EXPERIMENTAL STUDY OF HOLLOW FRP SECTIONS UNDER BENDING

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ABSTRACT
This paper presents an experimental study on hollow, fibre-reinforced polymer (FRP) sections subjected to bending. This study is part of an ongoing project, with the eventual goal being to use the sections as a bridge decking material. There are many advantages that FRP decking has over traditional materials, one being its corrosion resistant properties, which are especially beneficial in winter conditions where de-icing salts are necessary. As the popularity of FRP decking has grown over the past two decades, manufacturers have started producing various FRP sections and profiles that are available "off-the-shelf". The experimental testing materials consist of prefabricated, square, hollow structural glass FRP (GFRP) sections with an edge width of 100 mm and wall thickness 6 mm. The specimens are of varying lengths between 1000 mm and 3000 mm. In this paper, the behaviour of individual sections under four-point bending, along with load-deflection and load strain responses are presented; the outcome of this testing will determine if the specimens are viable for use as a bridge decking material.

KEYWORDS
GFRP, bending, bridge deck, experimental, hollow structural section.

INTRODUCTION
Bridge decking has traditionally been made from materials such as concrete or wood, and while structurally adequate, they face degradation over time given the conditions they are subjected to. In winter conditions, de-icing salts are commonly used and are particularly harsh on steel reinforced concrete decking slabs. This presents a significant problem in Canada as de-icing salts can be required for up to six months at a time in certain areas. The corrosion and subsequent degradation of reinforced slabs comes with increased need for service and replacement. A proposed alternative that would provide more durability, therefore requiring less maintenance, is the use of fibre-reinforced polymer (FRP) composites for bridge decking. They can provide similar material properties to steel or concrete but are resistant to the environmental factors that degrade those materials.

There have been various studies done on FRP decking that show its practicality. FRP tube structures have been tested as decking and have been successful handling fatigue conditions normally encountered on highways with little strength degradation (Kumar et al. 2003). Previous studies have shown that all-FRP decking using sandwich-panel type configurations are effective as bridge decking for which components can be purchased off the shelf (Bank 2006). Studies done by Williams et al. (1999) and Hou et al. (2018) have shown that FRP plates attached to FRP hollow structural sections are viable as well. Another method used to employ the beneficial properties of FRP in bridge decking is using it compositely with concrete as structural, stay-in-place (SIP) formwork. Overall, FRP SIP forms perform well, even under circumstances such as fatigue loading (Nelson et al. 2014) and when exposed to adverse conditions (Boles et al. 2015). Their versatility has led to implementation in various rehabilitation and new construction projects (Nelson et al. 2014). Currently, there is limited test data on the square, hollow sections solely used as modular components of bridge decking. This paper will examine the viability of off-the-shelf FRP sections for this application based on their response to bending.

EXPERIMENTAL PROGRAM

Material Properties

The specimens used in this study are prefabricated, pultruded, hollow-square GFRP tubes with an epoxy matrix. The tubes have dimensions of 100 x 100 x 6 mm (height, width, and thickness, respectively) and are 3000 mm long. Specimens were cut to lengths of 1000 and 2000 mm to be tested, and a 3000 mm long specimen was tested as well. An example of a specimen used for testing is shown in Figure 1a.

Through an ignition loss test, the tube walls were found to be comprised of a midsection with unidirectional fibres at 0° longitudinally, with a randomly oriented chopped fibre mat on each face. The results of the ignition loss test are presented in Figure 1b. The fibre weight fraction was found to be 66% and the fibre volume fraction was found to be 46%, based on known glass fibre properties and the results of the ignition loss testing (McCracken and Sadeghian 2018).

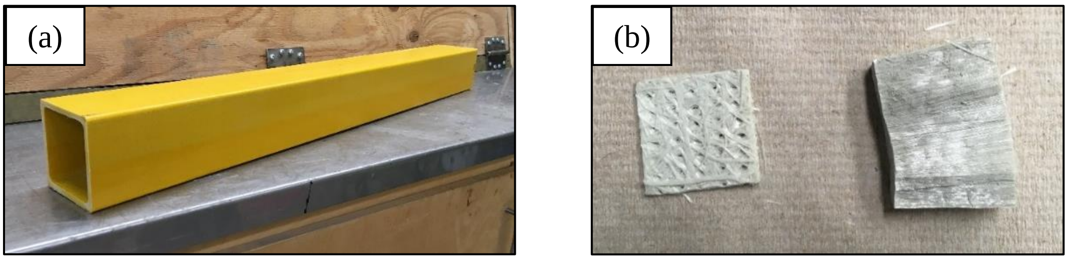

Figure 1: (a) 1000 mm specimen used for testing; (b) fibre components of specimen.

Material properties were provided by the manufacturer for the specimens, but these properties seemed somewhat inaccurate when experimental test results were compared to a mathematical model based on conventional beam theory. Tension testing according to ASTM D3039 was completed on sections cut from the specimens (ASTM 2017). Tensile strength was found to be 600 MPa which is significantly different than the 230 MPa reported by the manufacturer. Likewise, the tensile modulus was found to be 35.2 GPa rather than the reported 24.2 GPa (both properties for the lengthwise direction of the tubes) (Hangzhou Wind Composite Co. Ltd. 2018). Testing will be completed to verify the reported lengthwise compressive strength and modulus of 280 MPa and 21 GPa (Hangzhou Wind Composite Co. Ltd. 2018). These tests will be done according to ASTM D3410 (ASTM 2016).

Test Matrix

Testing of different lengths of individual tubes gave insight to their behaviour when loaded. The tubes, of lengths 1000, 2000, and 3000 mm, were subjected to four-point bending. The lengths were chosen to reflect common girder spacings in Canadian highway bridges. The spacing between loading points was varied slightly between tests. In total, five single-tube specimens were tested. The test matrix is given in Table 1.

Table 1: Test matrix.

No.	Specimen I.D.	Length (mm)	Percent Spacing Between Loading Points
1	HSS1-01	1000	33%
2	HSS2-01	2000	20%
3	HSS2-02	2000	20%
4	HSS3-01	3000	20%
5	HSS1-02	1000	20%

Test Setup and Instrumentation

When conducting the four-point bending tests, the tubes were placed onto roller-pin supports and were loaded through a steel hollow structural section supported by steel cylinders and plates. When placed on the supports, an overhang of 50 mm was simulated on each end, making the effective length of each tube 100 mm less than the actual length. Axial strain gauges were attached to the tension and compression faces, and a string potentiometer was used to measure deflection. The test setup is shown in Figure 2.

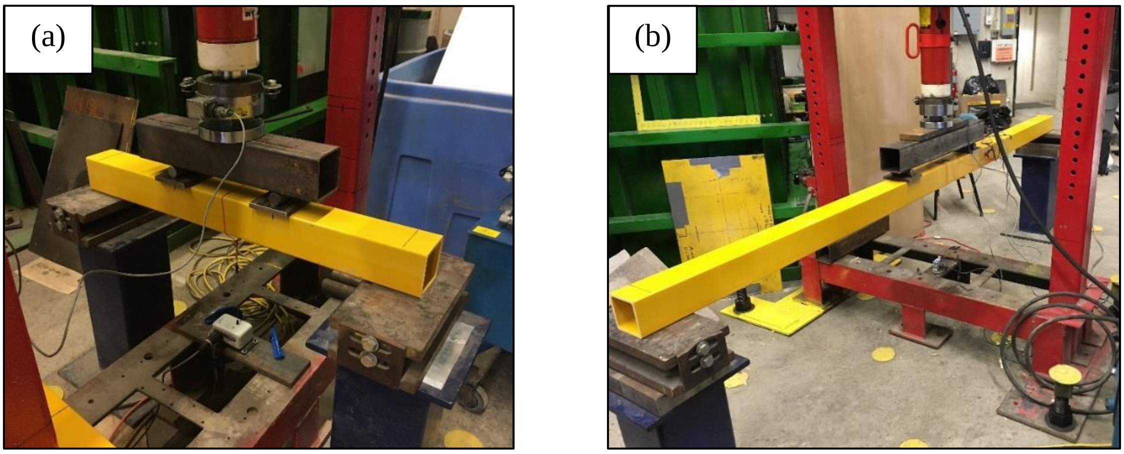

Figure 2: Experimental test setup (a) HSS1-01; (b) HSS3-01.

RESULTS AND DISCUSSION

Each tube was subjected to four-point bending and loaded at a rate of 2 mm/minute until failure. The tubes all failed in a similar manner, that being a very sudden, shear-type failure that originated in the corners of the tubes. While a bending failure was expected, it is hypothesized that due to the pultrusion process, the corners of the sections are naturally weaker points for shear in the beam. If the corners were to be somehow strengthened or the percent length between loads were increased, it is more likely that a true bending failure would occur. Images of beams after failure can be seen in Figure 3.

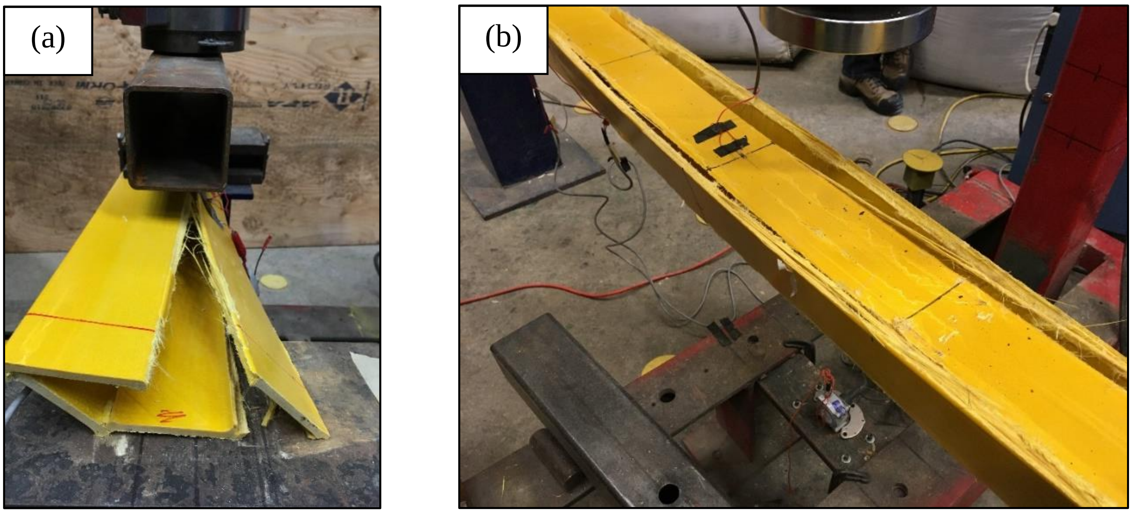

Figure 3: Failure of tubes from four-point bending test (a) HSS1-02; (b) HSS3-01.

From the four-point beam testing, the main responses observed were load-deflection and load-strain. For all beam tests, these results follow a consistent, linear trend. Sample graphs for load-deflection and load-strain response can be seen in Figure 4 (below).

Regarding practicality as a bridge decking material, the 1000 mm tubes have adequate stiffness, but their length is not practical for use in highway bridge decking; the 2000 mm and 3000 mm tubes had considerable deflections and would need to be stiffer to be considered useful. A proposed solution for this is to pour a minimally reinforced concrete slab over top of the tubes. This would, theoretically, limit the deflections by increasing overall stiffness, as well as allow for more control over the sudden nature of failure. This proposed configuration is not unlike an FRP stay-in-place form and will be tested in the future.

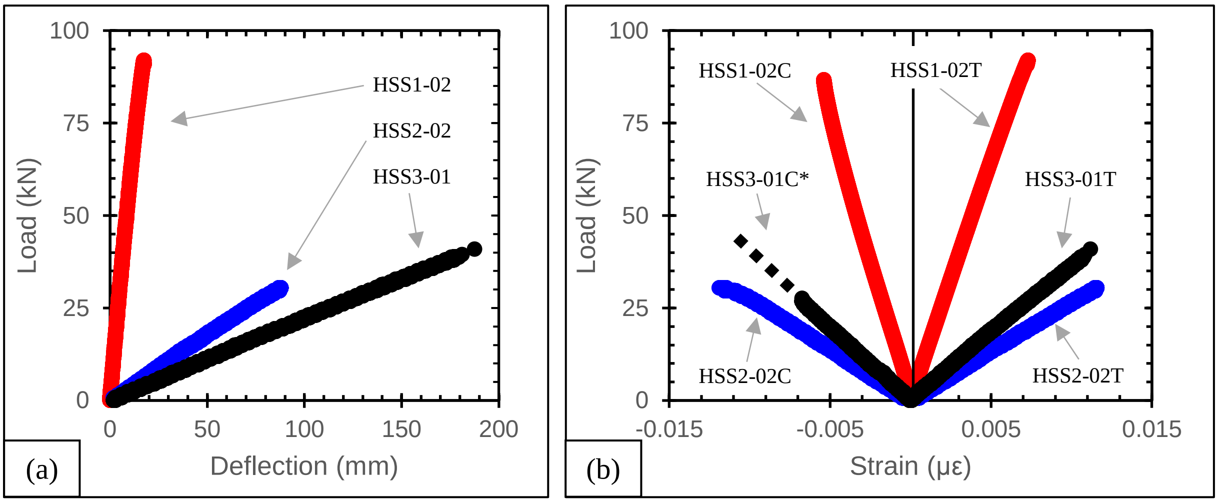

Figure 4: Results from four-point bending tests (a) load-deflection response; (b) load-strain response (T and C refer to tension and compression, respectively).
* Strain gauge for HSS3-01C failed during testing, dotted line shows expected strain response.

CONCLUSIONS

Four-point bending tests were conducted on GFRP hollow structural sections of varying lengths to examine behaviour as a part of an ongoing study to assess their viability as a bridge decking material. All tubes behaved similarly and failed suddenly, due to shear. While the strength of the tubes is generally adequate, their flexibility is an issue that hinders their ability to be used as the sole material in a modular highway bridge deck. A proposed solution that will be tested is creating a composite deck out of the GFRP tubes and a concrete slab.

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