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DEVELOPMENT OF A TEST METHOD FOR STRAIN RATE TESTING OF FLAX FRPS IN DIRECT TENSION

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Abstract: Materials typically exhibit higher strength and stiffness when loaded under a high strain rate. Therefore, to accurately predict impact response of structures, it is important to understand the effect of strain rate on the mechanical behaviour of constituent materials. In this study, a test method is developed to test the effect of strain rate on the tensile behaviour of flax fibre-reinforced polymers (FFRPs). A total of 20 test specimens will be prepared for these tests, the main parameter being the thickness of the FFRP (one, two or three layers of bidirectional flax fabric). The test method was developed because the available equipment was unable to test at high strain rates. The new test method uses a drop weight to break a tensile specimen. The top of the test specimen is securely connected to a load cell and a test frame. The bottom of the test specimen is connected to a drop weight. To achieve varying displacement rates, the weight and drop height can be adjusted. The system is currently being verified by testing aluminum specimens with well known static properties. Once verified, the system will be calibrated by testing additional tension coupons with a variety of drop weights to determine what weight is required to achieve each desired displacement rate. This research is in progress and more results will be available at the time of the conference.

1 INTRODUCTION

Flax fibre-reinforced polymers (FFRPs) are gaining popularity as a potential natural alternative to synthetic fibre-reinforced polymers (FRPs). In recent studies they have been used as face materials for sandwich panels tested under both axial and flexural loading (Betts et al. 2017a; Codyre et al. 2016; Mak et al. 2015). Sandwich panels with FFRP faces have also been tested under impact loading by Betts et al. (2017b). The purpose of this study is to determine the properties of FFRPs under high strain rate tensile loading in order to accurately model the behaviour of the sandwich panels during an impact event. Some studies have tested natural FRPs, specifically hemp FRPs, and hybrid natural-synthetic FRPs at different strain rates (Fotouh et al. 2014; Kim et al. 2012) but there is a gap in the research regarding FFRPs and the effect of specimen thickness on the high-strain rate behaviour of natural FRPs.

As presented in the study by Betts et al. (2017a), the same FFRPs have been tested under quasi-static tensile loading. As materials often exhibit higher strength and stiffness under high strain rate loading, it is important to understand the response of FFRPs to these types of loads to properly model sandwich panels with FFRP faces under impact loading. Additionally, it is important to have a test procedure able to determine the high rate tensile properties of FFRPs. As a part of this study a high strain rate tensile test procedure was developed and is currently being verified by testing aluminum specimens. FFRP specimens will be tested using this proposed test method and the results will be compared with the measured static properties to determine the effect of strain rate on the mechanical properties of FFRPs.

2 PROPOSED TEST METHOD

To test specimens at a high strain rate, a drop weight test was developed. The principle of the test is that a weight is dropped from a set height for each test specimen. The weight impacts a plate which then transfers the force into the specimen through a steel rod. A strain gauge on each specimen will be used to determine the strain rate of the test for each given weight and height. To change the strain rate, the drop weight or drop height can be adjusted.

The test set-up is shown in Figure 1. A steel hollow structural section (HSS) beam was clamped to two secure supports. A 45 kN load cell was connected to the HSS beam with a threaded rod and a tensile grip was hung from the bottom of the load cell. The specimen was placed in the grips and a two-metre long steel guide rod was attached to the bottom tensile grip. It is important that the stiffness of both the HSS crosshead beam and the steel guide rod are high enough such that any deflection in the test set-up is negligible compared to the action of the test specimen. An impact plate was placed at the bottom of the two-metre steel rod to stop the drop weight and in turn break the tensile specimen. A strain gauge is required at the centre of each side of the test specimen.

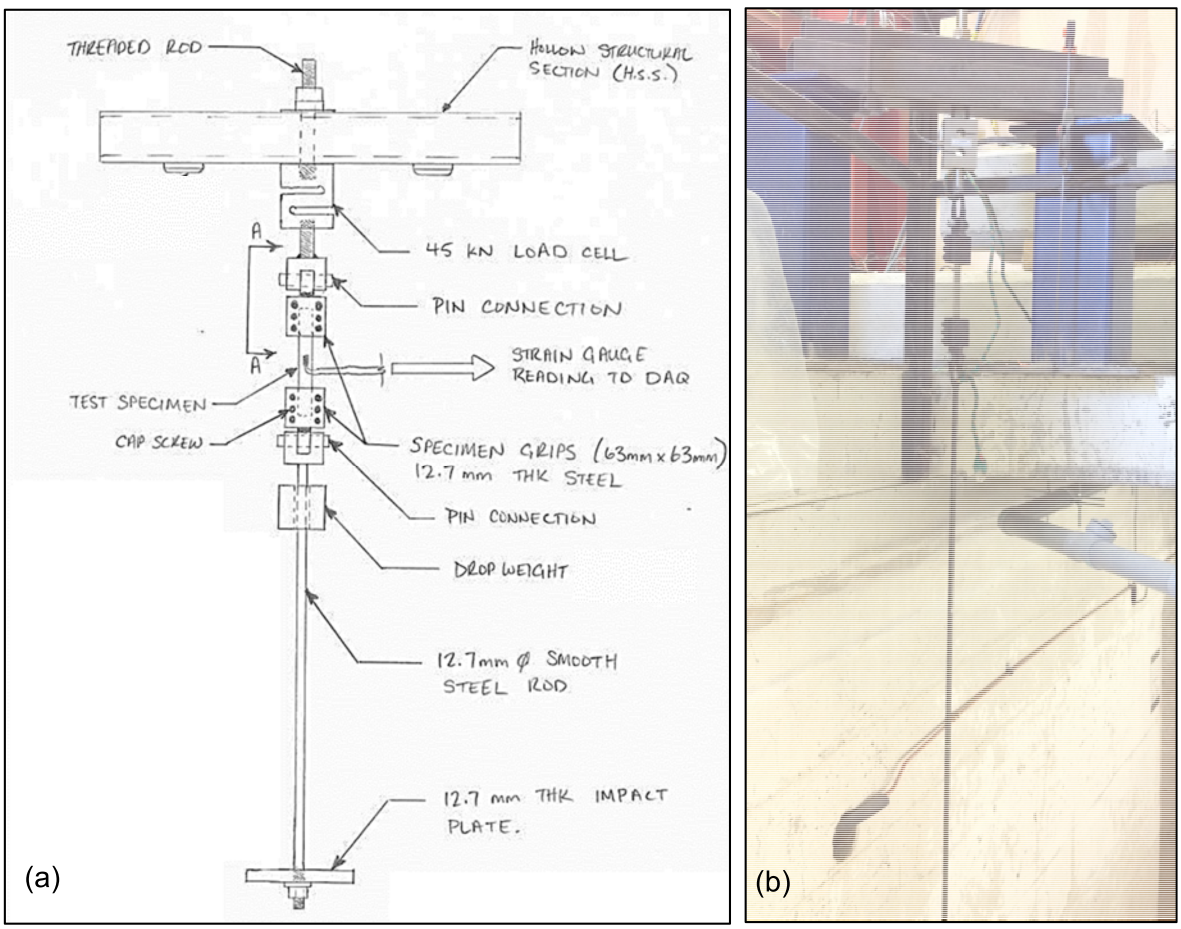

Figure 1: Test set-up: (a) drawing and (b) a photo of test fixture

To verify the test method, five aluminum specimens, as shown in Figure 2a, were prepared according to ASTM E8 (ASTM 2016). The drop height required to break the aluminum specimens was determined in previous tests. The stress-strain results of the tests are shown in Figure 2b. This figure shows that the results are consistent graphically.

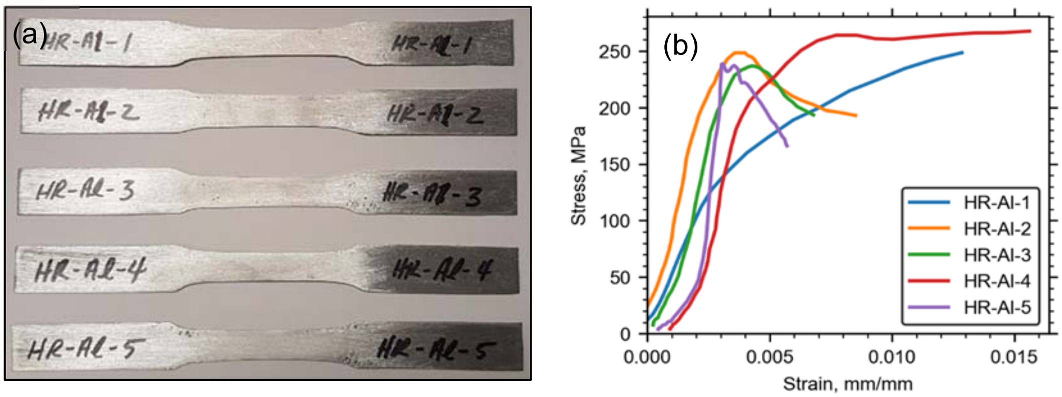

Figure 2: Test method verification (a) specimens (b) stress-strain results of HR-Al test specimens

The aluminum specimens were tested using a drop weight of 2.353 kilograms from a height of 1220 mm. The data from the load cell and strain gauge were sampled at 50 kHz and the test results are presented in Figure 2b.

Upon examination of the load and strain data, it was evident that there was a time lag between the data readings. This time lag is caused by the stress wave that travels through the system which reaches the strain gauge before the load cell. In the aluminum tests, the time lag varied from 0.002 seconds to 0.003 seconds. As shown in Figure 3, the strain data for each test was shifted to match the load data to account for the time lag between measurements.

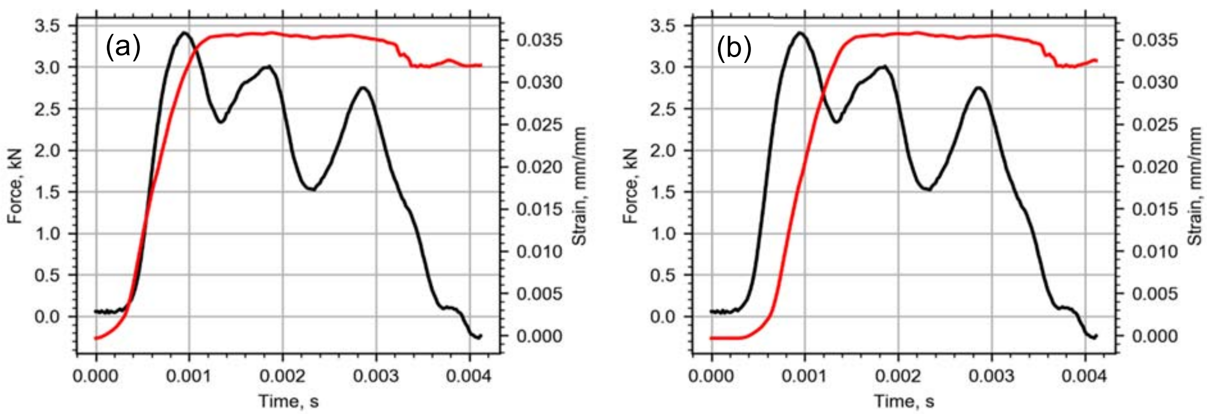

Figure 3: Load and strain data for specimen HR-Al-1 (a) as measured and (b) adjusted for time lag between measurements

The modulus of elasticity (Young's modulus) and the strain rate of the tests were both determined by finding the slopes of the first linear portions of the plots presented in Figure 4. These slopes were calculated by fitting a linear trendline to the data between the start and end of the linear portion of the plots.

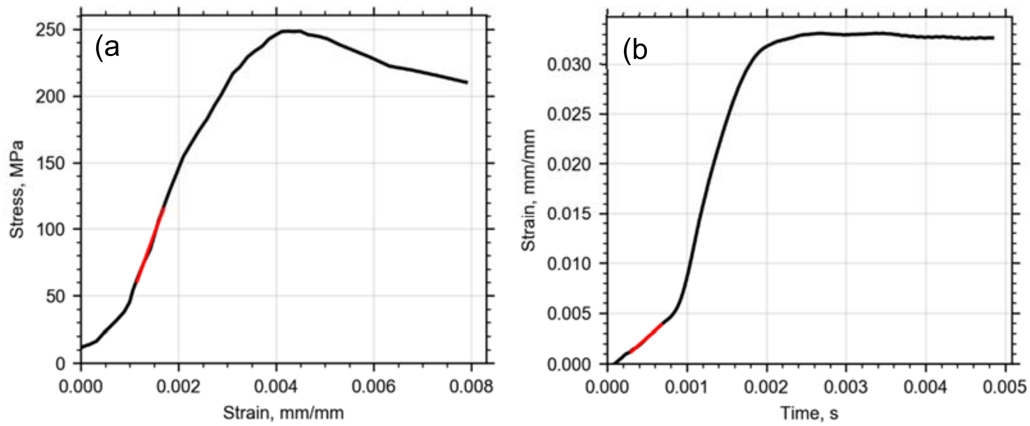

Figure 4: Determination of (a) Young's modulus and (b) strain rate

Table 1 shows the results of the aluminum specimens. The table shows that the results of specimen numbers 2, 3 and 4 are consistent. However, the modulus and strain rate measurements for specimens 1 and 5 are not consistent with the other measurements. However, it should be noted that the measured tensile strength for all the specimens is within the expected range for the aluminum, which is promising. This shows that the test method is worth further investigation and warrants further investigation and more development.

Table 1: Aluminum specimen results

Specimen	Young's Modulus (GPa)	Tensile Strength (MPa)	Calculated Strain Rate (s^{-1})
HR-Al-1	42.4	281.1	56.2
HR-Al-2 *	102.2	248.5	6.8
HR-Al-3	100.4	245.5	7.1
HR-Al-4	96.9	267.5	5.8
HR-Al-5	206.6	245.4	3.9
Average	109.7	257.6	16.0
St. Dev.	59.6	16.0	22.5

* Specimen did not rupture

There is the potential that the connections between the specimen grips and the impact rod and the load cell aren't rigid enough and that the stress wave travelling through the system loses energy in the movement of these connections. Future tests will include the implementation of more rigid connections between the specimen grips and the rest of the system. Another source of error in this series of tests is that only one strain gauge was used on each specimen. When the test method has been refined, future test specimens will include a strain gauge at the centre of each side of the specimen and the average of the results will be used.

3 EXPERIMENTAL PROGRAM

3.1 Test Matrix

As a part of this study, 15 specimens will be tested under high-rate tensile testing using the proposed test procedure. The main test parameter is specimen thickness: one, two or three layers of bidirectional flax fabric. The test matrix is presented in Table 2.

Table 2: Test matrix

Specimen Group	Number of Specimens	Number of Flax Layers
T-HR-1FL	5	1
T-HR-2FL	5	2
T-HR-3FL	5	3

3.2 Specimen Fabrication

The FFRP specimens were cut from the facing of a sandwich panel tested previously by Betts et al. (2017). A sample sandwich panel and the location of the specimens cut from each sandwich panels are shown in Figure 5.

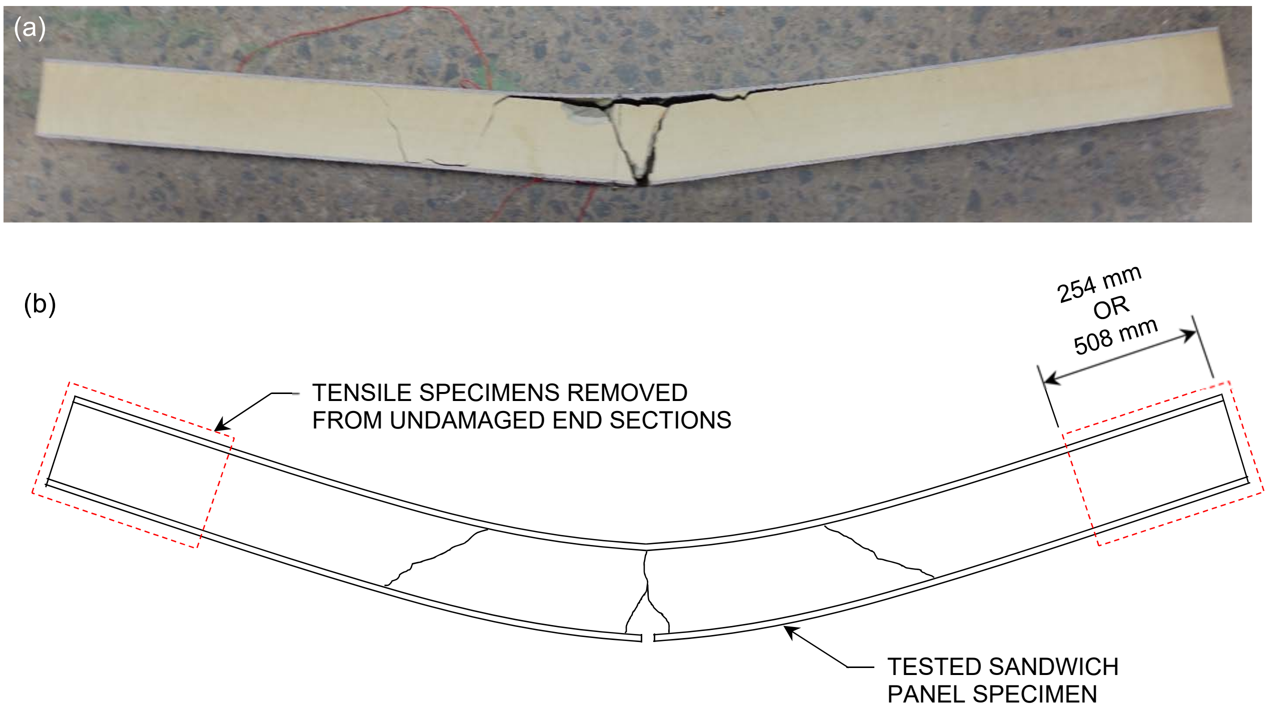

Figure 5: Specimen extraction: (a) sandwich panel and; (b) location of tensile specimen removal from sandwich panels tested by Betts et al. (2017)

The procedure of cutting the tensile specimens from the sandwich panel started by cutting a 254 mm section off of the end of the panel using a band saw as shown. The band saw was then used again to cut away most of the foam core from each face. The foam remaining on the FFRP sheet was removed carefully with a scraper and sandpaper. The FFRP sheet was then cut into 25.4 mm wide strips and 63.5 mm tabs were adhered to each end of the specimens using the same bio-based epoxy used to fabricate the original sandwich panels. A strain gauge was then applied to the centre of each side of the specimens. The specimens will be tested upon verification of the test method.

4 CONCLUSIONS

As a part of this study, a test procedure was developed to test flax fibre-reinforced polymers (FFRPs) in tension at high strain rates. The test procedure consists of a drop weight impact test applied to tensile specimens. To verify the test procedure a set of aluminum specimens were tested. The results of three of these specimens were consistent, however two of the specimens showed inconsistent results. These tests showed that the test procedure is worth further investigation.

A potential source of error is the connections between the specimen grips and the rest of the system. In future tests, a more rigid connection will be implemented to mitigate the loss of stress wave energy in the connection. Future verification work also includes the comparison of test data with quasi-static tensile tests performed on additional aluminum test specimens. Additionally, to improve the accuracy of the strain measurements on the next series of aluminum specimens, two strain gauges will be used on each specimen: one at the centre of each side.

After the test set-up has been verified, it will be used to test FFRP specimens. This data is invaluable in developing a model to predict the behaviour of structural systems containing FFRPs under dynamic loading. The verification and validation of the test method, as well as the results of the FFRP tests will be available at the time of the conference.

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