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Characterisation of the mechanical properties of pultruded fibre-reinforced polymer tube

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ABSTRACT

This paper presents an investigation on the mechanical properties of pultruded fibre-reinforced polymer (FRP) tube. Unlike typical FRP tube, the investigated tube has additional ±45° glass fibre reinforcement making it suitable for several structural applications. Tests on coupons and full-scale specimens were undertaken to determine the mechanical properties of the tube. Moreover, a finite element (FE) analysis was carried to simulate the compressive and flexural behaviours of full-scale specimen. Experimental results showed that coupon and full-scale specimens exhibited linearly elastic up to failure. The maximum variation of the experimental data is up to 8% indicating that the reproducibility of the test is quite reasonable and that the experimental procedures were conducted within the acceptable margin of error. The comparison between the compressive and flexural peak load values obtained experiment and FE methods revealed that their difference is less than 5%. Furthermore, the compressive and flexure failure modes obtained from the experiment were fairly simulated in the FE analysis. These indicated that FE analysis predicted reasonably the actual compressive and flexural behaviours of the pultruded FRP tube.

1. Introduction

Fibre-reinforced polymer (FRP) composites are meeting an increasing demand as construction material due to their excellent properties including light weight, high specific strength, corrosion resistance, and low maintenance cost. These characteristics made them a suitable alternative in replacing traditional materials such as concrete, steel, and timber in various applications in construction industry. FRP composites can be made by pultrusion, a mechanised process for producing continuous sections. The process consists of pulling impregnated filaments together with a mat or fabric through a heated die [1]. This method provided an advantage in terms of product consistency and economy in manufacturing closed-section profiles including FRP composite tubes [2].

Pultruded FRP tubes have been applied as an energy absorbing component in a vehicle as they collapsed in a progressive and controlled manner which results in high specific absorption in the event of crash [3,4]. These tubes have been also used as a structural decking component in bridges [5–11]. In Australia, pultruded FRP tubes were adopted in piling [12] and electrical transmission [13] applications. Fig. 1 shows the application of a 100 mm square pultruded tubes as power pole cross-arms. The impact behaviour and residual properties of these tubes were reported in previous studies conducted by [14,15] and [16], respectively. Aside from the beneficial properties of fibre composites mentioned earlier, these FRP cross-arms provide additional protective layer of insulation and do not sustain a flame thereby virtually eliminating pole top fires making them suitable as structural component in electrical poles [13]. A significant feature of this pultrusion tube is the presence of ±45° glass fibre reinforcement in addition to the main fibres on the tube provides a stronger structural resistance along the transverse direction. Unlike typical pultrusion tubes, this unique property makes this tube suitable for several structural applications particularly as hollow FRP tube. Although direct comparison of the results was not performed on the structural performance of the tubes with and without additional ±45° glass fibre reinforcement, it is however conclusive that the overall structural performance of the former will be much better than the latter. This component can be subjected by different structural loadings (i.e., compressive and flexural) and therefore an investigation on its mechanical behaviour is significant on this type of application to ensure that it can sustain these loading conditions.

This paper presents the characterisation of the mechanical properties of a 100 mm square pultruded tube used as an FRP power pole cross-arm. The main objective of this work is to investigate the behaviour of the tube under compressive and flexural

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Fig. 1. Pultruded FRP tube as power pole cross-arms [13].

loadings. Tests on coupons and full-scale specimens were undertaken to determine the mechanical properties of the tube. The compressive, tensile, and flexural tests on coupons were conducted following the standards defined in ASTM: D695, ISO 527 [17], and ISO 14125 [18]; respectively. On the other hand, the tests on full-scale specimen were performed using the procedures available in previous studies. The details of these tests are presented in the next sections. Aside from these tests, a finite element analysis (FEA) was carried to simulate the compressive and flexural behaviours of full-scale specimen. The results obtained from the experiment were compared with those of FEA.

2. Material and experimental methods

2.1. Material

The square composite tube (Fig. 2) investigated is manufactured by Wagners Composite Fibre Technology (WCFT) based in Toowoomba, Australia. It is made from vinyl ester resin with E-glass fibre reinforcement and manufactured using the process of pultrusion. The mass density of the pultruded tube is 1970 kg/mm^3. Table 1 displays the section properties of the pultruded tube. Burnout test as per ISO 1172 [19] conducted on the coupons taken from the tube showed an overall glass content of 76%. Starting from the exterior of the wall, the stacking sequence of the plies is in the form of [0°/+45°/0°/−45°/0°/−45°/0°/+45°/0°], where the 0° direction coincides with the longitudinal axis of the tube. The presence of ±45° glass fibre reinforcement provided a stronger performance making this tube suitable for structural application.

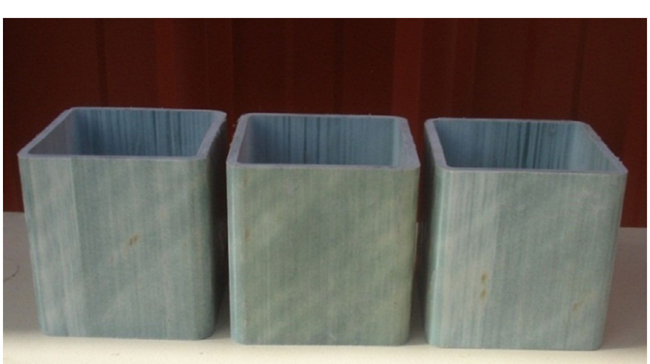

Fig. 2. Oblique view of the pultruded FRP tube.

Table 1
Section properties of the 100 mm square pultruded tube[a].

Properties	Value
Nominal depth, d (mm)	100
Nominal width, b (mm)	100
Nominal thickness, t (mm)	5.25
Internal radius, r_i (mm)	4.75
External radius, r_e (mm)	10
Gross area (mm^2)	1932
Moment of inertia, I_x (10^6 mm^4)	2.86
Moment of inertia, I_y (10^6 mm^4)	2.86

[a] WCFT product specification.

2.2. Coupon tests

The experimental characterisation of the coupons has been performed using compressive, tensile, and flexural tests. The results obtained from coupon tests provided the property values used in the FE analysis. Table 2 shows the details of the specimens and the standards used in the coupon tests.

The compressive test was conducted using the procedure defined in ASTM: D695. The test was performed in the MTS 810 Servo-hydraulic testing machine. Compressive test coupons with nominal width of 12.5 mm were loaded using an end-loaded, side supported (gripping pressure of 8.5 MPa), with an unsupported length of 20 mm. A total of 5 specimens were tested for each tube in which at least one was taken from its four sides. Slicing of the coupons was carefully done by using a wet saw machine. The test was conducted at a loading rate of 1.5 mm/min until failure. Two of the 5 specimens were instrumented by a 6 mm long uniaxial strain gage attached on the 20 mm unsupported length using an epoxy adhesive. Recording of data for compressive test, as well as the flexural and tensile tests, was generated using Systems 5000 data logger. Fig. 3a illustrates the test set-up used in performing the compressive test.

The tensile test was performed in a 100 kN capacity MTS Insight Electro-mechanical testing machine using a crosshead speed of 2 mm/min. The test was conducted in accordance with standard ISO 527 [17]. A total of 5 coupons were cut from each tube using a wet saw machine and tested. A 50 mm long gripping tabs (same material as the tested specimens) were attached to both ends of the specimen using Techniglue CA epoxy adhesive. Two of the specimens were instrumented by a 20 mm gage length uniaxial strain gage. An extensometer was also provided at the gauge length to measure the longitudinal and transverse deformations for determination of the Poisson's ratio. The experimental set-up used in conducting the tensile test is shown in Fig. 3b.

The specimen was tested under three-point static bending using the standard procedure defined in ISO 14125 [18]. Similar with the compressive and tensile tests specimens, a total of 5 replicates were tested. The test was performed in a 10 kN capacity MTS Insight Electro-mechanical testing machine with a loading rate of 3 mm/min until failure. A span l_s of 84 mm was selected giving a span to depth ratio of 16:1, according to the standard. The specimen was held and pressed, respectively, by two fixed supports and loading steel cylinders having a diameter of 10 mm. Fig. 3c demonstrates the test set-up used in performing the flexural test.

2.3. Full-scale tests

There is currently no standard method in performing compressive test on composite tubes. As a result, the procedures made available from the literature were considered as a guide in conducting the test. Specifically, the method adopted by Guess et al.