The 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-12)
& The 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures (APFIS-2015)
Joint Conference, 14-16 December 2015, Nanjing, China

TESTING AND CHARACTERIZATION OF PULTRUDED GLASS FIBER REINFORCED POLYMER (GFRP) BEAMS

Majid Muttashar[1, 2], Warna Karunasena[1], Allan Manalo[1], and Weena Lokuge[1]

[1] Centre of Excellence in Engineered Fibre Composites (CEEFC), Faculty of Health, Engineering and Sciences, School of Civil Engineering and Surveying, University of Southern Queensland (USQ), Toowoomba, Queensland 4350, Australia.

[2] Civil Engineering Department, College of Engineering, University of Thi Qar, Iraq.
Email: majid.alzaidy@gmail.com; karu.karunasena@usq.edu.au; allan.manalo@usq.edu.au; weena.lokuge@usq.edu.au
(Corresponding Author: Mobile +61415562821)

Keywords: Characterization, GFRP beams, Elastic properties, Full scale test

ABSTRACT

Elastic properties of the fiber reinforced polymer (FRP) composite represent a significant effect on the structural behaviour of this material. Therefore, it is important to use an accurate method to determine these properties as the behaviour is often governed by deflection rather than strength. In this study, full size pultruded glass FRP (GFRP) beams were used to determine the elastic properties using static four-point bending with different shear span to depth (a/d) ratios. Two different methods -back calculation and simultaneous - were then employed to evaluate the flexural modulus and shear stiffness and were compared with the results of the test using coupon specimens. The results indicate that the elastic properties determined from full scale test using back calculation method can reliably predict the load - deflection behaviour of the pultruded GFRP beams.

1 INTRODUCTION

Fibre reinforced polymers (FRP) have been used widely in structural components of bridge systems, crosswalk and structures exposed to corrosive environment due to their excellent strength and weight characteristics, corrosion resistance and environmental durability [1]. In addition to these advantages, the process of producing composite sections allows the designer to specify different material properties for different parts of the cross section [2]. Nevertheless, the use of these advanced materials in structural applications is constrained due to limited knowledge on their material properties and structural behaviour. Therefore it is of paramount importance to investigate the properties of pultruded FRP sections so that they can be broadly utilised in structural applications.

Several researches reported the effective mechanical properties of the composites using coupon specimens [3, 4]. However, the limitations in the test methods and equipment required to characterise the properties of thick FRP composites along with the limited dimensions in the transverse direction of the majority of the pultruded GFRP sections added a new obstacle to the applicability of available test standards [5, 6]. As a result, full scale test methods have been developed to determine the properties of FRP profiles for use in structural engineering applications.

Experimental work using full scale sections test to determine the mechanical properties of FRP composite beams was conducted by Bank [7] and Neto and Rovere [8] . In both researches, same test procedure and almost similar section properties were used. However, there was a disagreement on research finding as Bank [7] used back calculation method (BCM) while Neto and Rovere [8] used the graphical (simultaneous) test method (SM). Due to this divergence, there is a need to conduct more experimental tests to justify which method is more appropriate to characterise the mechanical properties of FRP composite. In this study, the elastic properties of the pultruded glass FRP (GFRP) beams were evaluated using full-scale beams with different shear span – to - depth (a/d) ratios under static four-point bending test. Both simultaneous (graphical) and back calculation methods were used to calculate the *E* and *G*. The calculated properties *E* and *G* were compared with the results of the coupon test. Finally, the structural behaviour was predicted according to the suitable elastic properties.

2 EXPERIMENT PROGRAM

Pultruded GFRP square sections (125 mm x 125 mm x 6.5 mm thickness) produced by Wagner's Composite Fibre Technologies (WCFT), Australia were used in this study. These sections are made from vinyl ester resin with E-glass fibre reinforcement. The density of these pultruded profiles is 2050 kg/m^3. As per standard ISO 1172 [9], the burnout test revealed an overall glass content of 78% by weight in these profiles. Table 1 shows the mechanical properties of the pultruded sections determined from coupon tests.

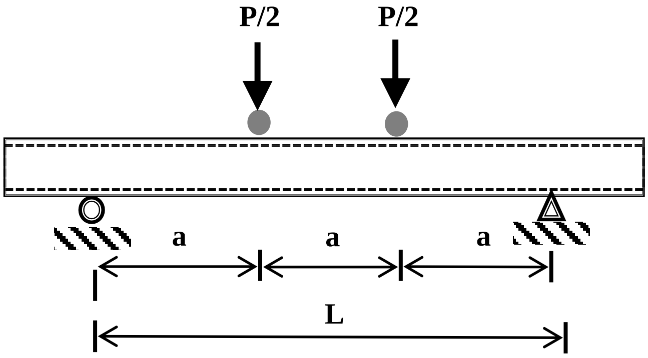
GFRP pultruded profiles with three different a/d ratios were tested under static four - point bending. The details of the tested specimens are listed in Table 2. The load was applied at the third points of the span and shear span to total length (a/L) was maintained at 1/3 for all tests. Figure 1 shows the schematic illustration of the test set-up and the tests were conducted according to ASTM D7250 [10]. A 2000 kN capacity servo hydraulic testing machine was used with a loading rate of 2 mm/min. All specimens were tested only up to approximately 20% of the failure load to ensure that the beams are still in the elastic range. Strain gauges (PFL-20-11-1L-120) of 20 mm length were attached to the bottom face of the mid-span of the specimens. Laser displacement transducer was used to measure the mid span displacement. The applied load and the displacement of the loading ram were recorded using "System 5000" data acquisition system equipment.

Table 1 Mechanical properties from coupon test

Properties	Average value	Std. Deviation
Compressive modulus (Longitudinal), GPa	38	1.4
Compressive strength, MPa	640	37
Tensile modulus (Longitudinal), GPa	42	2
Tensile strength (MPa)	741	39
Flexural modulus (Longitudinal) (GPa)	39.3	2.3
Shear modulus (Longitudinal) (GPa)	5.7	0.4

Table 2 Details of the tested specimens for the elastic properties

Span length, L (mm)	Shear span, a (mm)	a/d
600	200	1.6
900	300	2.4
1200	400	3.2



*All dimensions are in mm as per Table 2

Figure 1 Experimental set-up and instrumentations

3 EXPERIMENTAL RESULTS

Two methods have been used to calculate the elastic properties of the GFRP sections. Firstly, back calculation method has been used to calculate *E* from stress and strain data and *KGA* (shear stiffness) from load and deflection data. The variations of *E* with load for all specimens are shown in Figure 2 while the variations of *KGA* values with load are presented in Figure 3. From these curves, *E* and *KGA* were computed from the average of several points spaced within a range of L/800 to L/600 deflection as suggested by Hayes and Lesko [11]. The average calculated value of *E* was 47.2 GPa which is 20% higher than the coupon test results. Shear modulus was calculated as 4 GPa. Secondly, a graph for $6A\delta/PL$ versus $(L/r)^2$ was plotted as shown in Figure 4. As these terms came from the Timoshenko Beam Theory (TBT) where the deflection for four – point bending with the load applied at a distance (*a*) from the support point (*a=L/3* in this case, where *L* is the beam span) can be obtained as follows:

$$\delta = (23PL^3/1296\,EI) + (PL/6KGA) \quad (1)$$

$$E = (23) / (216*slope) \quad (2)$$

$$KG = 1/intercept \quad (3)$$

A linear regression (as shown in Figure 4) was used to obtain the slope, intercept and the coefficient of correlation. The *E* and *G* values were then calculated using equations 2 and 3, respectively. The *E* was 56.1 GPa which is higher than the coupon test results by about 43 %. In contrast, *G* is 3.3 GPa which is less than the average value for standard pultruded profiles by about 17 %.

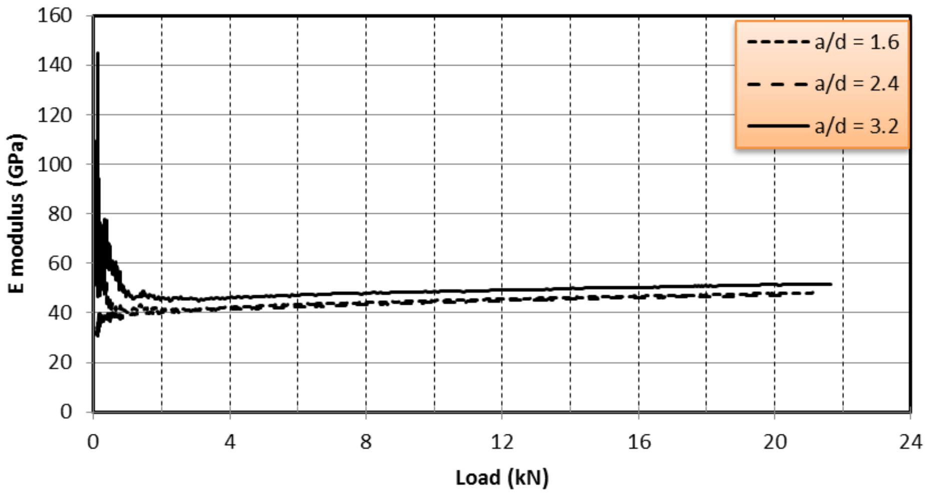


Figure 2 Flexural Modulus (*E*) versus Load for different a/d ratios

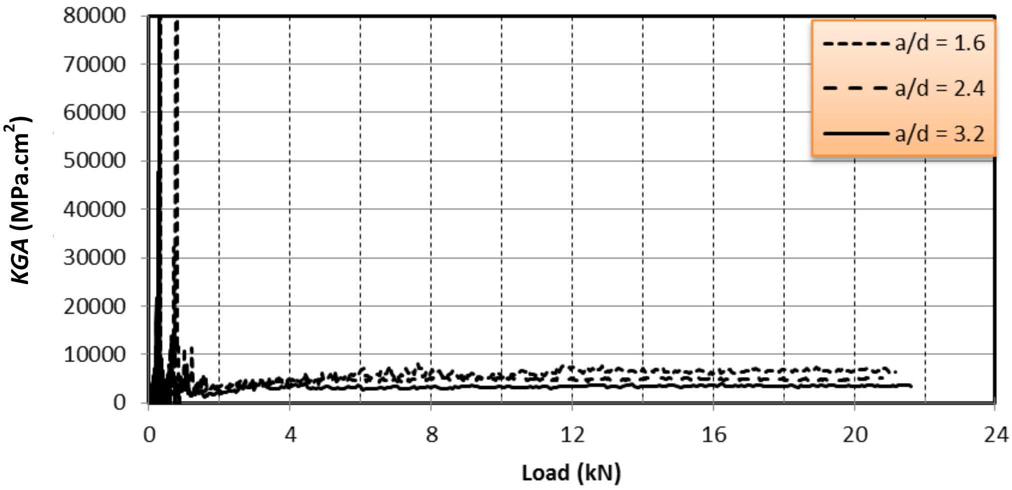


Figure 3 Shear Stiffness (*KGA*) versus Load for different a/d ratios

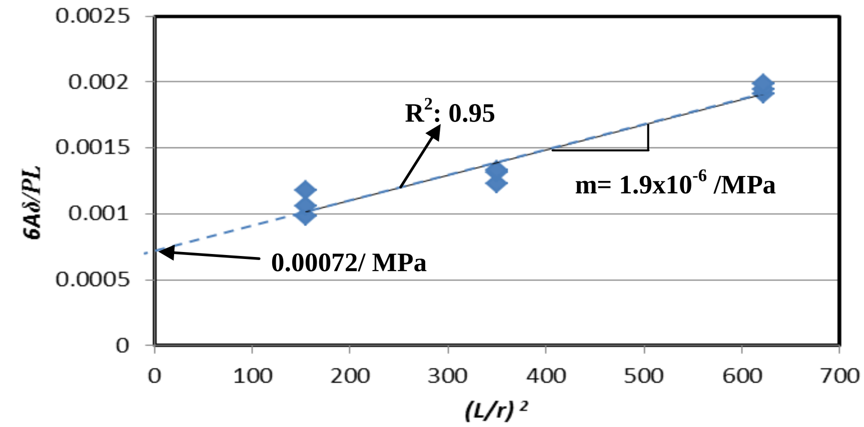


Figure 4 Typical graph to determine *E* and *KGA* using simultaneous method

4 DISCUSSION

Table 3 gives a summary of the properties of the GFRP profiles based on the coupon and full size tests. A clear difference between the values that determined from coupon and full size tests can be seen from the table. A significant difference is noted of the *E* value with 20% (BCM) and 42.7% (SM) higher than coupon test results, respectively. In addition, *G* modulus was 42.5% (BCM) and 72.7% (SM) higher than coupon test values. These differences might be due to the orthotropic of the material which could be caused by the difference of mechanical properties between a solid bar of rectangular section and a full size profile of thin- walled section. On the other hand, 18.8% and 21% was the difference between BCM and SM for *E* and *G* values, respectively. Using these properties, the failure deflections of the full-scale pultruded GFRP beams were calculated and compared with the experimental results. A comparison between the experimental and the predicted deflection calculated by using TBT for different a/d ratios is shown in Figure 5. It can be seen that the TBT provides a good approximation for the curves determined by the experimental tests. However, considering the properties from the coupon test will result in overestimated values. In contrast, it can be observed from the figure that the theoretical results from TBT basically agree well with the experimental results with a/d ratios of 1.2 to 3.6 by using material properties from full scale test. Nevertheless, for beams with a/d ratio higher than 3.6 the analytical results using SM under predicted the experimental results. On the other hand, using the elastic properties from BCM to calculate the beam deflection showed a good correlation with the experimental results for all a/d ratios. Therefore, it can be concluded that the elastic properties (*E* and *G*) determined using the BCM can reliably predict the behaviour of full scale GFRP beams. The main reason for difference between the coupon and full scale results is the effect of fibre eccentricity on the magnitude and distribution of the stresses in the small solid coupon of composite material. As a result, minor variation in fibre volume in parts of the specimen cross section will not affect the overall properties of the specimen. On the other hand, the sensitivity of the accuracy of deflection measurement especially for low a/d ratio and determining the slope (of the regression line through the data points) can lead to a significant change in the *E* and *G* calculations.

Table 3 Summary of experimental properties for GFRP beams

Test type	*E* modulus GPa	*G* modulus GPa
Coupon	39.3	5.7
Back calculation method	47.2	4
Simultaneous method	56.1	3.3

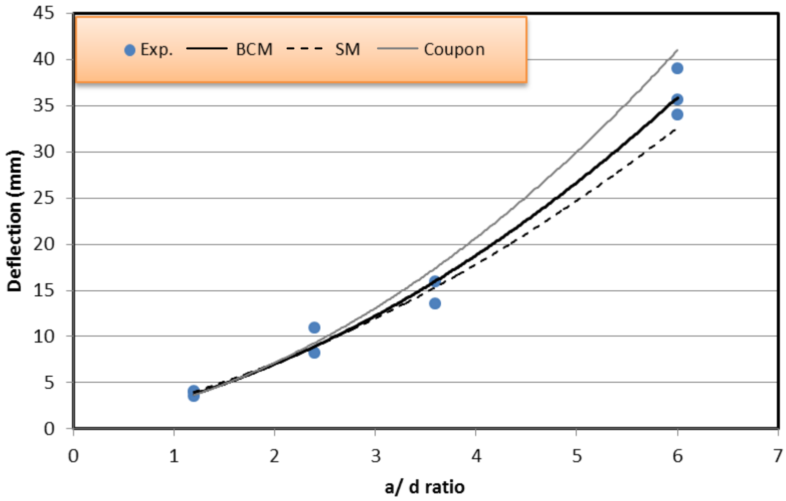


Figure 5 Comparison of theoretical and experimental deflection of beams with different a/d ratios

5 CONCLUSIONS

Testing and characterization of elastic properties of GFRP pultruded beams was investigated using the four-point bending test with different shear span to depth (a/d) ratios. Following are the conclusions based on the experimental investigation:

- A significant difference on the elastic properties was found between the coupon and full scale test results.
- The back calculation method (BCM) gives more reliable values of effective flexural and shear moduli of pultruded hollow GFRP sections compared with simultaneous method (SM) and coupon test.
- A good correlation between the predicted and the actual failure deflection was achieved using the elastic properties determined from BCM

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Wagner's Composite Fibre Technologies (WCFT) for providing the GFRP pultruded sections. The first author would like to acknowledge the financial support by the Ministry of Higher Education and Scientific Research-Iraq.

REFERENCES

[1] Hollaway L. A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties. Construction and Building Materials. 2010;24:2419-45.
[2] Bank LC. Shear coefficients for thin-walled composite beams. Composite Structures. 1987;8:47-61.
[3] Davalos JF, Salim H, Qiao P, Lopez-Anido R, Barbero E. Analysis and design of pultruded FRP shapes under bending. Composites Part B: Engineering. 1996;27:295-305.
[4] Roberts T, Masri H. Section properties and buckling behavior of pultruded FRP profiles. Journal of reinforced plastics and composites. 2003;22:1305-17.
[5] Manalo A, Mutsuyoshi H, Matsui T. Testing and characterization of thick hybrid fibre composites laminates. International Journal of Mechanical Sciences. 2012;63:99-109.
[6] Cardoso D, Harries K, Batista E. On the Determination of Mechanical Properties for Pultruded GFRP Sections. International Conference on FRP composites in Civil Engineering. Vancouver, Canada: Internationl Institute for FRP in Construction 2014.
[7] Bank LC. Flexural and shear moduli of full-section fiber reinforced plastic(FRP) pultruded beams. Journal of Testing and Evaluation. 1989;17:40-5.

[8] Neto A, Rovere H. Flexural stiffness characterization of fiber reinforced plastic (FRP) pultruded beams. Composite Structures. 2007;81:274-82.
[9] ISO 1172. Textile-glass-reinforced plastics, prepegs, moulding compounds and laminates: Determination of the textile-glass and mineral-filler content- Calcination methods. 1996.
[10] ASTM D7250. ASTM D7250/D7250M-06 Standard practice for determine sandwich beam flexural and shear stiffeness. West Conshohocken, (PA): ASTM International; 2006.
[11] Hayes M, Lesko J. The effect of non-classical behaviors on the measurement of the Timoshenko shear stiffness. Proc 2nd Inter Conf FRP Composites in Civil Engineering–CICE2004. p. 873-80.