with FRP sheet confined concrete specimens with similar nominal confinement ratios. Tested CFFT specimens failed in a brittle manner due to rupture of fibres and crushing of concrete. Experimental results showed that CFRP CFFT specimens achieved almost similar confined concrete strengths and confined concrete axial strains to that of 2.6 times thicker GFRP CFFT specimens. Tested CFFT specimens exhibited smaller confined concrete strengths and confined concrete axial strains than FRP sheet confined concrete specimens with similar nominal confinement ratios.

1 INTRODUCTION

Fibre Reinforced Polymer (FRP) composites are widely used to enhance strength and ductility of Reinforced Concrete (RC) column specimens by confining the lateral dilation of the concrete [1]. Concrete Filled Fibre Reinforced Polymer tube (CFFT) column specimens are considered as viable alternative of steel RC column specimens for new column construction. The CFFT serves as a formwork, a barrier to corrosion accelerating agents, and longitudinal and transverse reinforcement [2-4]. The strength and ductility of FRP confined concrete depends on the type of fibres, thickness of fibres, orientation of fibres, cross-sectional shape of specimen and unconfined compressive strength of the concrete [5, 6]. Ozbakkaloglu [6] reported that specimen size (height to diameter ratio) and manufacturing method of FRP tubes have minimum effect on the strength and ductility of short CFFT specimens subjected to concentric axial compression. The increase in the strength and ductility of CFFT specimens is primarily dependent on the confinement effectiveness of FRP tube in confining the dilated concrete which is a function of material properties (thickness, modulus of elasticity and ultimate tensile strain) of fibres, diameter of FRP tube and unconfined compressive strength of the concrete [7, 8]. The orientation of the fibres in FRP tube is the other parameter that can significantly affect the confinement effectiveness of FRP tube. It has been reported that fibres oriented along the circumferential direction are more effective in increasing the confined concrete strength and strain of CFFT specimens than skew fibres with fibres oriented at angles other than 90° to the longitudinal direction [8, 9].

This experimental study reports the observed failures, and axial load-deformation, axial stress-strain and axial stress-circumferential strain behaviour of circular CFFT specimens tested under concentric axial compression.

2 EXPERIMENTAL PLAN

This experimental study reports the influence of Carbon FRP (CFRP) and Glass FRP (GFRP) tubes on the axial compressive behaviour of circular Concrete Filled Fibre Reinforced Polymer Tube (CFFT) column specimens. Six circular CFFT specimens of 152.5 mm in diameter and 305 mm in height filled with ready mix concrete having 28 days compressive strength of 37 MPa were tested at the High Bay Laboratories of School of Civil, Mining and Environmental Engineering, University of Wollongong, Australia.

CFRP and GFRP tubes with 0.5 mm and 1.3 mm in thicknesses were selected, respectively. FRP tubes were machined by automated filament winding method to have a uniform tube thickness [10]. FRP tubes were designed with alternate fibre layers oriented along the circumferential direction and skew direction (60° to the longitudinal direction). This stacking sequence of fibres orientation was repeated until the required thickness of the FRP tube was achieved. FRP tube with all the fibre layers oriented along the circumferential direction would have resulted in premature failure of the tubes due to transverse separation of fibres as the capacity of the resin to resist the lateral expansion of the concrete core would have exhausted. The skew fibres provide a component along longitudinal direction which prevents the transverse separation of fibres [9]. CFRP tubes consisted of 63% carbon fibres and 37% resin by volume, whereas GFRP tubes consisted of 60% glass fibres and 40% of resin by volume. The manufacturer [10] provided material properties of FRP tubes are reported in Table 1.

Table 1 Manufacturer provided FRP tube properties [10]

Material	Modulus of Elasticity of fibres E_f [GPa]	Ultimate tensile strength of fibres f_{fu} [MPa]	Ultimate tensile strain of fibres ε_{fu} [%]
CFRP Tube	230	5080	2.2
GFRP Tube	80	2000	2.5

In designing FRP tubes, the effect of confinement effectiveness of FRP tubes and compressive strength of concrete on the axial load-deformation was considered. The confinement effectiveness of FRP tube was considered in terms of confinement pressure (f_l) (Equation 1):

$$f_l = \frac{2E_f t_f \varepsilon_{fu}}{D} \tag{1}$$

where, E_f is the modulus of elasticity of fibres in MPa, t_f is the thickness of fibres in mm, ε_{fu} is the ultimate tensile strain of fibres and D is diameter of CFFT in mm. The effect of compressive strength of concrete (f_{co}) on confinement effectiveness was taken into account in terms of nominal confinement ratio (f_l / f_{co}) (Equation 2):

$$\frac{f_l}{f_{co}} = \frac{2E_f t_f \varepsilon_{fu}}{Df_{co}} \tag{2}$$

The circular CFFT specimens were designated according to the type of FRP tubes and the specimen number in the series. In this experimental study the influence of two types of FRP tubes i.e., CFRP Tube (CT) and GFRP Tube (GT) was investigated under concentric axial compression. The circular CFFT specimens were divided in two series. The CFRP tubes and GFRP tubes with three specimens in each series were tested under concentric axial compression. For example a CFFT designated as CT-1 indicates a CFRP tube confined concrete specimen tested under axial compression and the first in the series. The details of tested circular CFFT specimens are presented in Table 2.

Table 2 Details of circular CFFT specimens tested in this study

Specimen ID	Nominal Tube thickness t [mm]	Nominal Height of CFFT H [mm]	Nominal Diameter of CFFT D [mm]	Nominal Confinement Ratio f_l / f_{co}
CT-1	0.5	305	152.5	0.90
CT-2	0.5	305	152.5	0.90
CT-3	0.5	305	152.5	0.90
GT-1	1.3	305	152.5	0.92
GT-2	1.3	305	152.5	0.92
GT-3	1.3	305	152.5	0.92

3 INSTRUMENTATION AND TEST METHODOLOGY

To measure axial deformations, the circular CFFT specimens were instrumented with two Linear Variable Displacement Transducers (LVDT) to measure axial deformation. Two strain gauges in axial direction were attached on opposite sides of FRP tube to measure axial strains in FRP tube. Two strain gauges in lateral direction were attached on opposite sides to measure lateral strains in FRP tube (Figure 1).

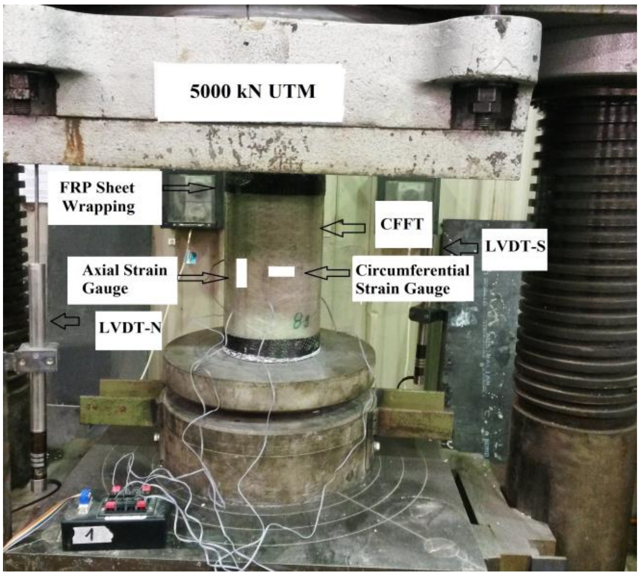


Figure 1 Axial compression testing arrangement

The circular CFFT specimens were tested in concentric axial compression in the 5000 kN Denison Universal Testing Machine (UTM). To prevent premature failures of the circular CFFT specimens, the ends of the specimens were wrapped with two layers of 0.5 mm thick and 35 mm wide CFRP sheets. Top end of circular CFFT specimens was capped with high strength plaster to distribute axial loads uniformly over the cross section of specimen. Tested CFFT specimens were preloaded to 100 kN and unloaded to 20 kN under a force controlled load application at a rate of 50 kN/min to adjust minor eccentricities due to uneven surfaces and alignment of CFFT specimen within the loading plates of the UTM. Afterwards, the test continued under displacement controlled load application at a rate of 0.3 mm/min until the rupture of FRP tube.

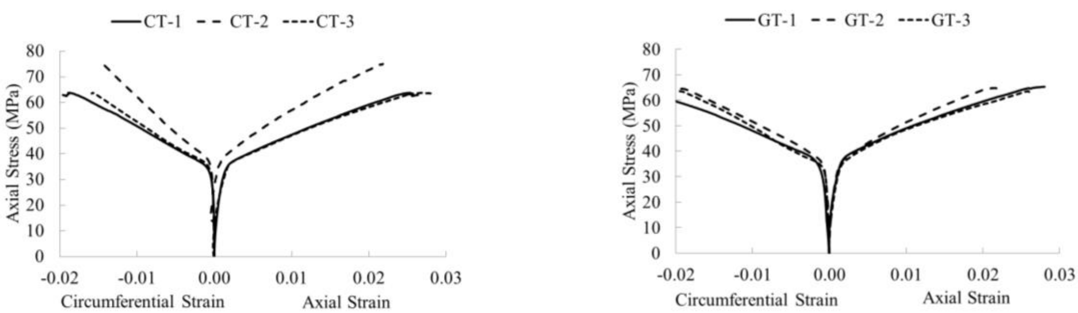
4 OBSERVED FAILURE AND STRESS STRAIN BEHAVIOUR OF TESTED CIRCULAR CFFT SPECIMENS

The failure of circular CFFT specimens was characterized by ruptured fibres and crushing of the concrete as shown in Figure 2. The failure in CFFT specimens were initiated with snapping sounds of rupturing of fibres. Increased axial load resulted in louder snapping sounds of rupturing of fibres along with crushing of concrete. The final failure in CFRP CFFT specimens was more brittle than that of GFRP CFFT specimens which may be attributed to larger modulus of elasticity of CFRP fibres than that of GFRP fibres.

(a) CFRP CFFTs (b) GFRP CFFTs

Figure 2 Observed failures in tested circular CFFT specimens

Axial stress-strain and axial stress-circumferential strain behaviour of circular CFFT specimens is defined by steep rising curve (first ascending part) followed by mild rising curve (second ascending part) as presented in Figure 3. The first ascending part exhibited a sharp rise in axial stress with relatively smaller increase in axial and circumferential strains in FRP tubes. During this phase, Poisson's ratio of concrete was smaller than that of FRP tube as FRP tube confinement was not much activated and increased axial stress was due to axial load resisted by concrete only. Increased axial load resulted in increased axial and circumferential strains due to volumetric expansion of the concrete. Increased circumferential strains exerted increased circumferential pressures on FRP tube. As circumferential pressure increased beyond critical value of stress, FRP tube confinement was activated. The second ascending part illustrated mild rise in axial stress with large increase in axial and circumferential strains in FRP tubes showed increased effectiveness of FRP tube in confining the micro-cracked concrete. The slope of the second curve depends on the confinement effectiveness of FRP tube. The second ascending part in case of CFRP CFFT specimens was steeper than GFRP CFFT specimens which indicated larger confining capacity of 0.5 mm thick CFRP tubes than 1.3 mm thick GFRP tubes.



(a) CFRP CFFTs (b) GFRP CFFTs

Figure 3: Axial stress-strain and axial stress-circumferential strain of circular CFFT specimens

5 TEST RESULTS AND COMPARISON WITH AVAILABLE FRP SHEET STUDIES

The peak axial load-deformation, and confined concrete strength and confined concrete axial and circumferential strain at peak stress of tested circular CFFT specimens are presented in Table 3.

Table 3 Test results of circular CFFT specimens

Specimen ID	Peak axial load [kN]	Deformation at peak axial load [mm]	Confined concrete strength f_{cc} [MPa]	Confined concrete axial strain at peak stress ε_{cc} [%]	Circumferential strain at peak stress ε_{cir} [%]
CT-1	1173.5	5.4	63.7	2.54	1.89
CT-2	1366.3	5.6	75.0	2.40	1.50
CT-3	1177.0	5.1	63.7	2.70	1.60
GT-1	1192.1	6.5	65.3	2.80	4.80
GT-2	1185.1	6.0	64.7	2.20	2.00
GT-3	1159.5	5.7	63.5	2.61	1.99

Confined concrete strengths and confined concrete axial strains of tested circular CFFT specimens are compared with the confined concrete strengths and confined concrete axial strains of available FRP sheet confined concrete specimens with almost similar nominal confinement ratios (Table 4). Tested CFRP CFFT specimens results are compared with CFRP sheet confined concrete specimens results reported by Berthet et al. [11] and Jiang and Teng[12]. Tested GFRP CFFT specimens results are compared with GFRP sheet confined concrete specimens results reported by Ahmad et al. [13] and Bullo [14]. Tested CFRP CFFT specimens resisted 52.3% and 38.0% smaller confined concrete strengths than CFRP sheet confined concrete specimens in Berthet et al. [11] and Jiang and Teng[12]. Confined concrete axial strains of tested CFRP CFFT specimens were almost similar to CFRP sheet confined concrete specimens in Berthet et al. [11] and Jiang and Teng [12]. Tested GFRP CFFT specimens resisted 44.1% and 49.7% smaller confined concrete strengths than GFRP sheet confined concrete specimens reported by Ahmad et al. [13] and Bullo [14]. Tested GFRP CFFT specimens exhibited 42.4% smaller confined concrete axial strains than GFRP sheet confined concrete specimens reported by Bullo [14]. The confined concrete strengths and confined concrete axial strains of tested circular CFFT specimens were smaller than FRP sheet confined concrete specimens with similar nominal confinement ratios and these results are consistent with the experimental confined concrete strengths and confined concrete axial strains reported in Toutanji [15].

Table 5 Experimental results of FRP sheet confined concrete specimens

Study	Diameter D [mm]	Height to diameter ratio H/D	Unconfined concrete strength f_{co} [MPa]	Thickness of FRP sheet t [mm]	Modulus of Elasticity of fibres E_f [GPa]	Confined concrete strength f_{cc} [MPa]	Confined concrete strain ε_{cc} [%]
Berthet et al.	160.0	2.0	40.1	0.99	230	142.4	2.46
[11]	160.0	2.0	40.1	0.99	230	140.4	2.39
Jiang and	152.0	2.0	38.0	0.68	241	110.1	2.55
Teng [12]	152.0	2.0	38.0	0.68	241	107.4	2.61
Ahmad et al.[13]	102.0	1.99	39.0	0.88	48	115.3	-
	150.0	2.0	32.5	1.15	65	118.8	4.28
Bullo [14]	150.0	2.0	32.5	1.15	65	130.2	4.04
	150.	2.0	32.5	1.15	65	135.8	4.84

6 CONCLUSIONS

This experimental study reported six circular CFFT (three CFRP CFFTs and three GFRP CFFTs) specimens tested under concentric axial compression. The main outcomes of this study are as follows:

The observed failure in circular CFFT specimens was characterized by ruptured fibres and crushing of concrete.

Axial stress-strain and axial stress-circumferential strain behaviour of both types of circular CFFT specimens was similar. First ascending part of axial stress-strain and axial stress-circumferential strain depends on compressive strength of concrete. The second ascending part of axial stress-strain and axial stress-circumferential strain depends on confinement effectiveness of FRP tube and was steeper in case of CFRP CFFT specimens than GFRP CFFT specimens.

Tested circular CFFT specimens exhibited smaller confined concrete strengths and confined concrete axial strains than FRP sheet confined concrete specimens with similar nominal confinement ratios.

REFERENCES

[1] T. Ozbakkaloglu and T. Vincent, *Axial compressive behaviour of circular high strength concrete filled FRP tubes.* Journal of Composites for Construction, 2013: p. 04013037-1-11.

[2] Q.S. Khan, et al., *Flexural Testing of Concrete Filled Fibre Reinforced Polymer Tubes (CFFT) with and without internal Fibre Reinforced Polymer (FRP) Reinforcement*, in *27th Biennial National Conference of the Concrete Institute of Australia in conjunction with the 69th RILEM Week Conference*. 2015: Melbourne, Australia.

[3] D. Lillistone and C.K. Jolly, *Concrete filled fibre reinforced plastic circular columns*, in *Composite construction-conventional and innovative conference, composite construction-Conventional and innovative*. 1997. p. 759-764.

[4] A. Mirmiran and M. Shahawy, *A new concrete-filled hollow FRP composite column.* Composites Part B: Engineering, 1996. 27(3–4): p. 263-268.

[5] A. Mirmiran, et al., *Effect of column parameters on FRP confined concrete.* Journal of Composites for Construction, 1998. 2(4): p. 175-185.

[6] T. Ozbakkaloglu, *Compressive behavior of concrete-filled FRP tube columns: Assessment of critical column parameters.* Engineering Structures, 2013. 51(0): p. 188-199.

[7] T. Vincent and T. Ozbakkaloglu, *Influence of concrete strength and confinement method on axial compressive behaviour of FRP confined high and ultra high strength concrete.* Composites Part B: Engineering, 2013. 50: p. 413-428.

[8] T. Vincent and T. Ozbakkaloglu, *Influence of fibre orientation and specimen end condition on axial compressive behaviour of FRP confined concrete.* Construction and Building Materials, 2013. 47: p. 814-826.

[9] W.K. Hong and H.C. Kim, *Behaviour of concrete columns confined by carbon composites tubes.* Canadian Journal of Civil Engineering, 2004: p. 178-188.

[10] *CST COMPOSITES*. 2014 [cited 2014; Available from: http://www.cstcomposites.com/products-and-services/tubes-rods-and-components/.

[11] J. Berthet, E. Ferrier, and P. Hamelin, *Compressive behaviour of concrete externally confined by composite jackets. Part A: Experimental study.* Construction and building materials, 2005. 19(3): p. 223-232.

[12] T. Jiang and J. Teng, *Analysis oriented stress strain models for for FRP confined concrete.* Engineering Structures, 2007. 29(11): p. 2968-86.

[13] S.H. Ahmad, A.R. Khaloo, and A. Irshaid, *Behavior of concrete spirally confined by fiberglass filaments.* Magazine of Concrete Research, 1991. 43(156): p. 143-148.

[14] S. Bullo. *Experimental study of the effects of the ultimate strain of fiber reinforced plastic jackets on the behavior of confined concrete*. in *Composites in Construction*. 2003. Cosenza, Italy.

[15] H. Toutanji, A., *Stress-Strain characteristics of concrete columns externally confined with advanced fibre composite sheets.* ACI Materials journal, 1999. 96(3): p. 397-404.