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Behaviour of column constructed with FRP tubes filled with concrete

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Abstract. This paper investigates the behaviour of Concrete-Filled FRP Tubes (CFFT) as columns. The experimental programme consists of preparing and testing one steel column acting as control sample and three columns made with GFRP. The GFRP tubes were produced by filament winding method where the amount and orientation of the fibres was changed. The tubes had dimensions of 1000x100 mm (length x diameter) and were filled with C25/30 concrete. The columns were tested under compression and the load was applied at a pace rate of 0.5 mm/min. It was found that the GFRP tubes can efficiently confine the concrete and could be used as alternative material to steel tubes. The steel and GFRP samples developed a high level of strain throughout the testing. The GFRP sample with fibre orientation of 90° failed by FRP rupture, whereas the remaining samples failed by buckling. The orientation of the fibres at 90° was more efficient than orientation of fibres at 45° in terms of increasing the ultimate capacity. The GFRP samples displayed lower ultimate capacity compared to steel samples with same wall thickness, but increasing the wall thickness of the GFRP columns increased the ultimate load accordingly.

1 Introduction

Reinforced Concrete (RC) structures require periodic maintenance and monitoring in order to sustain their design life and durability. The structures built in close proximity to a marine environment, bridges and car-parks are under higher risk of corrosion. The risk of corrosion for Concrete Filled Steel Tube (CFST) is significantly higher as the steel tubes are directly exposed and the outside layer of steel is not protected by alkalinity of concrete [1]. Over the past few decades, Fibre Reinforced Polymer (FRP) composites have been used in the construction industry as an alternative to steel reinforcement. FRP materials provide several advantages over steel such as, high tensile strength, light weight, higher corrosion and chemical resistance [2]. Although the initial construction cost of FRP RC members is relatively higher; the total life cycle cost is expected to be less [3].

The behaviour of Concrete Filled FRP Tubes (CFFT) have been investigated in the literature for new columns as alternative to CFST and steel RC columns [4], [8-14]. In this method, FRP tubes are used as formwork to contain the fresh concrete which results in significant cost reduction [5]. However, the primary reason for the use of FRP tubes is confinement of concrete which eliminates the use of longitudinal and transverse reinforcement [6]. The orientation of the fibres in CFFT tubes dictates whether it acts as longitudinal or transverse reinforcement [4]. It is reported that CFFT tubes improve the ductility of columns and increase the shear resistance of the CFFT columns [7,8].

The axial compressive behaviour of CFFT columns have been experimentally investigated over the past two decades [4], [8-14]. FRP tubes produced by the filament winding method, are reported to deliver strength, ductility and large energy absorption [9,10]. Experimental and analytical studies were conducted to develop equations for predicting compressive strength and failure strain of carbon and glass FRP composite tubes [11]. The behaviour of filament-wound CFRP columns built at different angles of winding were experimentally and analytically presented [12]. FRP tubes could be effectively used to confine high and ultra high-strength concrete (HSC and UHSC) and to achieve a highly ductile compressive behaviour [13]. Carbon CFFT columns tested under eccentric loading are less effective in terms of confinement compared to steel helices. However, addition of FRP bars inside the concrete increases the axial load and deformation at maximum loads compared to RC columns [4]. The parametric study on carbon FRP tubes shows that fibre orientation, FRP bar reinforcement ratio and confinement ratio has a direct impact on $P – M$ (axial load – moment) interactions of CFFT columns.

This paper presents the experimental results of the glass CFFT columns tested under axial loading. The experimental variables are the fibre orientation and wall thickness of the FRP tubes. The results are analysed and compared with a steel CFST column. This research is aimed to enhance and reinforce the current understanding of confining concrete compression elements.

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2 Experimental programme

2.1. Details of specimens

The experimental programme consisted of a total of four specimens, three made of glass FRP and one specimen made of steel. The specimens were cylindrical in shape and had dimensions of 1000 x 100 (height x diameter). Table 1 shows the specimen designation and details. The wall thickness of the first three samples were identical whilst the wall thickness of the fourth sample was three times thicker. The GFRP tubes were filament wound with various winding angles with respect to the longitudinal axis of the tube. Fig 1 shows the filament winding process for different orientation of the fibres.

Fig. 1. Filament-winding process for production of GFRP tubes at different angles (a) 45° (b) 90°

Table 1. Details of test specimens.

Sample Designation	Winding angle (°)	Number of layers	Wall thickness (mm)
Steel	N/A	N/A	3.6
FRP-45	45	5	3.6
FRP-90	90	6	3.6
FRP-Mix	10/60/90	14	10.8

2.2. Material properties

2.2.1 Concrete

The concrete used for this research was batched and mixed at Kingston University's concrete laboratory. Natural aggregates with maximum diameter of 10 mm were used in the mix. The compressive strength of the concrete was determined after 28 days, and on the day of testing by testing a series of concrete cubes and cylinders. The characteristic compressive strength of the concrete for all the samples was C25/30 on the day of testing. The tubes were filled in layers and the concrete was well-compacted with a needle vibrator. The concrete mix design is shown in Table 2.

Table 2. Concrete mix design.

Materials	Amount
Cement (kg)	339
Water (kg)	210
Sand (kg)	667
Coarse aggregates (kg)	1184

2.2.2 Steel and GFRP

The circular hollow section used in this experiment was manufactured by Parker Steel. These tubes were cold formed, made with mild steel and with a yield strength of 235 MPa. The type of glass fibre used for production of GFRP tubes was 185 OCV with tensile strength of 11 N per fibre. The fibres were wrapped at different angles on a mandrel (core) with a size of FI 100 mm x 1110 mm. Three types of resin system were mixed at specific ratio for creating the tubes namely, epoxy resin LY 1135, Araldite 917 and Ascc.960. The fibres were wrapped at a speed of 21 m/min. The tubes were cured at a temperature of 80 – 100°, for a duration of 4 – 5 hours.

2.1. Instrumentation and testing procedure

The specimens were instrumented with nine strain gauges and four linear variable differential transformers (LVDTs) to monitor the behaviour of the columns throughout the testing. The strain gauges were mounted on the outer surface of the tubes. Three strain gauges were installed at the mid-point of the tubes and the remaining six strain gauges were installed at the top and bottom end of the tubes. These strain gauges were evenly spaced around the perimeter of the tube and created an angle of 120 degrees. The LVDTs were mounted on the top and bottom of the load-plate in order to monitor the axial deformation of the columns. The instrumentation of the column is shown in Fig 2.

The samples were tested under monotonic axial compression using a Denison 1000 kN compression machine. The top and bottom ends of the columns were capped with high-strength steel plates, in order to uniformly distribute the load and prevent localised crushing. The application of the load was displacement-controlled with a speed of 0.5 mm/min. The data was recorded at a rate of 10 data/sec using data loggers. Fig 3 shows the test setup for testing the columns.

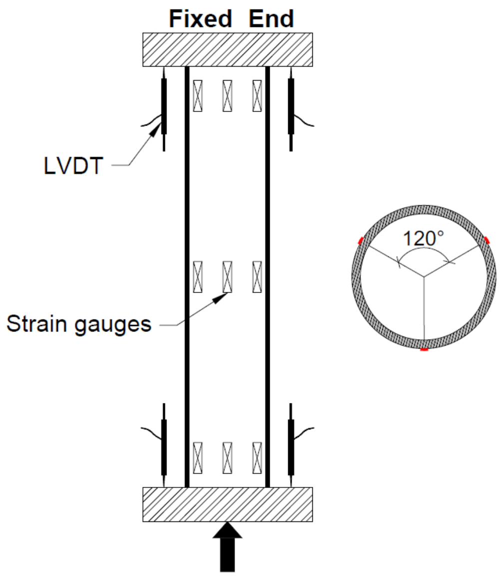

Fig. 2. Column instrumentation.

Fig. 3. Test setup for testing columns under compression.

3 Test results and discussion

3.1. Load-displacement

The load-displacement graph for the steel and GFRP samples is presented in Fig 4. At the initial stages of the loading, the columns adjusted in the testing frame which is observable from the initial negative curvature in the graph.

The steel sample displayed an elastic-plastic behaviour throughout the testing. This sample showed a linear behaviour from the start of the loading until reaching its obvious plastic behaviour at a load over 750 kN. The yielding occurred at a load of 774 kN with approximately 7mm axial displacement. A sudden drop in the load could be observed after the yield point. The capacity of this column started to gradually decrease when it reached its plastic limit.

The FRP-45 column displayed a very similar behaviour to the steel column. This sample reached its maximum load at a displacement of around 11 mm during its linear stage. Although, normally, FRP materials only display linear behaviour, here, due to the composite action with the concrete and the buckling effect, non-linear behaviour is evident above 330 kN as shown in Fig 4. This sample maintained a significant amount of its peak-load at the beginning of the plastic stage.

The performance of the FRP-90 column was relatively different from the steel and FR-45 sample. It displayed a higher degree of deformability throughout the testing. The FRP-90 column displayed a linear behaviour and the failure initiated at a load of 618 kN with a displacement of 26 mm. The failure was relatively brittle with rupture of GFRP walls of the tube and no buckling was observed.

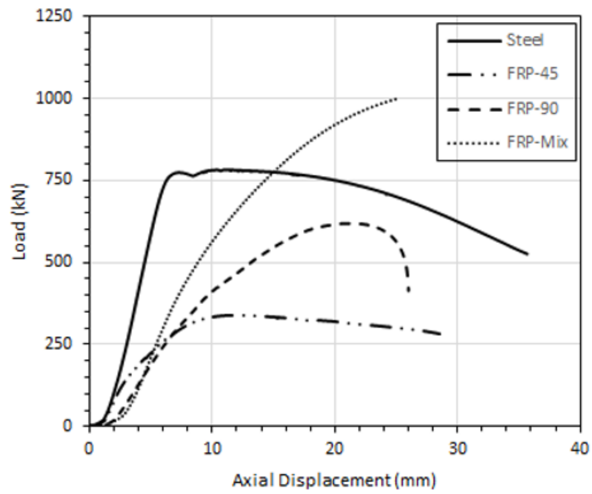

Fig. 4. Load vs axial displacement for all samples.

The FRP-Mix sample which had a wall thickness of 10.8 mm displayed the highest maximum load and exceeded the capacity of the testing frame. A linear behaviour up to a load of 250 kN is observable from Fig 4. However, the slope of the curve is getting gentler which points towards failure of the column. The column is expected to probably reach to 10% of its current maximum load at the failure point. The column was intact after the testing and no sign of damage was visible by visual inspection.

3.2. Observed failure modes

The failure modes for the steel and GFRP columns are shown in Fig 5. Two types of failure modes were observed for the tested columns; buckling and rupture of

FRP fibres. The steel and FRP-45 samples failed by mid-span buckling. Both of the columns maintained a significant amount of load with large amounts of deformability. The FRP-90 sample failed by rupture of FRP fibres at the mid-span. The column failed abruptly and split into two pieces.

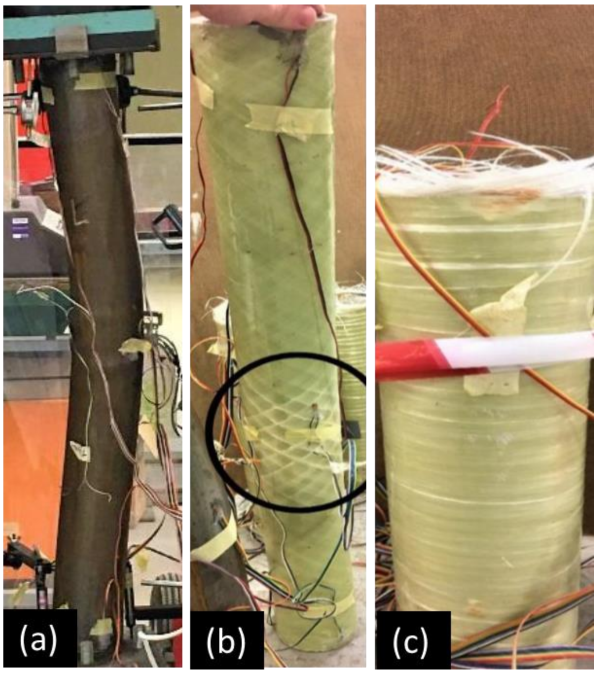

Fig. 5. Failure mode of all samples (a) steel (b) FRP-45 (c) FRP-90.

3.3. Ultimate load

The ultimate failure load for all the samples is shown in Fig 6. Although, the FRP-45 and the FRP-90 sample had the same wall thickness, there was a significant variation in their respective ultimate load. The FRP-90 sample was more effective in confining the concrete and displayed almost double the load compared to the FRP-45 sample. It is evident that the fibre orientation (winding angle) plays a significant role in the failure mode and ultimate load of CFFT. The GFRP tubes with similar wall thickness to the steel tube, displayed a lower ultimate load. The ultimate capacity of the FRP-90 sample was about 21% lower than the steel sample. The GFRP-Mix sample, which had a wall thickness of three times higher than steel sample, displayed the highest ultimate load which reached loads of in excess of 1000 kN.

The efficiency of GFRP tubes with identical cross-sectional area to steel tubes is relatively low. The CFST and CFFT tubes displayed significantly higher capacity compared to normal RC columns; therefore, the CFFT tubes could be used as an alternative to RC columns. Future design of such elements have to include consideration for appropriate fire protection, such as intumescent paint or encasing them in fire resistant materials. By increasing the wall thickness of the GFRP tubes, similar behaviour to steel tubes in terms of ultimate load and ductility could be achieved. The GFRP tubes have the potential to be used as alternative to steel tubes in corrosive environments.

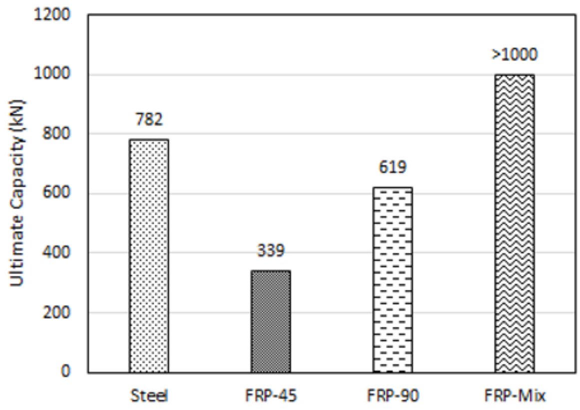

Fig. 6. Ultimate load for all samples.

4 Conclusions

This paper has presented the experimental results of testing CFST and CFFT tubes in compression. The influence of the fibre orientation and the wall thickness of the GFRP was investigated in this study. The following conclusions can be drawn:

1. The GFRP tubes produced by the filament winding method, could be used as an alternative material to steel tubes. The GFRP tubes with the same wall thickness to steel tubes displayed a lower ultimate load but achieved a substantial level of deformability. The difference in ultimate load of the GFRP and steel sample was around 21%.
2. The orientation of the fibre (winding angle) in GFRP tubes dictated the ultimate load and failure type. The capacity of FRP-90 sample was approximately two times higher than the FRP-45 sample. The orientation of fibres at 90° depicts stirrups in RC columns which successfully confine the concrete.
3. By increasing the wall thickness of the GFRP tubes, the ultimate load was increased accordingly. The FRP-Mix sample exhibited higher load and greater level of deformability throughout testing.

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