THE BOND EFFECT ON FLEXURAL BEHAVIOR OF CONCRETE -FILLED RECTANGULAR FRP-TUBE BEAMS

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Abstract— This paper presents an experimental study of an Alternative methods of mechanical bonding between FRP tube jacket with Concrete surface on concrete filled rectangular FRP tube beams under flexural behavior by the way of fasting steel anchors and screws. Eleven beam specimens, 2000 mm long, were tested under a four-point bending load, All the beams were cast with the same concrete patch with different cross sections. Three Control specimens with out any bond strengthening and Eight beam specimens bonded with different methods of mechanical bonding strengthened using Anchors and Screws with Various anchors spacing and distributions. All The CFFT-beams that strengthening in bonding using anchors and screws, show greater flexural resistance than the CFFT-beams without any bond strengthening, while the CFFT-beams that strengthening in bonding using anchors, show greater stiffness than the CFFT-beams that contain screws.

Index Terms— Fiber-Reinforced Polymer, Filament Winding, Concrete-Filled FRP Tube, Beams, bond strengthening, Flexural behaviour, anchors, screws.

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1 INTRODUCTION

Engineers and scientists are searching for innovative solutions that provide longer life and require less maintenance than conventional materials and systems. One of such innovations is concrete-filled fiber-reinforced polymer (FRP) tubes (CFFTs) which are becoming an attractive and alternative system for many special types of structural applications especially those attacked by corrosive environments such as piles, bridge piers, bridge girders, monopoles, and overhead sign structures. The outer FRP tubes provide corrosion resistant elements, lateral and longitudinal reinforcement, lightweight permanent formworks, in addition to confining the inner concrete core. On the other side, the concrete core supports the tube against local buckling in addition to its role in resisting compressive loads. Limited researches was carried out on the effect of the bond behavior on (CFFTs) as beams especially those with rectangular sections as well as they used a conventional bond method such as adhesive epoxy and sand coating. [Mirmiran et al. 2000; Doval et al. 2001; Fam and Rizkalla 2002; Cole and Fam 2006; Fam et al. 2005; Yu et al. 2006; Mohamed and Masmoudi 2010b; Zakaib and Fam 2012; Belzer et al. 2013; Abouzied 2016; Abouzied and Masmoudi 2016, 2018] [1-13]. In this study, the author tries to find a more sustainable methods to bond between the FRP jacket and the concrete surface using mechanical technique, method of bond strengthening with mechanically steel anchorages and screws is developed in this research study instead of conventional bond methods such as adhesive epoxy and sand coating.

2 RESEARCH SIGNIFICANT

The research aims to study the effect of mechanical bonding for CFFT-beams to enhance the flexural beam capacity using anchors and screws bonded and pressing on FRP laminate surface with concrete to prevent de-bonding. Also, the research investigates the effect of anchors spacing and distribution in enhancing the flexural strengthening capacity for the beam.

2 TEST PROGRAM

2.1 Fabrication of GFRP Tubes

To achieve the objectives of this study, a filament winding machine was constructed in the Department of Structural Engineering at Helwan University, as shown in Figure 1, in order to manufacture rectangular or square glassfiber-reinforced polymer tubes (GFRP tubes), these tubes different in thickness and configuration, and acts as stay-in-place forms, protective jackets for the embedded concrete and steel, and as external reinforcement in the primary and secondary direction of the structural member. This machine consists of : (1) Wood table with fiber roving fixed on it. (2) The resin bath, is a stainless steel bath, installed on a carriage moving at different speeds,

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as shown in Figure 1. Fixed at both ends of the bath, a stainless steel comb that the fibers enter and exit through it, and fixed at the end of the bath a tool for wiping the excess resin from the fibers after submerging it in the bath. After the fibers are immersed in the resin and out of the bath, the fibers are collected in a flat strip by passing the fibers through a ring, this ring controls the width and thickness of the fibers before winding them on the mandrel, as shown in (See Figures 1). (3) The mandrel of the machine, is the column which the fibers are winding around it after the exit them from the resin bath. The mandrel has the same dimensions as the tube or beam to be designed. The mandrel have round corners of 25 mm radius. The mandrel is free to move and wraps at different speeds (See Figure 1).

2.2 Materials

The FRP tubes were composed of E-glass fibers and Polyester resin. Two fibers type was used, a single end roving of Fiber E-glass and E-glass Fiber woven roving or bi-directional E- glass Fiber sheet (is the glass-fiber sheet, that contain longitu- dinal and transverse fibers in a ratio 1: 1), as shown in Figures (2,3). Table 1 show the properties of fibers and the resin used based on the manufacturer data.

2.3 Mix proportion of Concrete and Casting

GFRP tubes were fixed on vertical frames and the concrete was poured into them from top end gates as shown in Figure 4. Supporting the tubes against movement and blocking their ends were enough to start the casting process, because the tubes worked as a stay-in-place formwork. All the beams were cast with low strength concrete to highlight the effect of confinement of the FRP tubes on the concrete core. The mix proportions for cubic meter of concrete includes 300 kg of cement, 150 litre of water, 1200 kg of limestone aggregate with a maximum size of 14 mm, 800 kg of sand. Solid content of 32%, was added to the mixture before casting the tubes to enhance the concrete workability. The CFFT beams were covered tightly with plastic sheets and the moisture that surrounded the beams (under the cover) had been kept at high level for 7 days. At least six concrete cylinders were tested under compression machine after 28 days of casting according to ASTM C39 (2012), as shown in Figure 5. The average unconfined compressive strength ($f'c$) was 14.5 N/mm^2.

2.4 Test specimens and parameters

The experimental program investigates the Bond development between FRP tubes and concrete under the flexural behaviour of Eleven CFFT beam specimens as shown in Figure 6 (a-k). These specimens included Eleven GFRP tubes, composed of typical E-glass fibers and Polyester resin, three conventional GFRP tubes beams as a control specimen, One GFRP tube fastened with Screws, and Seven GFRP tubes fastened with 10 mm Steel anchorages, were fabricated by filament winding process and hand lay-up technique in the Civil Engineering Department at Helwan University. The following part description the details of the used materials, beam specimens, fabrication process, test setup, has been used throughout the experimental program.

Fig.1 - Filament Winding Machine

Fig.2 - E-glass Fiber Roving

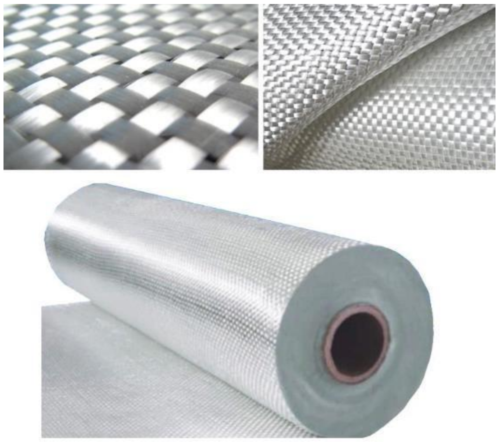


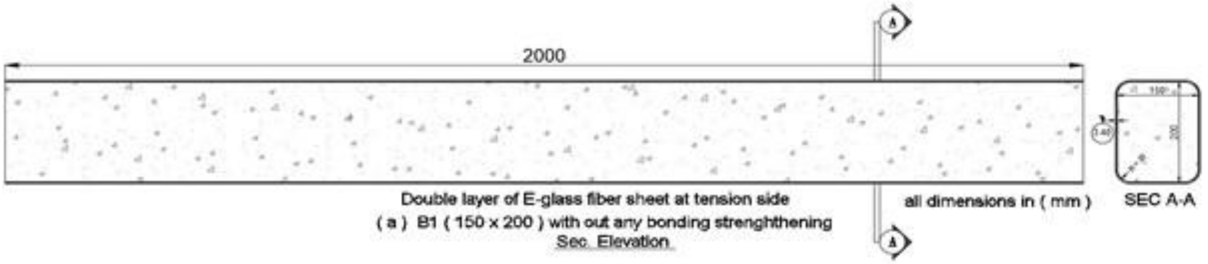
Fig.3 – E-glass Fiber Roving

Fig.4 - Casting Process

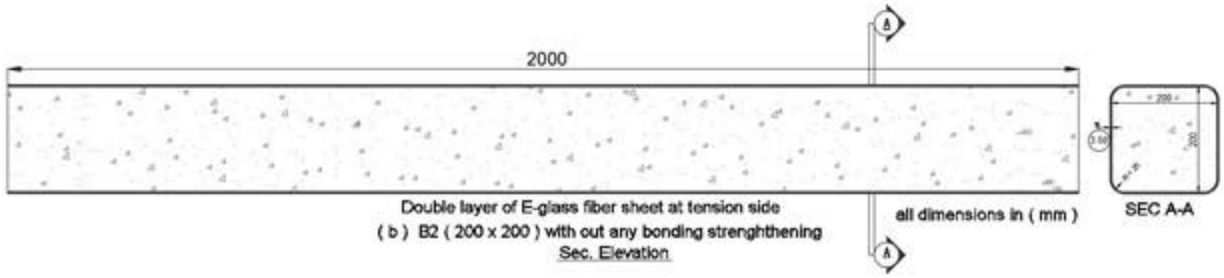
Fig. 5 - Compression Test by MTS Machine

Table 1: Physical and Mechanical Propeties of Material

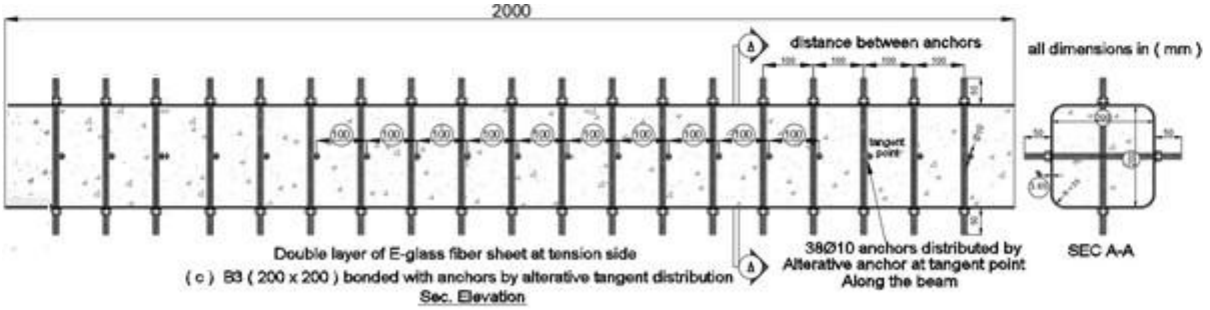
Type of Material	Physical and Mechanical Propeties					
	Tesnile Strength (Mpa)	Elastic Modulus (Gpa)	Fiber content %	Elongation %	Density (Kg/m^3)	Curing Temp. (^{o}c)
E-glass Fiber Roving	1117	52	70	2.5	2.54	35°c
E-glass Fiber Sheet	1500	80	60	2	3	35°c
Polyester rein	50	1.5	--	3	1170	65°c



Double layer of E-glass fiber sheet at tension side
(a) B1 (150 x 200) with out any bonding strenghthening
Sec. Elevation

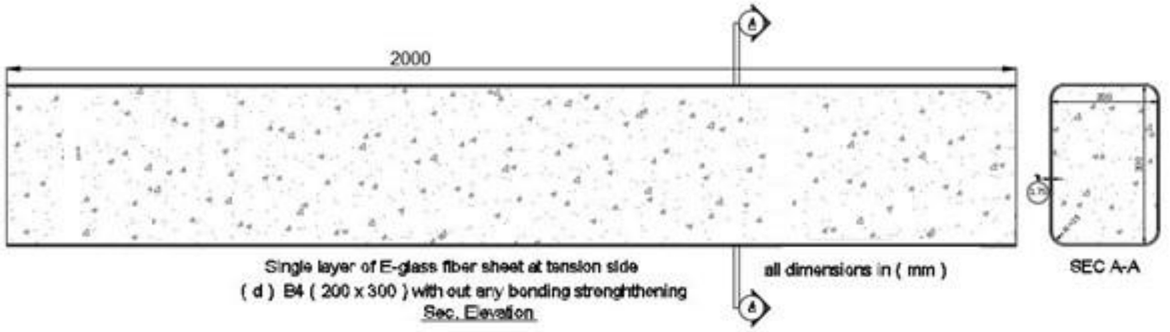


Double layer of E-glass fiber sheet at tension side
(b) B2 (200 x 200) with out any bonding strenghthening
Sec. Elevation

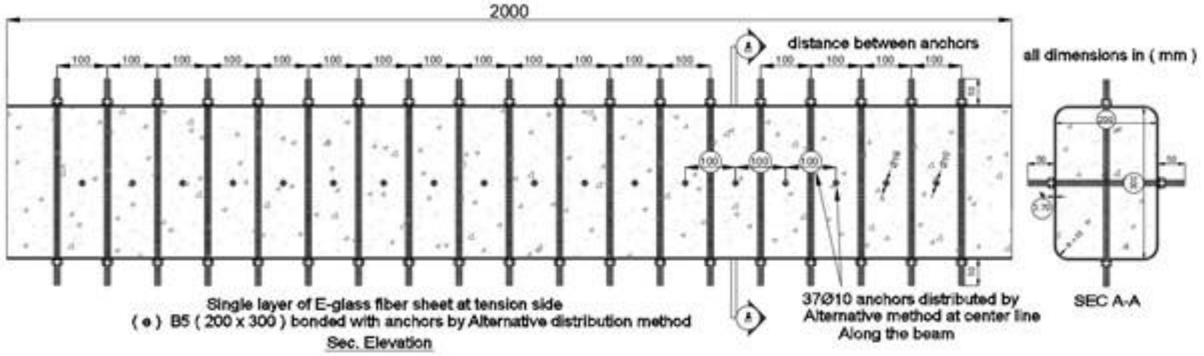


Double layer of E-glass fiber sheet at tension side
(c) B3 (200 x 200) bonded with anchors by alterative tangent distribution
Sec. Elevation

38Ø10 anchors distributed by
Alterative anchor at tangent point
Along the beam

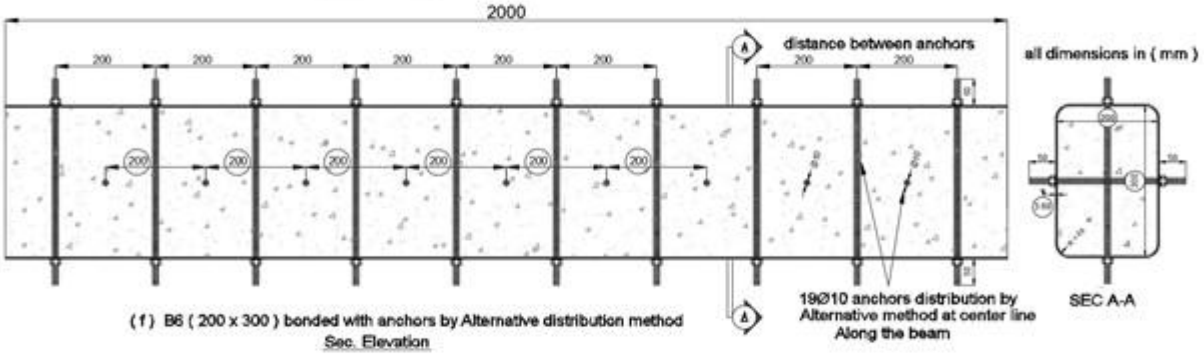


Single layer of E-glass fiber sheet at tension side
(d) B4 (200 x 300) with out any bonding strenghthening
Sec. Elevation



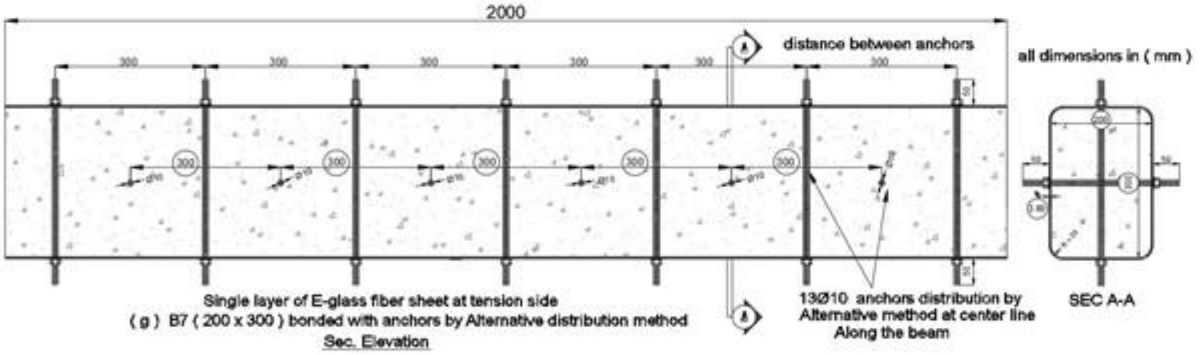
Single layer of E-glass fiber sheet at tension side
(e) B5 (200 x 300) bonded with anchors by Alternative distribution method
Sec. Elevation

37Ø10 anchors distributed by
Alternative method at center line
Along the beam



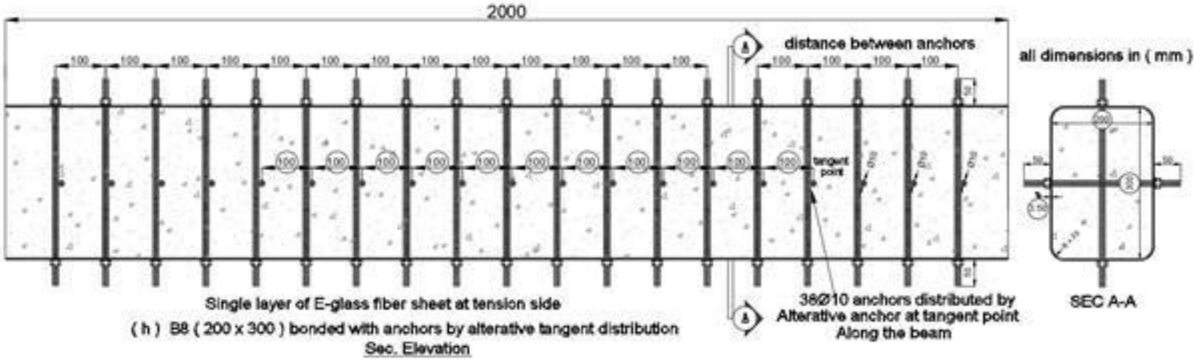
(f) B6 (200 x 300) bonded with anchors by Alternative distribution method
Sec. Elevation

19Ø10 anchors distribution by
Alternative method at center line
Along the beam

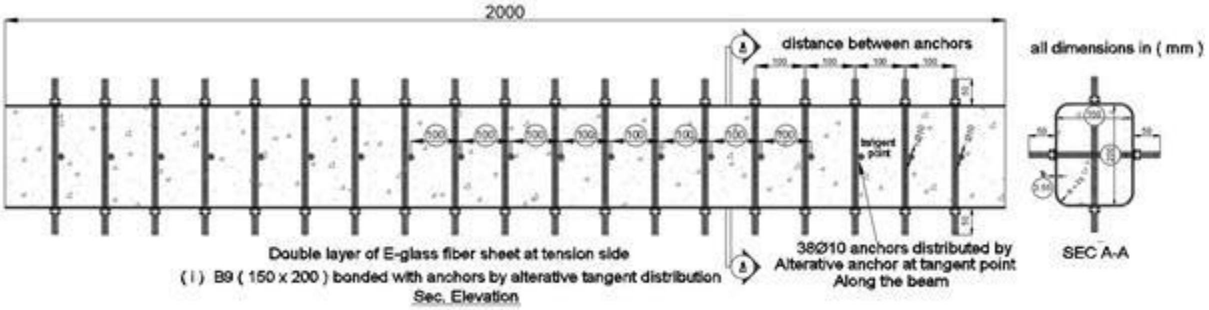


Single layer of E-glass fiber sheet at tension side
(g) B7 (200 x 300) bonded with anchors by Alternative distribution method
Sec. Elevation

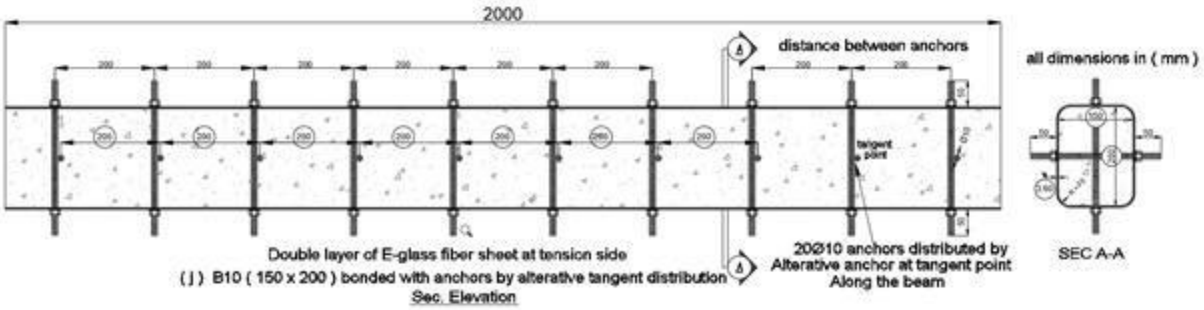
13Ø10 anchors distribution by
Alternative method at center line
Along the beam



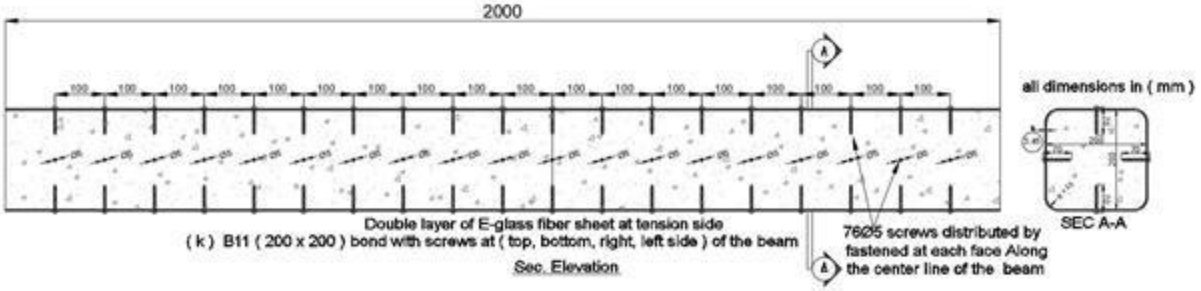
Single layer of E-glass fiber sheet at tension side
(h) B8 (200 x 300) bonded with anchors by alterative tangent distribution
Sec. Elevation



Double layer of E-glass fiber sheet at tension side
(i) B9 (150 x 200) bonded with anchors by alterative tangent distribution
Sec. Elevation



Double layer of E-glass fiber sheet at tension side
(j) B10 (150 x 200) bonded with anchors by alterative tangent distribution
Sec. Elevation



Double layer of E-glass fiber sheet at tension side
(k) B11 (200 x 200) bond with screws at (top, bottom, right, left side) of the beam
Sec. Elevation

Fig.6 - Description of the Specimens (dimensions are in mm)

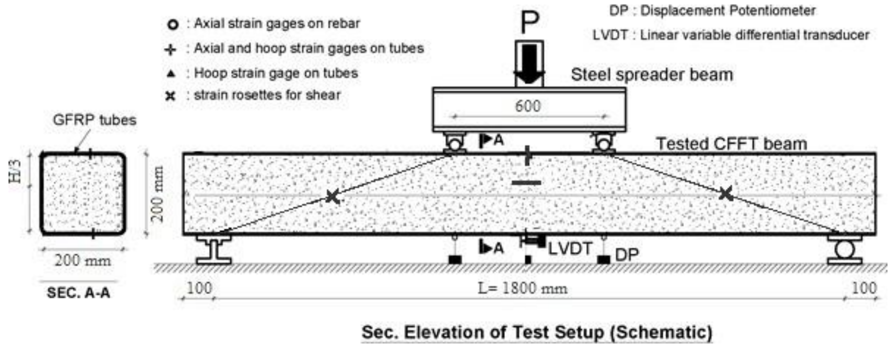


Fig. 7 - Typical Schematic of Test Setup and Instrumentations (Dimensions are in mm)

2.5 Test Setup and Instrumentations

The beams were tested using a four-point bending setup over a simply supported span of 1800 mm long and the distance between the applied concentrated loads was 600 mm centered with the beam length as shown in Figures 7. These lengths give a span-to-depth ratio of 10 and shear span-to-depth ratio of 3. As such, it is believed that the beams tested in this study are governed by flexure [Cole 2005] [2]. The beams were loaded under displacement control using MTS machine with a capacity of 50 kN. Three displacement potentiometers (DPs) were used to monitor the deflection profile along the beam length. Linear variable differential transducers (LVDTs) were attached at the beams top and bottom faces of the tubes, to monitor the extreme axial compressive and tensile strains. Before test, eight axial and transverse strains gages, 10 mm long, were bonded directly on the outer tubes surfaces at their top and bottom faces, corners, and at the depth of the beam (at H/3 from the top surface). The objective of the strain gages measurements is to draw the strain profile and to record the confining action around the section. Finally, strain rosettes were located at the center of the shear span and the midheight to investigate the shear response of the beam as shown in Figure 7. The load, deflection, and strains were recorded automatically during the tests using a data acquisition system that record the readings.

Table 2: Configurations and Mechanical Properties of Fabricated Filament-Wound GFRP tubes

Specimens	Cross-section (mm²)	Stacking sequences	*tf (mm)*	%Fibers (By Weight)	Axial to transverse fibers Ratio	Axial direction			Transverse direction		
						Elo (GPa)	Flo (MPa)	εlo (mm/m)	Etr (GPa)	Ftr (MPa)	εtr (mm/m)
B1	150x200	[90°, sheet, 90°]	3.4	62	**0.5 at tension side**	13	118	7.7	15	268	17
B2	200x200		3.50	65		13.8	120	8.7	15.3	271	17.7
B3	200x200		3.65	62		13.5	122	8.5	15.5	275	18
B4	200x300		3.75	62	**zero**	12	110	7.5	12.5	260	16
B5	200x300		3.70	63		11.5	115	7.0	11.5	255	15.5
B6	200x300		3.60	65		12.5	110	7.3	11	250	15
B7	200x300		3.80	60		12.2	117	7.6	12	265	15.5
B8	200x300		3.50	63		11	105	7.1	11.3	256	15.3
B9	150x200		3.55	60	**0.5 at tension side**	14	125	8.2	15.6	270	18
B10	150x200		3.60	65		13.7	121	7.8	14.5	276	17.5
B11	200x200		3.45	63		14	127	8.8	15.2	280	18

3 RESULTS AND DISCUSSION

The objective of this study is investigating experimentally the effect of mechanical bonding for FRP tubes with concrete under the flexural behaviour of square CFFT beams. This objective was accomplished as the shear failure was avoided and all the tested beams failed at the pure flexure zone and the full composite action between the hybrid section structural components was accomplished because no slippage failure was recorded. The applied moment was calculated by multiplying the concentrated load (P/2) with the shear span (a), while the deflection was measured at the mid-span at three points.

Although the concrete core was hidden behind the tubes surface and it was difficult to see the first crack, the cracking moment (Mcr) was evaluated from the readings of the strain of the FRP tubes and the curvature response change. Table 3 summarizes the beam test results as the flexural moments at the first crack, ultimate moments, mid-span deflection (at the peak), the failure mode, stiffness and energy absorption. The energy absorption determined as the area under the moment-deflection curve until the peak load.

3.1 Failure Patterns of CFFT Beams

All the tested CFFT beams failed under flexure without any signs of shear failure, web buckling, or slippage between the concrete core and the tubes. The corners of the square filament-wound FRP tubes indicated stability until the end of the tests without any separation. The stable composite action of the filament-wound FRP tubes during the test can be attributed to existence of transverse fibers that eliminates outward buckling of the axial fibers and connects strongly the tube flanges with the tube webs preventing their separation at the corners. In the tested square CFFT beams, insignificant micro surface cracks were formed in the matrix. However, these cracks were hard to be observed unless applying direct light on the tubes surface. These cracks were vertical with different heights according to their position along the beam length. In other words, their height is directly related to the moment profile along the beam span. They were formed when the matrix tensile stresses exceed the maximum allowable stress of the resin matrix, which was 50 MPa according to the manufacturer data.

Fig. 8 - Failure Pattern of Specimens

3.2 Moment–Deflection Response

We can divide these specimens into three groups depend on there different cross sections. The first group (150x200 mm^2) includes the (B1), (B9) and(B10), the second group (200x200 mm^2) includes the (B2), (B3) and(B11), and the third group (200x300 mm2) includes the (B4), (B5), (B6), (B7) and(B8). (See Figers 9,10,11 and 12).

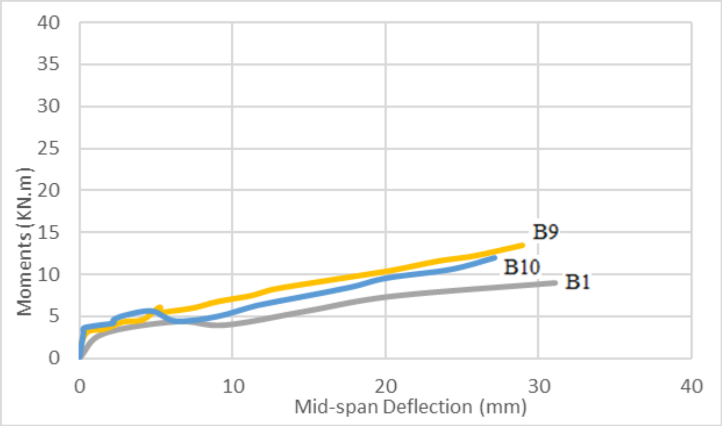


Fig. 9 - First Group (150x200 mm^2)

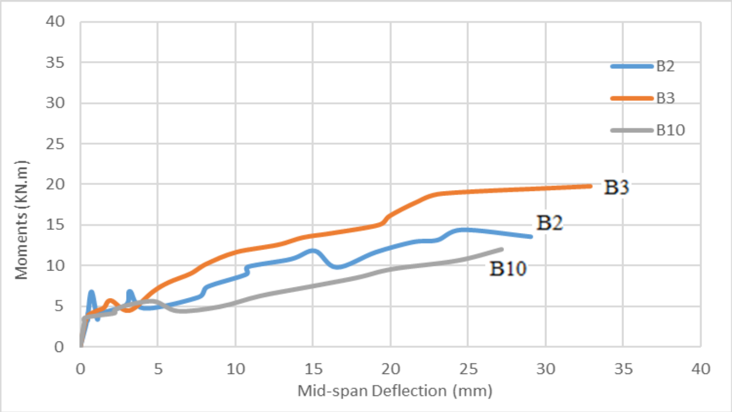


Fig. 10 - Second Group (200x200 mm^2)

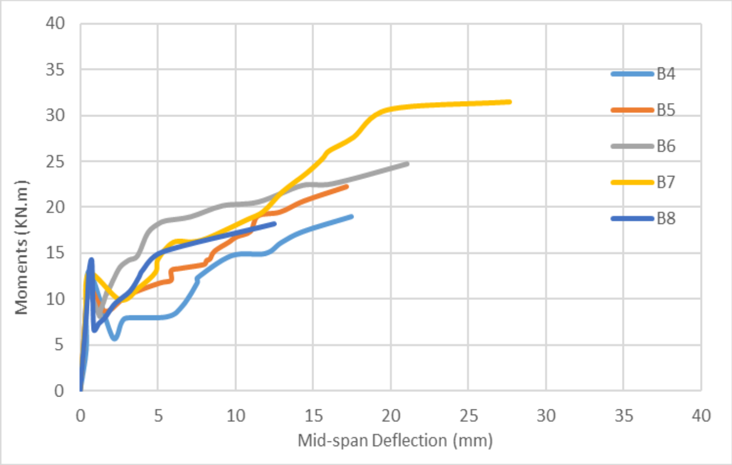


Fig. 11 - Third Group (200x300 mm^2)

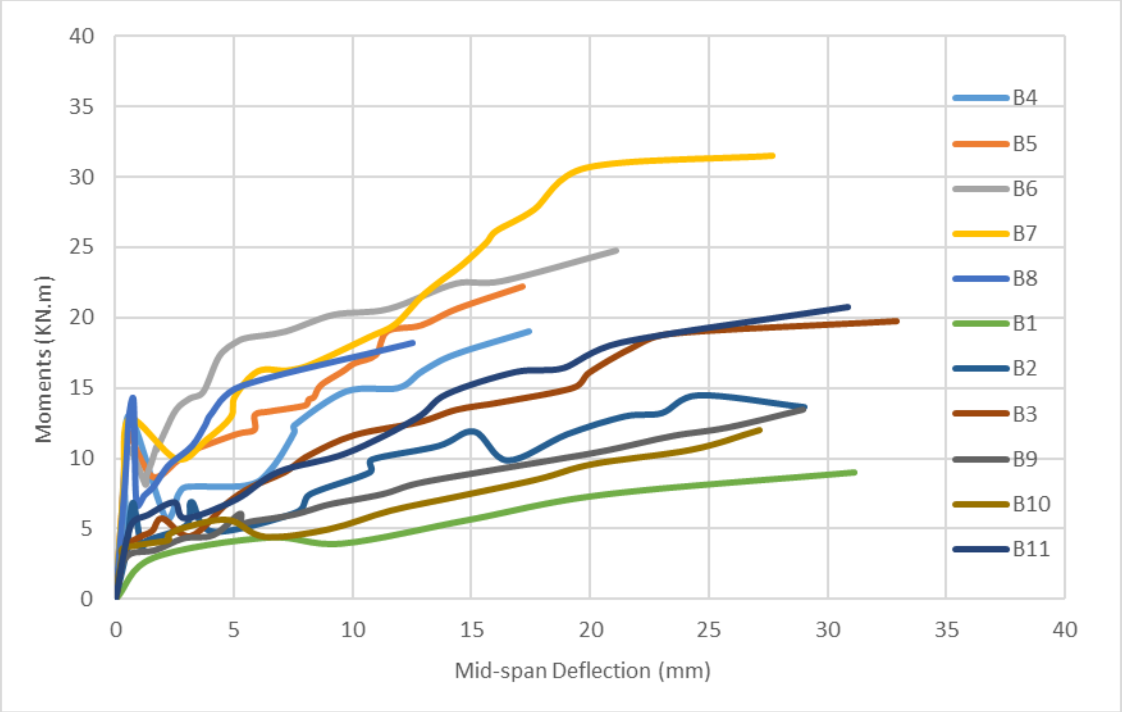
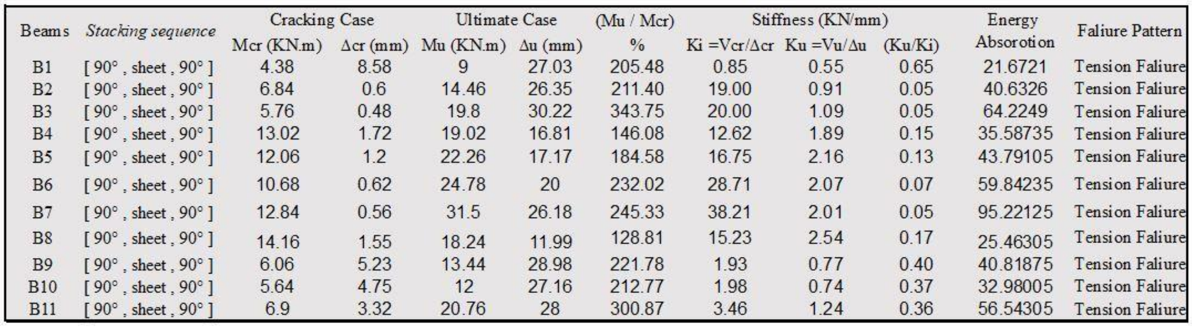


Fig. 12 - Moment-Deflection Response of CFFT Beams

Table 3: Experimental Results of CFFT beams



Beams	*Stacking sequence*	Cracking Case		Ultimate Case		(Mu / Mcr)	Stiffness (KN/mm)			Energy Absorotion	Faliure Pattern
		Mcr (KN.m)	Δcr (mm)	Mu (KN.m)	Δu (mm)	%	Ki =Vcr/Δcr	Ku =Vu/Δu	(Ku/Ki)		
B1	[90° , sheet , 90°]	4.38	8.58	9	27.03	205.48	0.85	0.55	0.65	21.6721	Tension Faliure
B2	[90° , sheet , 90°]	6.84	0.6	14.46	26.35	211.40	19.00	0.91	0.05	40.6326	Tension Faliure
B3	[90° , sheet , 90°]	5.76	0.48	19.8	30.22	343.75	20.00	1.09	0.05	64.2249	Tension Faliure
B4	[90° , sheet , 90°]	13.02	1.72	19.02	16.81	146.08	12.62	1.89	0.15	35.58735	Tension Faliure
B5	[90° , sheet , 90°]	12.06	1.2	22.26	17.17	184.58	16.75	2.16	0.13	43.79105	Tension Faliure
B6	[90° , sheet , 90°]	10.68	0.62	24.78	20	232.02	28.71	2.07	0.07	59.84235	Tension Faliure
B7	[90° , sheet , 90°]	12.84	0.56	31.5	26.18	245.33	38.21	2.01	0.05	95.22125	Tension Faliure
B8	[90° , sheet , 90°]	14.16	1.55	18.24	11.99	128.81	15.23	2.54	0.17	25.46305	Tension Faliure
B9	[90° , sheet , 90°]	6.06	5.23	13.44	28.98	221.78	1.93	0.77	0.40	40.81875	Tension Faliure
B10	[90° , sheet , 90°]	5.64	4.75	12	27.16	212.77	1.98	0.74	0.37	32.98005	Tension Faliure
B11	[90° , sheet , 90°]	6.9	3.32	20.76	28	300.87	3.46	1.24	0.36	56.54305	Tension Faliure

3 CONCLUSIOS

This study presents experimental investigations on the flexural behaviour of rectangular concrete-filled fiber-reinforced polymer (FRP) tube (CFFT) beams bonded with different bonding techniques. Several test variables were chosen to investigate the effect of the type of bond, mechanical anchorages and screws, and the effects of the distance between anchors at the bottom tube flange. To fulfil the objectives of the study, eleven beam specimens, 2000 mm long and 200× (150, 200, 300) mm^2 cross section, were tested under a four-point bending. These beams have tube thickness ranging from 3.4 mm to 3.8 mm, the ratios of the longitudinal fibers to the transverse fibers of the bottom tube flange are 0 and 0.50. The main conclusion of this study is:

1. The mechanical bonding using anchors and screws in Concrete-filled FRP tube (CFFT) beams showed a improve in the structure load carrying capacity and deflection.
2. The corners of the fiber reinforced polymeric tubes manufactured with filament winding technique showed high stability until the end of the tests, when no separation occurred in any of the tested beams. This is what distinguishes the fiber-reinforced polymeric tubes manufactured with filament winding technique versus other manufacturing methods specially the pultruded FRP tubes, which often fail due to the separation
3. The bonding technique using anchors fastened through FRP tube and concrete is very efficient technique compared to using Screws
4. Stiffness and the cracking moment (Mcr) of the rectangular CFFT beams are increases with increasing the distance between anchors.

5. The CFFT-beams, that distributed by alternative method between anchors, showed a higher-resistance-and-energy absorption than that the CFFT-beams that distributed by alterative tangent method between anchors Hence, the method of distribution between anchors has great importance in increasing the strength of the CFFT-beam and the energy absorption of that beams.

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