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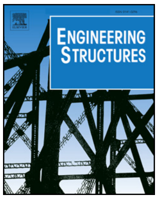

Composite Action Assessment of Concrete-Filled FRP Tubes Subjected to Flexural Cyclic Load

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ABSTRACT

Concrete filled fiber-reinforced polymer (FRP) tubes (CFFT) is a principal competitor to replace the conventional reinforced concrete (RC) members in severe environmental conditions. This paper investigates the composite action (interfacial bond) between the FRP tube and its concrete core. Four full-scale CFFT columns associated with RC footings were tested under lateral cyclic load without axial load. Two different diameters of CFFT columns were tested to study the size effect on the bond performance then consequently on the flexural behavior of the CFFT column. The interior surface of two FRP tubes have been covered by sand coating to improve the interfacial bond between the FRP tube and the concrete core. A new approach was proposed to evaluate the composite action between the FRP tube and the concrete core based on measuring strains inside the concrete core by using embedded concrete strain gauges. The assessment of the composite action between the FRP tube and the concrete core was implemented by comparing the interior concrete strains and the corresponding strains on the external tube skin. The experimental results illustrated that the bond significantly influences the flexural strength and stiffness of the CFFT column. Increasing the tube diameter leads to reduce the interfacial bond between the FRP tube and its concrete core. Using sand-coating as a bond enhancer improved the bond between the FRP tube and the concrete core, minimize the adverse effect of increasing the tube diameter, and increased the flexural capacity and stiffness of tested CFFT columns. An analytical model was developed to estimate the flexural capacity of the fully bonded CFFT member.

1. Introduction

Over the past two decades, concrete-filled fiber-reinforced polymer (FRP) tube (CFFT) members have been investigated extensively to understand their behavior under several loading types [1–7]. CFFT was developed as a superior alternative for several structural elements in the construction domain due to its high performance and durability. Besides its high strength, the FRP tube considers as a light-weight permanent formwork, noncorrosive longitudinal and transverse reinforcement, and confines the concrete core [7–11].

As is well known, slippage between the FRP circular tube and the concrete core adversely influences the flexural strength and stiffness [12–14]; so, developing an approach to assess and improve the bond between the tube and the concrete core is required. In addition, north-American design codes and guidelines prevent slippage in flexural-members and considered the full composite action as a fundamental demand in the flexural design assumptions.

Abouzied [15] created a rough texture on the inner surface of the FRP tubes to improve the bond between the tube and the concrete core. The texture roughness technique was implemented by applying a thin layer of epoxy to the inner skin of the tubes thereafter it was covered by silica sand; that is known nowadays as sand-coating technique. The author reported that no slippage was observed on the ends of specimens with sand-coating.

Belzer [16] investigated the degree of composite action between rectangular pultruded glass fiber-reinforced polymer (GFRP) tube and concrete. The experimental results of Belzer [19] showed that using epoxy to bond the FRP tube to concrete significantly increases the flexural capacity and stiffness of the rectangular CFFT.

The previous researches assumed full composite action between the FRP tube and its concrete core. They have mainly established their analysis on the slippage measurements between the concrete core and the FRP tube at ends of the CFFT-member. Authors believe that; the degree of the bond between the FRP tube and the concrete core differs

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along the span of the CFFT member according to the bending-moment distribution. The debonding occurs primarily at the maximum moment zone. Thereafter, the debonding propagates along the element span. Researchers capture the slippage at the ends of the CFFT, this slip value is representing the cumulative slippage occurring along the CFFT span. There are other parameters might constrain the slippage at the end of the CFFT member like the presence of the internal reinforcement in addition to the friction between the concrete core and the FRP tube along the parameter and the span of the CFFT member. So, the debonding may occur at the maximum moment zone (local debonding) and the slip may not be observed at the end of the CFFT. Therefore, no-slip at the end of the CFFT member is not a proof of full bond and should not consider as an evidence of the full composite action between the FRP tube and its concrete core.

This research introduces a new approach to assess the bond between the FRP tube and the concrete core by using embedded concrete strain gauges into the concrete core. This paper aims also at studying the composite action between the FRP tube and its concrete core and composite action effect on the flexural behavior of CFFT. In addition, the contribution of using sand-coating as a bond enhancer; to improve the bond between the FRP tube and the concrete core; is investigated.

The proposed assessment technique of the composite action is depending on measuring the compressive strain using embedded concrete strain gauges inside the concrete core. The principal concept of this technique is comparing the interior compressive concrete strain values with the compressive strain values on the external skin of the tube. The interior and exterior strain gauges were aligned together at the same position and height. In the case of the interior concrete strains equal to the exterior strain gauge on the tube surface, it means a full composite action has been accomplished. Otherwise, the tube and its concrete core are performing individually. Fig. 1 shows the principle idea of the proposed technique. where ε_{V1} is the vertical compressive strain inside the concrete core, ε_{V2} and ε_{V3} are the vertical compressive strain on the exterior surface of the FRP tube.

2. Experimental program

The experimental program describes the material properties details (FRP tubes, concrete, steel reinforcement), preparation of specimens (sand coating procedure, test specimens, assembling of the specimens), test setup, instrumentation, and test procedure.

2.1. Material properties

2.1.1. FRP tubes

The FRP tubes are circular pultruded tubes. All tubes are manufactured with electrical grade E-glass reinforcements in the form of unidirectional roving, Continuous Filament Mat (CFM) and stitched fabric mats [17]. The tubes are pultruded with high-performance Vinyl Ester (VE) and Polyurethane resins, VE resins are ideal for long-term performance in harsh marine environments, Polyurethane resins provide all the performance of VE resins in addition to optimal strength, toughness and impact resistance [17].

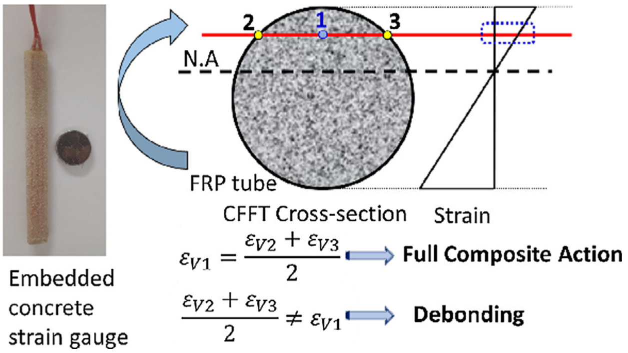

Fig. 1. The principle concept of the proposed technique to evaluate the composite action of CFFT members.

Table 1
Geometrical and Mechanical properties of GFRP tubes.

	C12		C16	
	Measured	Provided*	Measured	Provided*
D (mm)	305	305	406	406
t (mm)	12.7	12.7	12.7	12.7
f (MPa)	NM	480	NM	395
f_{cl} (MPa)	555	480	572	395
f_{tl} (MPa)	665	NP	711	NP
E_l (GPa)	36.5	40.7	38	41.3
EI (kg mm^2)	NM	5.17E + 11	NM	1.28E + 12
M_f (kN.m)	NM	392	NM	592

* Provided by the manufacturer, NM = Not Measured, NP = Not Provided

Two different tube diameters were used in this research; 305 mm and 406 mm (C12 refers to tubes with 305 mm diameter while C16 refers to tubes with 406 mm diameter). The tube thickness is constant in all tubes and equals 12.7 mm. For each tube, twelve coupon specimens were tested under axial tension and compression to determine the tubes mechanical properties on the longitudinal direction following the ASTM D3039/D3039M [18] and ASTM D695 [19], respectively. The manufacturer provided the tubes mechanical properties based on testing of the full section and following ASTM D6109 [20]. Table 1 illustrates the dimensions and the mechanical properties of both tubes in the longitudinal direction, where D is the tube outer diameter, t is the tube thickness, f is the average flexural strength, f_{cl} is the average compressive strength, f_{tl} is the average tensile strength, E_l is the Modulus of elasticity, EI is the bending stiffness, and M_f is the average moment capacity.

2.1.2. Concrete

Ready-mixed normal weight concrete of 35 MPa target compressive strength was used to fill the tubes. The tubes were positioned vertically for the concrete casting. The casting of the specimen started with filling the footing up to the bottom end of the FRP tube then the tubes filled completely. Thereafter, the footing was completed. For each specimen, nine cylinders and six prisms were prepared and tested on the same day of the test to determine the concrete compressive strength and the concrete modulus of rupture, respectively. The measured concrete properties of the four patches were approximately identical, the concrete compressive strength of the cylinders was 35 MPa ± 2 MPa and the modulus of rupture of prisms was 4.0 MPa ± 0.3 MPa.

2.1.3. Steel reinforcement

Two varied sizes of steel reinforcement, M15 (16 mm diameter) and M10 (11.3 mm diameter) were used to reinforce the footing. The steel reinforcement bars have a modulus of elasticity and yield strength equal to 200 GPa, 420 MPa, respectively.

2.2. Preparation of specimens

2.2.1. Sand-coating procedure

The main purpose of using sand-coating is to establish a rough texture on the internal skin of the tube. The sand-coating process comprises three stages, the first stage is the coating of a VE resin layer on the interior skin of the FRP tube using paint-rollers. While the second stage is the covering the VE resin layer by using a coarse silica sand before the hardening of the VE resin. The third stage is the curing of the resin, which implemented by preserving the tubes in a curing room for three days at a constant temperature of 60-degree Celsius.