



# STRAIN AND DILATION OF GFRP CONFINED CONCRETE MEMBERS

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**Abstract**—The fiber reinforced polymer (FRP) composite materials have recently been used as internal, and external reinforcement in the field of civil engineering constructions. This paper presents the results, of strain and dilation of glass-FRP (GFRP), concrete members. The objective is to characterize and to investigate the compressive behaviors of the GFRP columns. The parameters were used in the investigation the effect of laminate thickness of the GFRP tubes, and concrete strength. The composite GFRP tubes are fabricated using the filament, winding technique. The diameter of the GFRP tubes which used in this investigation was 152 mm, the fibre orientation mainly in the hoop direction. The final failure modes, stress-strain, steel, GFRP and CFRP bars strain and, finally load-deformation behaviours were presented for all specimens.

**Keywords**—Fiber Reinforced Polymers, Concrete, Filament Winding, Confined.

## I. INTRODUCTION

“Fiber reinforced polymer, (FRP) composites have been increasingly used in concrete construction. FRP composites depending on the types have strength comparable, or greater to that of steel. FRP composites, which are made of reinforcing fibres and a thermosetting resin, have been widely used as advanced construction materials in, the field of the civil engineering. It is used as internal reinforcement for beams, slabs and pavements” (Balendran et al, 2002; Benmokrane et al, 2006). Also it is used as external reinforcement for rehabilitation and strengthening different structures (Spadea et al, 2000; Almusallam & Al-Salloum 2001; Teng and Lam, 2002). However, the application of concrete filled fibre reinforced polymer (FRP) composites tubes (CFRT) for different structural applications, such as precast piles, girders, and pier columns has gained approval in civil engineering structural applications (Mirmiran and Shahawy 2003; Fam et al 2003a,b; Karbhari et al. 2000; Karbhari 2004; Fam and Rizkalla 2003). The general process used to manufacture FRP tubes is one of placing and retaining fibre reinforcements in the direction needed to provide the hoop and axial strength. It can be done by pultrusion, filament winding, centrifugal casting or resin infusion. In the filament winding process, the placement of the primary fibre-glass reinforcement is tightly

controlled and can be oriented in either a hoop or axial direction or anywhere in between as needed to develop the necessary strength properties in the hoop or axial direction.

## Confined FRP Concrete Members

At the beginning of 1970s, the plastic pipes (PVC) were suggested to confine the concrete (Kurt 1978). However FRP composites have been proposed for confinement of concrete since the early 1980's. The concept of concrete filled FRP tube columns was introduced by Fardis and Khalili (1981; 1982), it was concluded that the failure of the system is governed by failure of the GFRP shell, also the fibres in the hoop direction confine the concrete by controlling its lateral expansion and micro-cracking, whereas fibres in the axial direction would resist tension caused by bending and improve buckling resistance. Many studies have been carried out on concrete filled FRP tubes in recent years. Most of these studies were on cylindrical dimensions (152 x 305 mm) or less and without internal reinforcement. Almost all these studies have shown that, the stress-strain responses of the CFRT under uniaxial loads present three regions (bilinearly curve). The stress-strain curves at the first stages of the loading for the confinement specimens were similar to the unconfined concrete up to the unconfined concrete strength. Softening started to present the second and the transition zone; in this region considerable “microcracks are produced in the concrete core, resulting in gradually increasing lateral expansion. The third region presents the second linear response on the stress-strain curve and hardening of the concrete, also the FRP tube is fully activated. It is generally recognized that this structural system of the CFRTS is improved ductility and increased the strength and failure strain by the confinement mechanism of the concrete core. Also the FRP tubes benefits are in providing shear or/and flexural reinforcement protective jackets, and permanent formwork. The importance of the bond between the FRP tubes and the concrete core is more significant in flexural members than in the axial members and can be achieved by using adhesive or mechanical shear connectors.”

## II. RESEARCH METHODOLOGY

### A. GFRP Tubes

“Three types of glass-fiber reinforced polymer GFRP tubes were used. The GFRP tubes were fabricated using filament winding technique; E-glass fiber and Epoxy resin were

utilized for manufacturing these tubes. The internal diameter for all tubes is constant equal 152 mm. Table 1 presents the details for the three types A, B and C of the GFRP tubes, where  $E_x$  and  $E_y$  are the Young's Modulus in the longitudinal and hoop direction. The laminate theory is used to calculate the Young's Modulus in the axial and transverse directions based on the mechanical properties of the fibre and resin which was supplied by the manufacture."The Split-disk test and coupon tensile test were performed according to ASTM D-2290-04 and ASTM D 638-03 standard, respectively, on five specimens from each type of the tubes, (see Tubes Figure 1). The experimental results were close to the theoretical results. "Figure 2 shows the average load-strain relationship for each type of the tubes for the split-disk test, and as expected, the highest hoop tensile force values were obtained for the specimens of tube type C which has the largest thickness. Also the load-strain curve for the split-disk test was linear up to failure for all specimens. Figure 3 present the axial tensile stress-strain responses for the three type of the GFRP tube resulted from the coupon tests."



Fig. 1. Finite element mesh

### B. Concrete Mixes

"All specimens were constructed from two batches (1 and 2) to take into consideration the effect of concrete strength on the compressive behaviors of the CFFT columns. Both concrete batches were supplied, by ready mix concrete supplier. The target strength of the first and second batches was intended to provide 30 MPa and 45 MPa, respectively. The maximum size of the coarse aggregates, was about 20 mm and 16 mm for the first and second concrete batches, respectively. Five plain concrete cylinders (152 x 305 mm) were prepared from each concrete batch. The average, concrete strength of all cylinders was found to be very close to 30 and 45 MPa for batch 1 and 2, respectively."

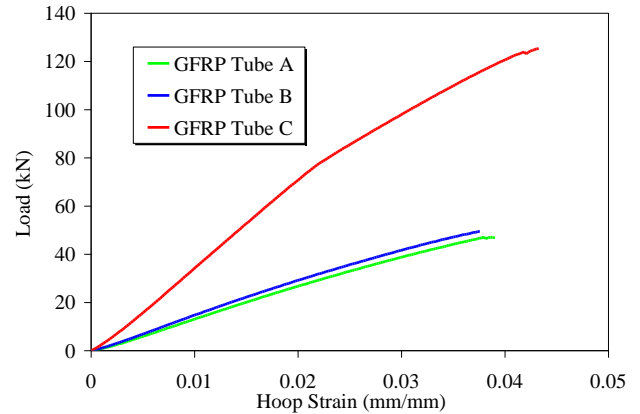


Fig. 2. Failure mode. Load-strain (radial) curve for the split-disk

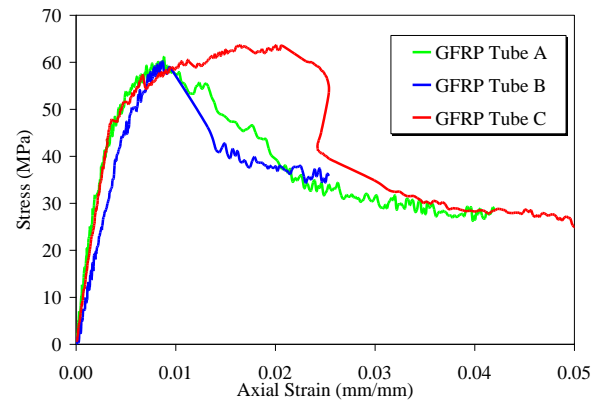


Fig. 3. Stress-strain curve for coupon tensile test

### C. Samples and Instrumentation

"This paper investigates the behaviors of the confined CFFT cylinders. The cross section diameter for all specimens is 152 mm. The test specimens are classified for six groups as shown in Table 2. The first group present ten plain concrete cylinders (152x305mm), five cylinders were casted for each type of the concrete batches. The second group present six CFFT cylinders casted from concrete batch (1), two cylinders were cut from GFRP tube type A, B and C which different in the thicknesses. The percentage of the GFRP, rein forcement ratio ( $4t/D$ ) is equal to 6.97, 7.5 and 13.15 for tube A, B and C, respectively, where,  $t$  is the thickness of the, GFRP tube. However, the specimens of group No. 3 similar to group No. 2 except the concrete used from batch (2)."

All the specimens were, cast with concrete in a vertical position. This was performed by fixing the, GFRP tubes specimens in a vertical position inside the wooden box formwork. Two holes were drilled at the top, and bottom of the wooden box to fix each specimen vertically. Also the bottom surface area of the wooden box was, attached with a horizontal wood plate to prevent the leakage of the concrete. There are different types, of the instrumentation in this study to capture the local, strain distributions and external instrumentation on the surface of GFRP tube. Before casting,

two of the longitudinal rebar, were instrumented by strain gages at mid height. Before, testing, two axial and two transverse electrical resistance strain gages were mounted 180 degree apart along the hoop direction for each specimen on the external surface of the GFRP tubes. The axial and horizontal displacement for each column was measured by linear variable displacement transducers, (LVDTs). The LVDTs used have a maximum range of (100 mm) and with accuracy of (0.01mms). Two circular steel tie raps of 4.0 mm thickness and 60.0 mm width were used to confine the two ends of loading at the top and bottom for each specimen, they were also used to avoid the local failure of the specimens, above and below the test regions. The specimens were tested using a 6,000 kN capacity FORNEY machine, the loading rate range was 2.0 to 2.50 kN/s during the test by manually, controlling the loading rate of the hydraulic pump.

### III. RESULTS AND DISCUSSION

#### A. General Behavior

Table 2 presents a summary of test results. The average ratios of confined concrete compressive strength to unconfined concrete cylinder strength ( $f'_{cc}/f'_c$ ) were presented for all specimens.  $P_{max}$  is the maximum axial load,  $\epsilon_{cc}$  is the ultimate axial strain of the confined CFFT specimens, also  $\epsilon_c$  is the ultimate axial strain of the unconfined concrete. Figure 7 and 8 show the failure mode for CFFT cylinders. All specimens failed due to the rupture of the fibre in the hoop, direction with sudden failure at the ultimate hoop stress resulting from the dilation of the concrete. The fracture of the GFRP tubes occurred along the total height of the cylinders started from top or bottom and extending to the opposite direction. The shape of the failure of the GFRP tubes was “zigzag” line normal to the direction of fibres, as already the fibres orientations of these tubes were manufactured in the hoop direction. Low sounds, heard during the early-to-middle stages of loadings were referred to the dilation, micro-cracking of concrete and offset of the aggregate, also at the higher levels of confining pressure; sounds were heard clearly due to rupture of the fibre. The failure was very explosive, especially for specimens, confined by tube A and B; also the concrete fell out of the tube in a crushed state immediately after the failure.



Figure 4 Failure Modes

#### B. Stress-Strain and Dilation Behavior

The stress–strain curve for the confined and unconfined concrete, cylinders for the different GFRP confinement cylinders are shown in Figures 5. The axial and lateral strains for all specimens were obtained from the average of four axial and four hoop gages, respectively for each tube type. Significant enhancement, in the strength as well as ductility for the CFFT cylinders was achieved. The strength of the confined concrete increased drastically with increasing the thickness of the GFRP tubes. However, the improvement in the strength for CFFT cylinders of group No. 2 (concrete strength 30 MPa) was higher than for specimens of group No. 3.

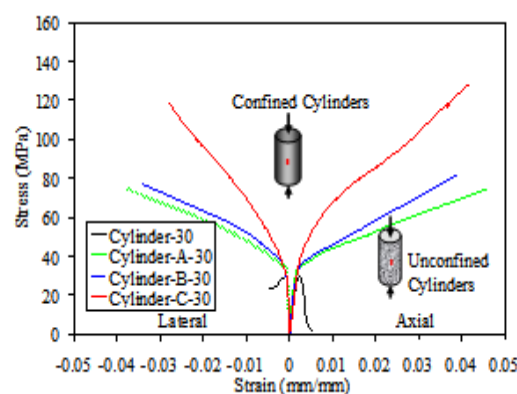


Figure 5. Stress-Strain of Group 2

The ultimate axial and hoop strains, for CFFT cylinders were close to the ultimate axial and hoop strains of the coupon tensile test and split disk test, respectively. Figure 12 shows the axial strain against, dilation relationships, for the CFFT



cylinders, where,  $\epsilon_{ch}$  is the ultimate, hoop strain of the confined CFFT specimens, The initial dilation, rate remains relatively constant, having a value approximately equals to Poisson’s ratio for the unconfined concrete. As the axial strain increases and lateral strain increase due to micro-cracking of the concrete, approximately at  $0.8 f'_c$  the, dilation rapidly increases depending on the level of the confinement of the FRP. Approximately at axial strain, equal to 1.2 to 1.3  $f'_c$ , the

confinement of the GFRP tube is fully active. Figure 12 shows the effect of the tube thickness, on the dilation ratio, at the first stage of the curve, the initial dilation only depends on the concrete. As the thickness of, the GFRP tube increases the dilation rate decreases at, all load levels after the first stage.

Table 1.Dimension and mechanical properties of fibre reinforced polymer tubes

Tube type	Internal diameter (mm)	Thickness (mm)	Number of layers	Stacking sequence	E <sub>X</sub> (MPa)	E <sub>Y</sub> (MPa)
A	152	2.65	6	[±60°] <sub>3</sub>	8785	20690
B	152	2.70	8	[±60°] <sub>4</sub>	8787	20860
C	152	6.40	14	[±65 <sub>3</sub> , ±45, ±65 <sub>3</sub> ]	9270	23630

Table 2. Details of specimens and summary of test matrix

Group No.	Specimen ID	Tube type	Height (mm)	GFRP Reinforcement ratio 4t/D <sub>t</sub> %	Internal reinforcement of rebar	Type of rebar	No of specimen	P <sub>max</sub> Failure Load (kN)	(f <sub>cc</sub> /f <sub>c</sub> )	(ε <sub>cc</sub> /ε <sub>c</sub> )
1	Cylinder-30	-	305	-	---	---	5	539	---	---
	Cylinder-45	-	305	-	---	---	5	811	---	---
2	Cylinder-A-30	A	305	6.97	---	---	2	1350	2.48	19.56
	Cylinder-B-30	B	305	7.50	---	---	2	1490	2.73	16.95
	Cylinder-C-30	C	305	13.15	---	---	2	2160	4.00	20.00
3	Cylinder-A-45	A	305	6.97	---	---	2	1620	1.98	16.4
	Cylinder-B-45	B	305	7.50	---	---	2	1850	2.26	18
	Cylinder-C-45	C	305	13.15	---	---	2	2596	3.17	18.8

**IV.CONCLUSION**

In general, the behavior of the concrete filled GFRP tubes are affected by tube thickness and concrete strength. The behaviors of the CFFT, cylinders under concentric axial loading were presented. The results for 10 unconfined cylinders were investigated. The findings of this research can be summarized as follows, the ultimate load capacity of the CFFT columns in this study did not affected by the Height to diameters ratio (slenderness ratio), which equal to 6 in this study for all specimens were reinforced with longitudinal rebars, as compared by the ultimate load capacity of the CFFT cylinders. The average ultimate rupture strain of the GFRP tubes is close to the rupture strain obtained from split-disk test. The confinement provided by the GFRP tubes improves both the load-carrying capacity and the ductility of the concrete

columns. The test results indicate that by increasing the thickness of the GFRP tubes a significant improvement is achieved in the confinement efficiency. The stress-strain curve of the CFFT tubes with and without longitudinal rebars is bilinear. The, initial dilation ratios for all specimens appear to be the same having a value approximately equals to Poisson’s ratio for the unconfined concrete, the peak dilation values depend on the confinement level of the GFRP tubes.

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