EXPERIMENTAL INVESTIGATION ON THE FLEXURAL BEHAVIOUR OF PULTRUDED GFRP BEAMS FILLED WITH DIFFERENT CONCRETE STRENGTHS

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ABSTRACT

Glass fibre reinforced polymer (GFRP) pultruded profiles are being increasingly used in the construction industry due to their numerous advantageous over the conventional materials. However, most pultruded GFRP sections fail prematurely without utilising their high tensile strength due to their thin-walled sections. As a result, several hybrid systems made out of GFRP profiles and concrete as a filler material have been proposed in order to enhance their structural performance. Most of these studies utilised high strength concrete wherein the additional cost does not justify the enhancement in the stiffness and strength of the infilled GFRP profiles. This paper presents an experimental investigation on the effect of the compressive strength of concrete infill on the flexural behaviour of beams with a view to determine a lower cost infill for GFRP profiles. Pultruded GFRP square beams (125 mm x125 mm x 6.5mm) were filled with concrete having 10, 37 and 43.5 MPa compressive strength and tested under static four-point bending. The results showed that the capacity of the filled beam sections increased by 100 to 141% than the hollow sections. However, the compressive strength of the concrete infill has no significant effect on the flexural behaviour of the beams. The increase in concrete compressive strength from 10 to 43.5 MPa increased the ultimate moment by only 19% but exhibited an almost same flexural stiffness indicating that a low strength concrete is a practical solution to fill the GFRP profiles.

KEYWORDS

FRP, Hybrid beams, Concrete infill, Low-strength concrete.

INTRODUCTION

Fibre reinforced polymer (FRP) composite materials have recently been used in the construction industry especially in corrosive environment. One of the innovative applications is the concrete filled FRP tubes (CFFTs) due to the relatively low elastic modulus as well as thin-walled sections of the FRP tubes. Extensive research was carried out on CFFTs as columns, but relatively limited research was conducted on CFFTs as beams (Fam & Rizkalla 2001; Mirmiran & Shahawy 1996; Mohamed & Masmoudi 2010; Ozbakkaloglu 2012). Most of these research concentrated on the ability of this system to take advantage of the confinement provided by the composite tube to the concrete core. The growing incorporation of CFFTs in compression application let to expand the investigation of the feasibility of this system for beam applications. In the last decade, several research efforts were made to investigate the flexural behaviour of concrete filled FRP tubes. Roeder, Lehman and Bishop (2010) concluded that the local buckling resistance of the FRP tubes increases due to the contribution of the concrete infill. Similarly, Fam and Rizkalla (2002) carried out experimental investigation on the flexural behaviour of hollow and filled GFRP circular tubes with a range of concrete infill strength between 30 and 60 MPa. They concluded that the flexural behaviour is affected to some extent by the concrete compressive strength. In addition, Mirmiran and Shahawy (1996) carried out experimental investigation to compare the flexural behaviour of concrete filled FRP tubes and the conventional reinforced concrete beams. The results showed the performance of the concrete filled beams is comparable or better than the conventional reinforced concrete beams. Chen and El-Hacha (2010) studied the flexural behaviour of FRP sections filled with ultra-high performance concrete (138 MPa). They concluded that the concrete core provides lateral support for the section and it prevents compressive flange buckling at higher loads.

Most of the previous research utilised high strength concrete as a suitable filling material of FRP where the additional cost does not justify the enhancement in the stiffness and strength of the infilled GFRP profiles. This paper presents an experimental investigation concerning the flexural behaviour of GFRP tubes filled with concrete having different compressive strength. The main objective of this study is determining a lower cost infill for GFRP profiles.

EXPERIMENTAL PROGRAM

Material Properties

Glass fibre reinforced polymer (GFRP) pultruded tubes and concrete are the main materials used in this study. Details of these materials are provided in the following sections.

GFRP tubes

A square Pultruded GFRP sections (125 mm x 125 mm x 6.5 mm thickness) produced by Wagner's Composite Fibre Technologies (WCFT), Australia were used in this study. The tubes were produced using pultrusion process using vinyl ester resin with E-glass fibre reinforcement. Burnout test was conducted according to ISO 1172 (ISO 1172 1996) where the density and the fibre volume fraction are found to be as 2050 kg/m3 and 78% by weight, respectively. The stacking sequence of the plies is $[0^0/+45^0/0^0/-45^0/0^0/-45^0/0^0/+45^0/0^0]$, where the 0^0 direction accords with the longitudinal axis of the tube. The mechanical properties (elastic modulus and shear modulus) of GFRP sections where determined previously by Muttashar et al. (2015). In addition, coupon tests were conducted to find the compressive and tensile strength of the sections. Table 1 shows the mechanical properties of the tested samples.

Table 1 Material property of the GFRP tubes from full scale test.

Material property	Symbol	Property value	unit
Density	ρ	2050	kg/m3
Tensile stress	σ_t	596	MPa
Tensile strain	ε_t	16030	Microstrain
Compressive stress	σ_c	550	MPa
Compressive strain	ε_c	11450	Microstrain
Elastic modulus	E	47.2	GPa
Shear modulus	G	4	GPa

Concrete

Three different concrete strengths were used as concrete infill of the tubes. Five plain concrete cylinders have been sampled from each batch and cured under the same conditions as the beam sections. The 28 days average compressive strength was of 10, 37.5 and 43.5 MPa, respectively.

Test specimens

Three GFRP hollow sections and six GFRP filled sections were used in this study to investigate the flexural behaviour. The total length of the tested beams was 2000 mm. The details of the tested specimens are shown in Table 2. Considering the strength of the filled concrete, the specimens were identified using the code listed in the Table. The term BH indicates the hollow geometry, while, BC-10, BC-37 and BC-43 represent the beams filled with concrete having 10, 37 and 43 MPa compressive strength, respectively.

Table 2 Details of the test specimens.

Specimen ID	Description Concrete strength MPa
BH	-
BC-10	10
BC-37	37
BC-43	43

Test setup and instrumentation

Four-point bending test was performed over a simply supported clear span of 1800 mm following the procedure in ASTM D7250 (ASTM D7250 2006). The specimens were tested on a 400 kN capacity universal testing machine at a load rate of 3 mm/min. the load was applied at two points with a load span of 300 mm. Figure 1 shows the test set up for the flexural behaviour. To minimise the indentation failure, steel plates were added at the support and loading points. The strain on the top and bottom faces of the beams were measured by using four uniaxial strain gauges (types PFL-20-11-1L-120). The load was increased until failure. The load and mid-span displacement were measured with the electronic load cell and a laser displacement transducer connected to a Data Acquisition System, respectively.

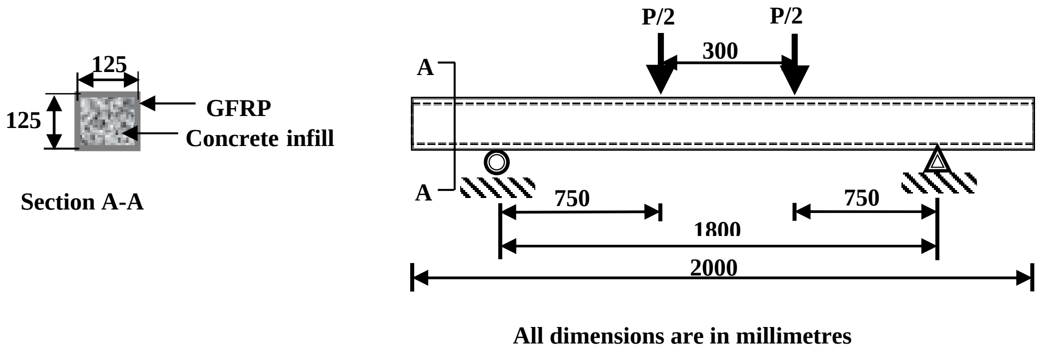


Figure 1 Experimental set up details

TEST RESULTS AND DISCUSSION

Moment-deflection behaviour

Figure 2 shows the moment-deflection response of the tested beams. The hollow beams (BH) showed a liner elastic behaviour until failure at 31 kNm. The average ultimate flexural stress at the top and bottom of the tested beams was 291 MPa. This stress value is approximately 45% of the compression failure stress based on coupon test results for GFRP profile. The main reason behind this behaviour is compression local buckling of the top flange at the constant moment region. The buckling is then followed by separation of the web-flange junction, delamination and crushing of the web. On the other hand, figure 2 shows the significant gain in strength and stiffness of the filled beams compared with the hollow beams. The overall behaviour of the filled beams is linear elastic until failure. The average failure moment of the filled beams BC-10, BC-37 and BC-43 is greater than the hollow beams by 100%, 140% and 145%, respectively. It is due to the contribution of the concrete core which restricting and delaying the local buckling of the GFRP tubes, the filled beams capacity is higher. However, with 335% increase in concrete strength from 10 to 43 MPa, only 19% is the improvement of the strength of the section. Two possible reasons might be causing this behaviour. Firstly, the brittleness of the concrete is increased with the increasing concrete strength. Secondly, the overall behaviour of the filled beams is controlled by the behaviour of the outside tube.

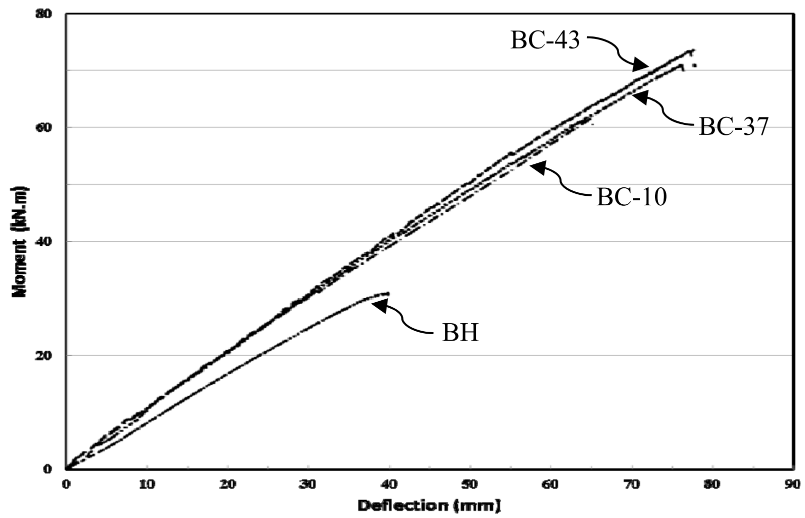


Figure 2 Moment-deflection behaviour of the tested beams.

Figure 3 shows the flexural stiffness of the tested beams. The average flexural stiffness, *EI* of the hollow beam is 2.38×10^{11} N.mm^2. this value was calculated using the following equation:

$$EI = \frac{Pa}{48\Delta}\left(3L^2 - 4a^2\right) \quad (1)$$

Where *EI* is the effective flexural stiffness in N.mm^2; *P* is the applied load in N; *a* is the shear span in mm; Δ is the mid-span deflection mm; and *L* is the span in mm. The calculated un-cracked flexural stiffness of the 10 MPa and 43 MPa concrete are 3.19x1011 N.mm2 and 4.19x1011 N.mm2, respectively. These values are 34% and 75% higher than the stiffness of the hollow beams. These results reflect the contribution of the concrete core in the overall stiffness of the filled beams. On the other hand, the flexural stiffness of the beams after the initiation of the tensile cracks in the concrete is approximately 26% higher than the hollow beams for all types of concrete. These results might be attributed to the difference in the cracking stress between the 10 MPa and 43 MPa concrete that results in lower contribution of concrete area for higher concrete strength than lower concrete strength to achieve the equilibrium of the internal forces.

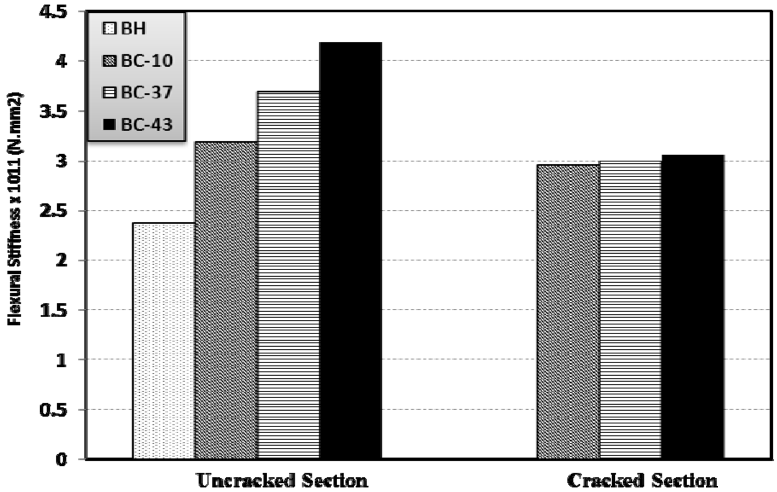
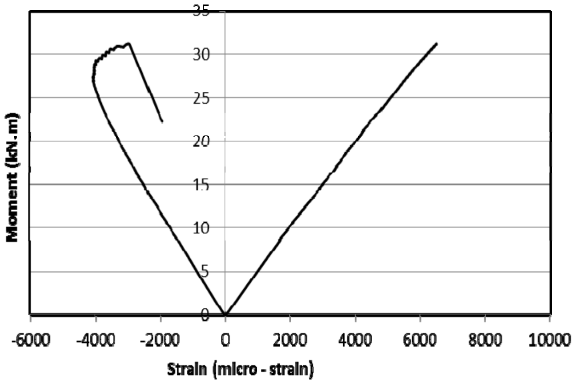
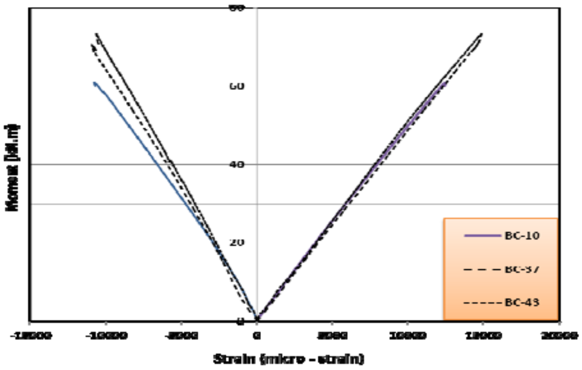


Figure 3 Flexural stiffness of un-cracked and cracked sections.

Moment-strain relationship

The moment-strain relationships of the hollow and concrete filled beams are shown in Figure 4. The figure shows that the hollow section failed at compressive strain of 3140 microstrains and tensile strain of 6100 microstrains. The compressive strain tends to become positive which reflecting the local buckling effect on the top flange as shown in Figure 4a. In contrast, the filled beams failed at tensile strain of 12400, 14800 and 14820 microstrains for BC-10, BC-37 and BC-43, respectively as shown in Figure 4b. These strain levels are much higher than that of hollow beams in addition it approximately represents 77, 92 and 93% of the failure strain of the pultruded GFRP section based on coupon tests (Table 1). These results indicate that no tension failure had occurred at the tension site. Similarly, the tested beams showed a higher level of compressive strains of 11100, 11200 and 11250 microstrains for BC-10, BC-37 and BC-43, respectively. Again, these values are much higher than the strain levels of hollow beams and it approximately represents 97, 98 and 98.5% of the ultimate compressive strains of GFRP section. The results indicate that the filled beams failed at onset of the compression failure.



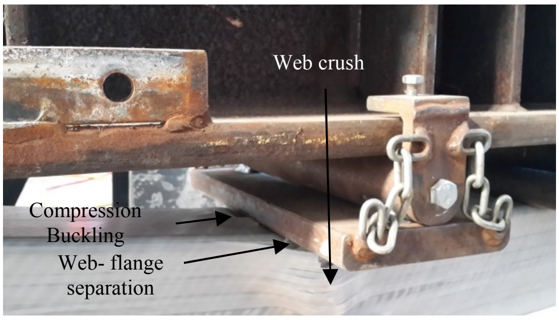


(a) Hollow beam (b) Filled beams

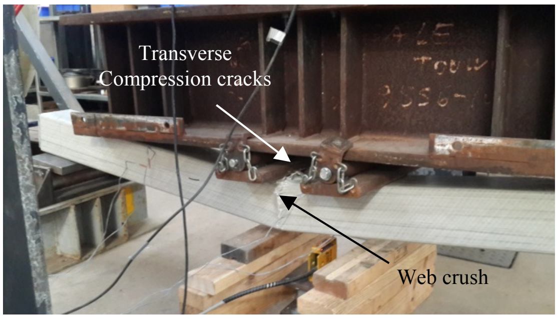
Figure 4 Moment-strain relationship of hollow and filled beams.

Modes of failure

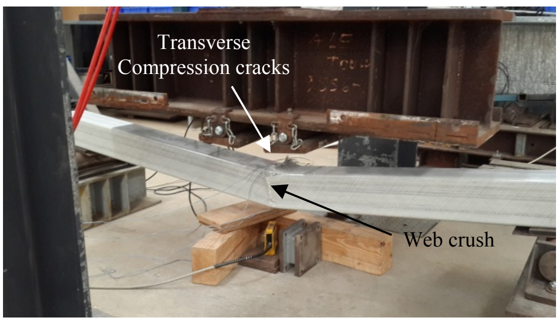
The failure of the hollow beams started with the local buckling of the top flange followed by separation of the web-flange junctions and by delamination and crushing in the web as shown in Figure 5a. Similar behaviour has been reported in the literature (Guades, Aravinthan & Islam 2014; Vincent & Ozbakkaloglu 2013). On the other hand, the failure of the filled beams began with an inflated flange at the compression side due to the high compressive strains followed by cracks in the fibres in the transverse direction. As the concrete core cracked, the failure progressed into the side as shown in Figure 5b, c and d. The complete failure occurred after the fibre cracking in the top flange and the webs of the section at a strain level of approximately 11200 microstrains. The strain level is far greater than the failure strain of the hollow beams which illustrates that the concrete infill prevented the occurrence of the local buckling. The results also indicate that no failure has been occurred in the tension side due to the fact that the tensile strain levels are still lower than the ultimate level.



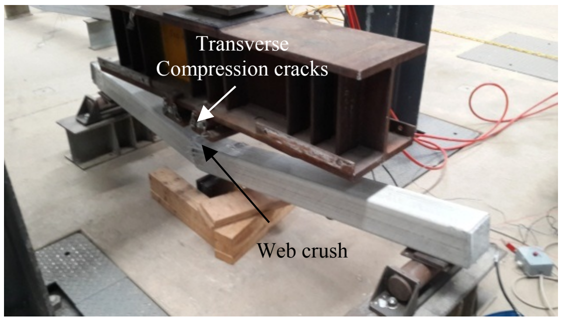
a) BH



b) BC-10



c) BC-37



d) BC-43

Figure 5 Modes of failure of the tested beams.

CONCLUSIONS

This paper presented the experimental results of four point bending tests on concrete filled GFRP tubes (CFFTs). Concrete compressive strength was the main parameter examined in this research. Based on the results, the following main conclusions can be addressed

- The concrete filled GFRP sections show a considerable strength and stiffness increase with 100-145% and 26%, respectively compared with the hollow sections.
- Increasing the compressive strength of the concrete core from 10 MPa to 43 MPa result in increasing the ultimate moment by 19%. However, the flexural stiffness of the filled beams is almost the same.
- In view of using concrete filled GFRP tubes as a viable structural solution to prevent local buckling of the tube, low strength concrete can be considered as a practical infill for the GFRP tubes.

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