FLEXURAL BEHAVIOR OF GLUED GFRP TUBES FILLED WITH CONCRETE

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Abstract
The corrosion of steel reinforcement is considered the greatest factor limiting the service life of reinforced concrete structures. Glass fiber reinforced polymers (GFRPs) are known as cost-effective materials offering long-term durability and less maintenance. As a result, these materials show great potential for use in the civil engineering applications. Due to the high cost of the manufacturing die, pultruded GFRP tubes are produced in specific cross-section dimensions only. For high load applications and to comply with the serviceability requirements, a number of these pultruded sections can be assembled together by gluing them appropriately. This study presents an experimental investigation onto the flexural behavior of glued GFRP tube beams with 1, 2, 3 and 4 - cells filled with concrete under four-point loading. The results show that the strength of the 4 cells glued beams increased by 150 % and 88% for hollow and filled beams, respectively, compared with its counterpart single cell beam. The filled beams failed at 42 – 88 % higher load and showed 10 – 22 % higher stiffness compared with their hollow counterparts. The results also show that gluing small section tubes to produce large section beam is a practical solution to enhance the flexural performance of the composite tubes.

1. Introduction

Glass fibre reinforced polymer (GFRP) shows a great potential to use in a variety of structural engineering application especially after the introduction of large volume automated technique (pultrusion). These materials demonstrate several advantages such as light weight, ease of installation, low maintenance, and resistance to harsh environmental conditions [1]. Current research focused mainly on the performance of structures made of FRP in combination with other materials (i.e hybrid

structures) [2, 3]. Due to the high cost of the manufacturing die, pultruded GFRP tubes have been produced in specific cross-section dimensions. Those sections are normally inapplicable to use as a structural element due to the fact that their section is small. As a result, research was conducted to develop a newly built up sections. Limited experimental attempts have been made to develop a multi-celled beam design by gluing the GFRP tubes together to make new sections [4, 5]. The results of these studies show that the beams are susceptible to local buckling and debonding between layers. In addition, due to time and cost limitation, the beams have not been tested up to failure. However, the researchers mentioned that the proposed design can be used in the building of all-composite bridge decks and other applications.
In this study, the authors propose to make GFRP beams from single-cell thin-walled tubes bonded together using adhesive. The study aims at investigating the flexural behaviour of the GFRP glued beams in terms of failure mode, strength and stiffness.

2. Experimental program

2.1. Material properties

A glass fibre reinforced polymer (GFRP) pultruded sections used in this study is made up of E-glass fibre reinforcement with vinyl ester resin produced by Wagner's Composite Fibre Technology (WCFT), Australia using pultrusion process. A square GFRP section of (125 mm x 125 mm x 6.5 mm thickness) is the component of the glued beam. The mechanical properties of GFRP section were determined previously by Muttashar et al. [6]. The elastic and shear modulus are 47.2 GPA and 4 GPa respectively. A value of 2050 kg/m3 and 78% by weight were determined from the burnout test for the density and the fibre volume fraction, respectively. Normal strength concrete (Bastion premix concrete) was used to fill the pultruded tubes. The 28-day average compressive strength for the infilled concrete was 32 MPa.

2.2. Test specimens

The beam specimens were prepared using the square pultruded tube. The tubes were glued together with an epoxy adhesive following a procedure provided by the manufacturer. The description of the tested specimens is listed in Table 1. In this table, the specimens were identified by codes such as 2C-32. The initial 2C represents the number of glued cells (i.e. 2 cells, with one glued to the top surface of the other) while the number 32 is used to indicate the grade of concrete infill (i.e. 32 MPa characteristic compressive strength). Only the top most cell of each specimen was filled with concrete in order to provide a support for the flange to prevent pre-mature failure of the section.

Table 1. Descriptions of the pultruded GFRP tested beams.

Details	Specimen Type							
	1C-0	1C-32	2C-0	2C-32	3C-0	3C-32	4C-0	4C-32
D (mm)	125	125	250	250	375	375	500	500
L_t (mm)	2000	2000	2750	2750	3700	3700	5000	5000
L (mm)	1350	1350	2400	2400	3450	3450	4500	4500
a (mm)	525	525	1050	1050	1575	1575	2100	2100
f'_c (MPa)	-	32	-	32	-	32	-	32

2.3. Test set-up and procedure

The test was conducted using static four-point bending following the ASTM D7250 standards [7] as shown in Fig. 1. The load was applied using 2000 kN universal test machine with a loading rate of 2 mm/min. The loading span varied depending on the total depth of the beam to maintain similar shear span to depth ratio, a/d, of 4.2. A laser displacement transducer and uniaxial stain gauges type pfl-20-11-1l-120 were used to measure the mid-span deflection and strain at top and bottom faces of the specimen, respectively. All beams were tested up to failure to obtain the strength and failure mode. The test data (load, deflection and strain) was measured and recorded using data logger system 5000.

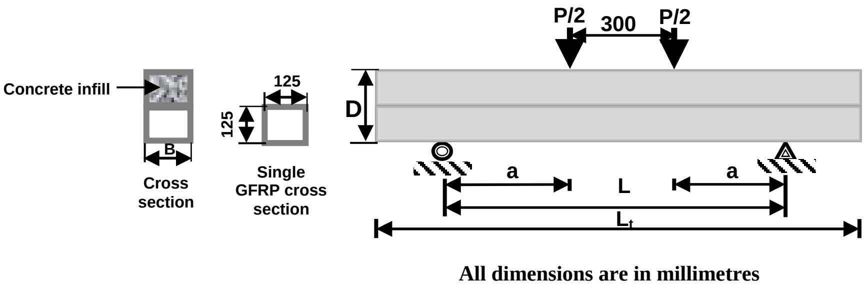

Figure 1. Flexural test set-up.

3. Results and Discussion

3.1. Failure mode

Experimental investigation showed that the glued composite beams exhibited different failure modes in hollow and filled sections. These failure modes are presented in Fig. 2. Local buckling at the top compression flange of the hollow beams was observed which results in the final failure. The failure initially occurred at the loading point and cracks appeared on the top of the compression flange of the beam. Then, the cracks progressed to the web-flange junction and finally they propagated into the web which leading to the final failure. It is interesting to note that the failure occurred only at the top cell of the glued section without any damage of the other cells in the section. For the filled beams, however, different failure mode has been observed. The failure started with a transverse cracks and delamination at the compression flange which then progressed to the web. No local buckling was observed due to the presence of the concrete core. The contribution of the concrete core was noticeable as the filled beams fail with higher load. Again, the failure of the filled beams was due to the failure of the top cell which did not result in a total collapse of the beam. This failure mode might be considered as appropriate failure for structural element at the failure was not really catastrophic. The beam with four glued cells shows different failure mode where the failure started at the web-flange junction of the hollow cell due to bearing pressure of the top filled cell. However, once the failure started at the hollow cell, the curvature of the top cell increases which result in a transverse cracks and delamination of the compression flange.

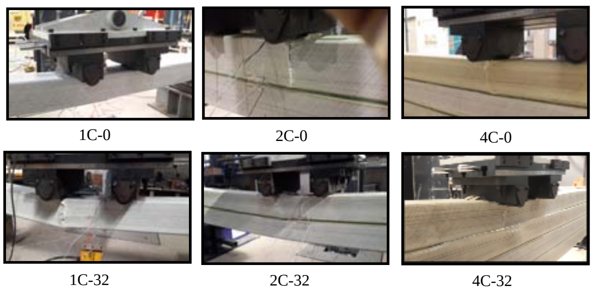

Figure 2. The mode of failure of single and glued beams.

3.2. Evaluation of flexural performance

Fig.3 shows the relationship between the number of glued cells and the failure load of the tested beams. It shows that there is a significant gain in strength of the glued beams compared with single cell beam for hollow and filled beams, respectively. It is clearly seen from the figure that the failure load of the beam increases with the increase of the number of glued cells in the cross-section. This is due to the contribution of the bonded horizontal flanges providing some reinforcing effect to delay the failure, thereby, increasing the strength. The failure load of the filled beams is higher than that of hollow beams due to the effect of concrete core in preventing the premature failure. The beams with 4 glued cells show 150% and 88% increase in the failure load for hollow and filled beams, respectively, compared with its counterpart single cell beams. Fig.4 presents the moment- deflection behaviour of

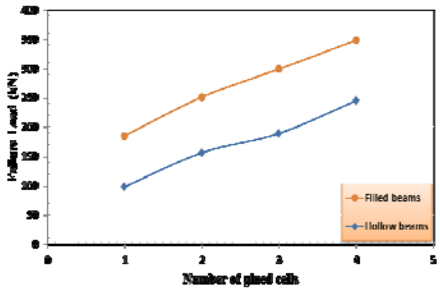

Figure 3. Failure load and number of cells relationship

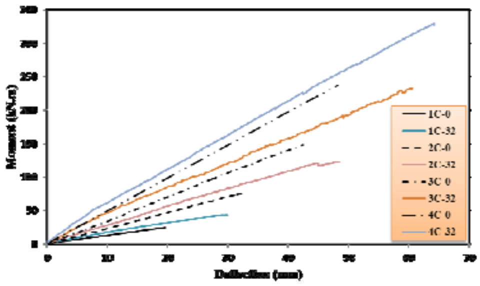

Figure 4. Moment-deflection behaviour of hollow and filled beams

hollow and filled beams. The figure shows that all beams behave linearly until failure. The figure also depicts that the filled beams has 10 – 22 % higher stiffness compared with its hollow beam counterparts.

3. Conclusions

Full scale glued GFRP tubes without and with infill were tested in flexure in this study under four-point bending, and compared with its single counterparts. Infilling was done by filling the top cell of the beams was with concrete. Based on the experimental results, the following conclusions can be drawn:

- The behaviour of single and glued hollow beams are governed by premature local buckling while the filled beams failed by compression failure of the top cells except for beam with 4 glued cells which failed by bearing.
- Gluing the cells together provided a higher strength compared to single cells. Up to 150% higher load was measured for glued hollow beams compared to single cell beam. Filling the top cell with concrete resulted in an additional 88% higher load compared to single cell filled beam.
- An increase of 10 – 22 % was observed on the flexural stiffness of the filled glued beams compared to the hollow beams.

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