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EFFECT OF ECCENTRICITY ON THE BEHAVIOR OF PULTRUDED FRP BOLTED JOINT

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ABSTRACT

Fibre reinforced polymer (FRP) composites are becoming an alternative choice for the development of structural truss system. It takes advantage of the unidirectional properties of fibre composites as truss members are subjected mostly to axial forces.The typical connection used for this type of structure is a bolted joint. This paper presents the behavior of closed section (100 mm x 75 mm x 5.25 mm) of pultruded glass FRP (GFRP) composite with bolted joint under eccentric loading. The T-joint component of the truss was designed with 1-bottom chord (1B) to simulate the eccentric condition and compared with a T-joint with 2-bottom chords (2B) for concentric loading. Stainless steel bolts (all-threaded) were used and tightened with a torque of 25N.m. The joint failed due to local punching shear at one side of the connection area due to eccentric effect and a load less than half that of the joint with concentric loading. It was found that the testing specimen with eccentricity experienced local damaged which had reduced its joint capability almost twice than that specimen without eccentricity'

Keywords: Pultruded FRP, Bolted Joint, Connection, Eccentricity, Failure modes

INTRODUCTION

Fibre reinforced polymer (FRP) composites materials have excellent attributes for application in civil structures such as buildings, bridges and also for reinforcing and strengthening existing structures. One of the favored FRP manufacturing process in civil construction is pultrusion (Jones and Ellis, 1986). For the past 20 years, pultrusion composites have been acknowledged as an alternative material from conventional and progressively used in the construction industry (Turvey and Wang, 2007). In addition to being a lightweight structure, pultruded glass FRP (GFRP) profiles can offer high resistance to aggressive environment which contributes to lower life cycle cost, high axial resistance and quick installation time (Keller,2001). These inspiring features of pultruded GFRP material are being used for the development of structural truss system and other civil structures as well (Pfeil et al, 2009). Since truss members are subjected only to axial forces, it can take advantage of the unidirectional properties of fibre composites and effectively utilises its material strength (Hizam et al, 2012). One of the main concern arise in designing the structures with pultruded GFRP is to provide an adequate connection system. This area continues to draw attention due to many possibilities of failure modes, the complexity of stress relieving mechanism and the complex nature of the stress fields in the vicinity of the joint (Khashaba, 2006). There are three (3) common techniques used to connect various types of pultruded structures which are bolted joint, adhesively bonded and a combination of both. In terms of practicality, bolted joint is the most preferable as it is relatively easy to assemble and is capable of transferring high loads (Mottram, 2009). In bolted connection design, the loading directions and fasteners must be arranged in a concentric manner (ASCE, 2010). Most research studies on FRP connection conducted to date are loaded concentrically (Ascione et al, 2010, Vangrimde and Boukhili, 2003, Xiao and Ishikawa, 2005) and there are several studies on the behavior of FRP materials under eccentric loading (Hadi, 2007 and Ragheb, 2010). However in practice, eccentricity may be unavoidable due to practical limitations in fabrication and erection. In addition, discrete load paths employed by bolted connection in order to transfer forces and moments will also influence the behavior of pultruded structure. Thus, studies of pultruded FRP with bolted connection under eccentric loading are important for its practical use. This paper investigates the behavior of pultruded GFRP bolted joints under eccentric loading and compared with the behavior of a double bottom chords (or concentrically loaded joint). All the pultruded GFRP T-joint specimens were tested to failure and its failure behavior were reported.

EXPERIMENTAL PROGRAM

The experimental program of this study involved a total of six (6) pultruded GFRP T-joint specimens had been assembled and were tested to failure in the tensile direction. There were two (2) experimental models prepared which corresponds to the specimens 1B, and 2B. The description of the specimens is listed in Table 1. One bottom chord specimen was used to create eccentric case, while two bottom chords is the typical configuration use in the industry (Figure 2).

Figure 1. Disassembled specimens of pultruded GFRP closed profile.

Table 1. Pultruded GFRP T-joint specimens.

FRP T-Joint group	Description	Nos
1B	1 bottom chord	3
2B	2 bottom chord	3

Material Details and Specimens Preparation

The composite material used for this test is pultruded glass FRP closed profile which was manufactured and supplied by Wagners Composite Fibre Technologies (WCFT). The nominal dimension of the pultruded GFRP closed profile was 100 mm x 75 mm x 5.25 mm. This material consists of reinforcements by long continuous fibres (unidirectional or 0^0) and stitched fabrics ($\pm 45^0$) which provide high longitudinal strength. The stacking sequence of pultruded glass FRP is 0^0 / 45^0 / 0^0 /-45^0 /0^0 /-45^0 /0^0 /45^0 /0^0. The matrix material is a vinyl ester resin. Table 2 shows the mechanical properties of the pultruded GFRP profile extracted from the WCFT product data sheet.

Table 2. Mechanical properties of 100 mm x 75 mm x 5.25 mm.

Mechanical Properties	**Longitudinal**	**Transverse**
Ultimate tensile strength (MPa)	650	41
Ultimate compressive strength (MPa)	550	104
Modulus of Elasticity (MPa)	35400	12900
Shear strength (MPa)	84	
Mass (kg/m)	3.28	
Density (kg/m^3)	1970	

Figure 2 illustrates the geometrical configuration of the pultruded GFRP T-joint and the test fixture used in this experiment. At the connection area between the steel test fixture and test equipment, two (2) M20 stainless bolts and mechanical inserts were used. The mechanical fasteners used to connect the T-joint were stainless steel (SS) 316 M20 (A325) together with SS washers and nuts. A tightening torque of 25 N.m was used to provide clamping pressure as recommended in (Manalo and Mutsuyoshi, 2011). Approximately 22 mm nominal bolt hole diameter was drilled using a special diamond-tipped bit and the edge distance from the bolt hole to base material is approximately 39 mm (2 times bolt diameter).

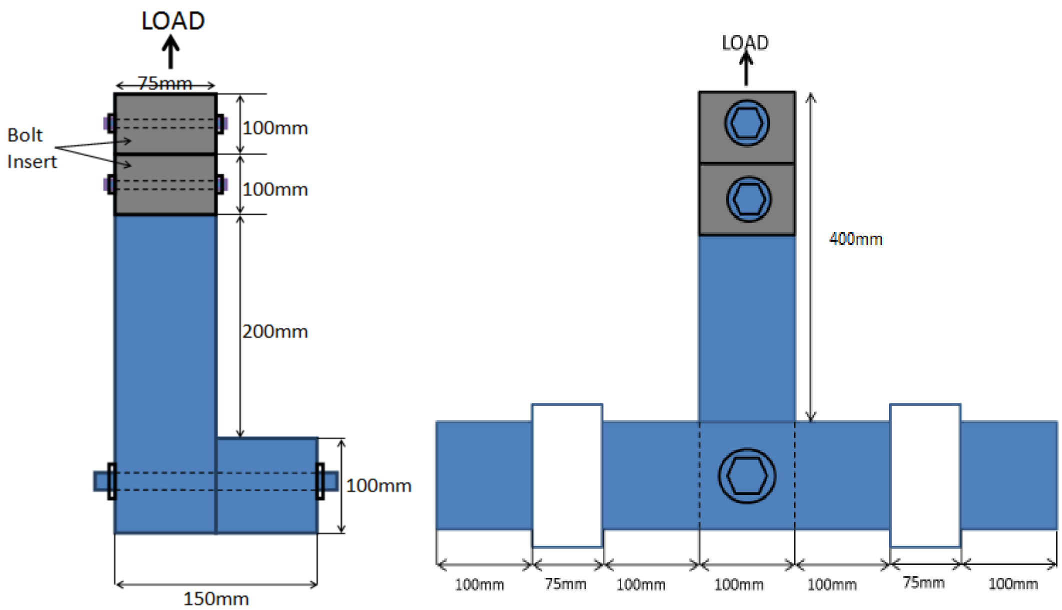

Figure 2. Geometrical configuration of pultrueded GFRP T-joint

Experimental Setup and Instrumentation

Pultruded GFRP T-joint specimens were tested up to failure in a tensile manner at P11 Laboratory of the Faculty of Engineering and Surveying at the University of Southern Queensland. The testing program was conducted using a loading machine (Transducer Techniques, model SWO-50K) with a capacity of 222kN. Steel test fixture was fabricated to attach the specimens at the load cell and the bottom girder of test frame of the machine to restraint the specimen's bottom chord. The experimental set-up is shown in Figure 3. Data logger (system 5000) was used to record the load applied and displacement (using a draw-wire displacement transducer with sensitivity 64.50 mV/V/inch). Calibrations of those instrumentations were performed prior to commencement of testing program. The failure modes of each specimen were observed during the loading and after the test had been completed.

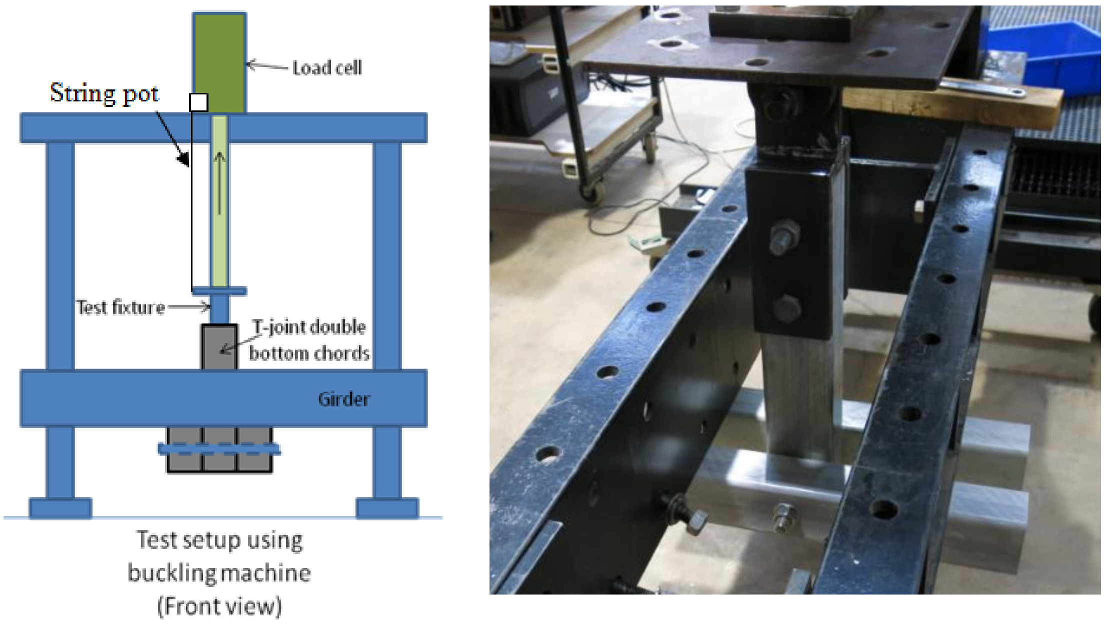

Figure 3. Pultruded GFRP T-joint experimental setup

RESULTS AND DISCUSSION

Table 3 shows the summary of the results of the testing program. Specimen 1B failed at an average load of 14.45 kN with an average displacement of 23.56 mm. Meanwhile, specimen 2B failed at an average load of 37.24 kN with an average displacement of 22.38 mm. It was observed that eccentric condition on pultruded GFRP bolted joint has resulted on reduction of joint strength and influences its failure behavior. The failure behavior of pultruded GFRP bolted joint is presented in the following section.

Effect of eccentric loading

The load and displacement relationship of 1B specimens is presented in Figure 4. All specimens showed almost linear behavior which occurred up to around 10-13kN with displacement between 20-25 mm. After this region, the curve became non-linear until failure. The first cracking sound could be heard at as low as around 8 kN which may indicates that the bolt was starting to slip into bearing. The highest failure load was obtained by 1B-2 specimen at 15.53 kN. Subsequently, the joint strength slowly decreased and the displacement continued to increase. It was noticed that, after the maximum load, the specimens did not fail abruptly suggesting that the members of T-joint were still intact. This is due to the lateral restrained produced by the bolt axial force (tightening torque). As the load was continued to apply, the contact pressure from the washer had progressively damaging the fibres and had caused local failure.

Table 3. Summary of results.

Specimens	**Failure load (N)**	**Displacement (mm)**
1B-1	12,857.81	19.13
1B-2	15,532.61	26.41
1B-3	14,969.50	25.13
Average	14,453.31	23.56
Std dev	1,410.14	3.89
Specimens	**Failure load (N)**	**Displacement (mm)**
2B-1	35,476.30	23.48
2B-2	38,995.78	21.76
2B-3	37,236.04	21.90
Average	37,236.04	22.38
Std dev	1,759.74	0.96

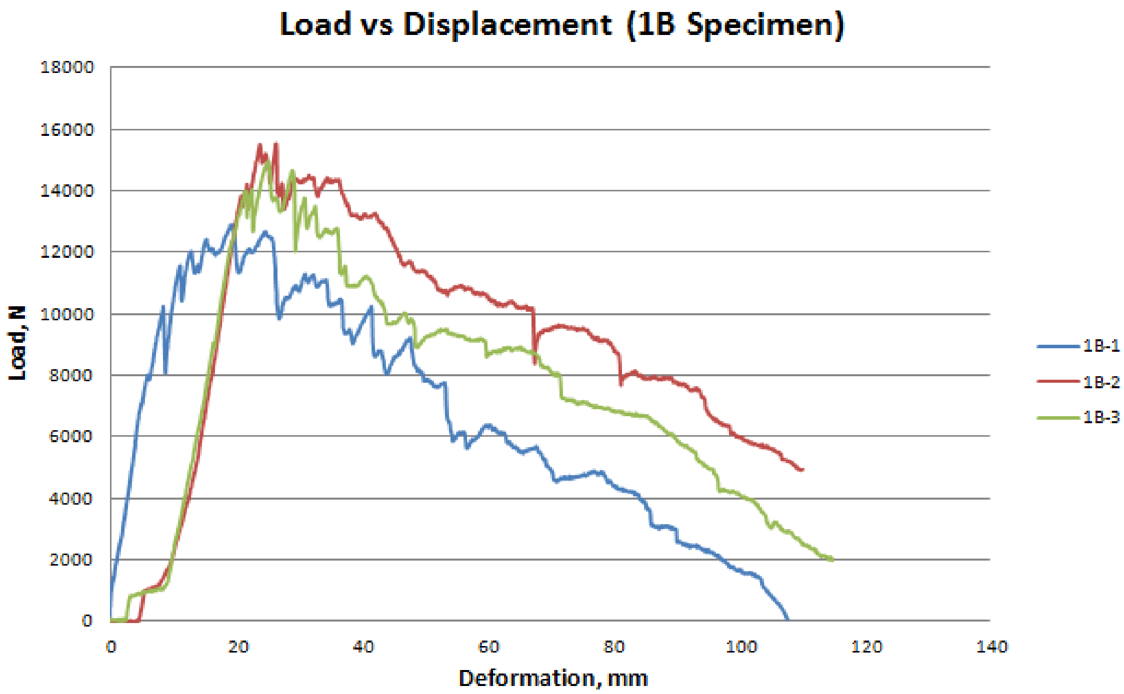

Figure 4. Load-displacement of 1B specimens

In order to further investigate the failure behavior at the connection area, the T-joint components were disassembled. The failure modes of pultruded GFRP T-joint 1B specimens (at connection area) were presented in Figure 5. During the application of the load, the specimens exhibited large rotation at the bottom chord due to moment created. This eventually had caused punching shear on the pultruded GFRP thin-walled which developed due to the eccentricity of the load applied on the connection. This has significantly affected the joint strength. Providing that the material is relatively low material stiffness and lower strength in the transverse direction (Bai and Yang, 2012), it also prone to fail in that manner. On the opposite plane which is facing the bottom chord, the final failure mode of shear-out was identified. The end distance (approximately 39 mm) to bolt diameter (20 mm) ratio is slightly below the minimum recommended parameters (which is 2) for lap joint connections (Bank, 2006). Since the material possesses low in-plane shear strength and together with the small edge distance in the direction of the load applied, it triggered the shear-out failure to occur. No sign of failure in the bolt was seen for the 1B specimens.

Figure 5. Failure modes of 1B specimens

Figure 6 shows the load-displacement behavior of 2B specimens. At an applied load of approximately 5 kN, the graph showed linear behavior up to final failure. At this stage, the load was transferred to the stainless steel threaded bolt, progressively damaging and shearing the thin wall of the pultruded GFRP. The average maximum load obtained for 2B specimen was 37.24 kN with a displacement of 22.38 mm. At the peak of the graph, there were several knees (in non-linear fashion) which may indicate some internal damage had occurred as the joint capacity decreased. After maximum load, the specimens were still capable to carry some loads, even though at a decreasing capacity, possibly due to the lateral restrained from both bottom chords which were obtained from the tightening torque of the bolt. After the loading was released, the specimens were disassembled and close visual inspections were made at the connection area to identify mode of failure. Figure 7 shows the failure modes of 2B specimens. All the 2B specimens failed in the same manner. The specimens failed due to shear-out at both sides and marginal bearing (local crushing) was observed at the bottom chord members. In the 2B specimens, the load applied were evenly distributed at both sides of connected area and developed identical failure mode. It was also observed that, the pultruded material in direct contact with the threaded bolt was heavily crushed and delaminated. With the thread, a significant reduction of joint strength identified when compare to the plain pin joint strength (Matharu and Mottram, 2012).

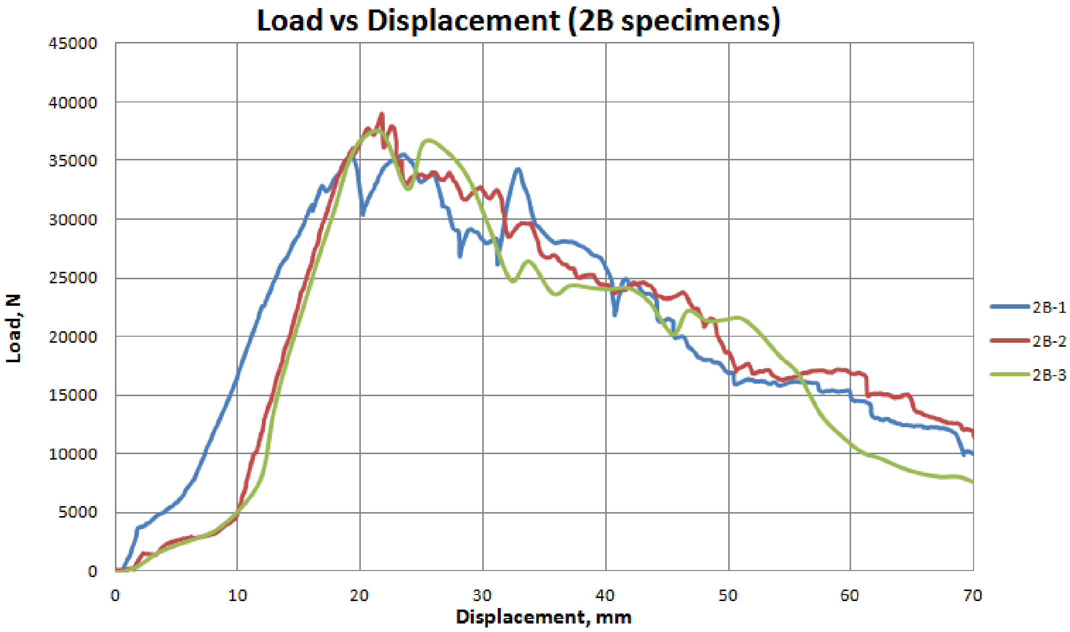

Figure 6. Load and displacement behavior for 2 bottom chord specimens

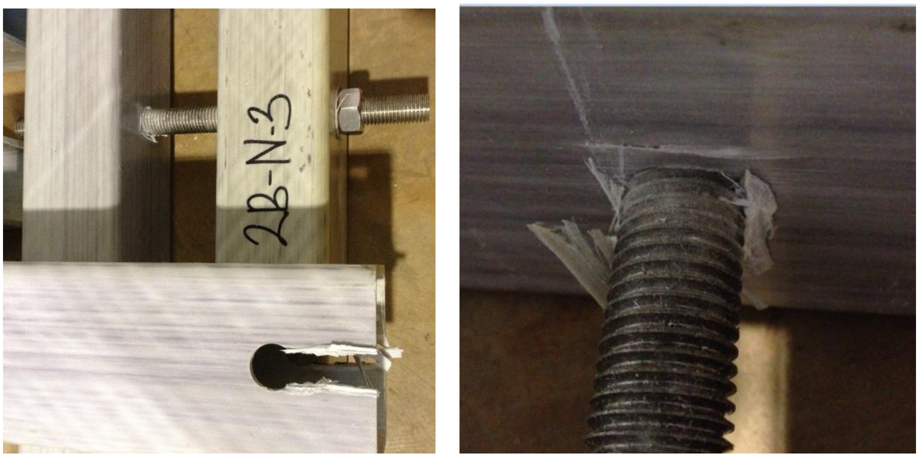

Figure 7. Failure modes of 2B specimens

Figure 8 shows the comparison of load-displacement behavior between 2B specimen and 1B specimen. According to the experimental results, the 2B specimen recorded more than twice the strength of bolted joint of 1B specimen. Contribution of two bottom chords have created concentric loading path, while eccentricity on 1B specimen significantly reduced the bolted joint capacity. The shear-out failure was observed on both 1B and 2B specimens. It developed predominantly due to combination of low end distance to bolt diameter ratio and low in-plane shear strength of the material. Local punching shear was observed at 1B specimen due to the moment created by eccentric loading. This could be improved if the rotational at the connection area due to eccentricity could be restrained. Closed profile (rectangular shapes) of pultruded GFPR was chosen because it can improve the torsional rigidity, stiffness and the weak axis strength (Smith et al, 1998), however in this study, the eccentricity spacing is too big to endure. By introducing some type of filler inside the hollow section especially at the connection area, it might help to improve the joint strength, rigidity and restrict rotational movement.

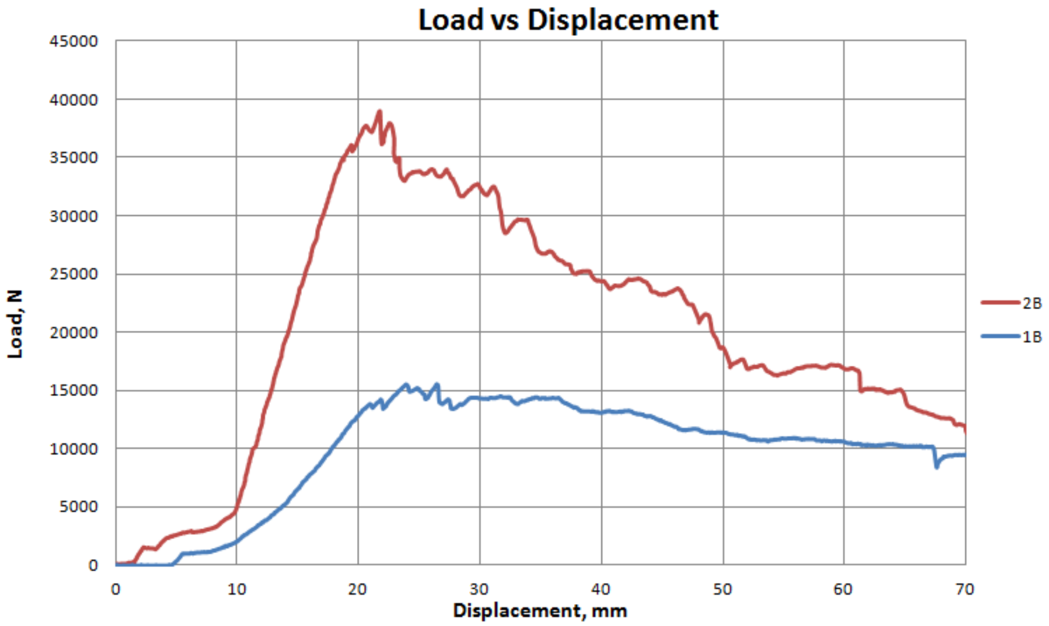

Figure 8. Load-displacement relationship between 2B and 1B specimen

CONCLUSION

Six specimens of pultruded GFRP bolted joint had been tested in two cases, with and without eccentricity. The results showed that the joint strength is significantly decreased due to the effect of eccentric loading. For 1B specimens, different mode of failure from the typical FRP connection failure modes was observed. The local punching shear was developed at one side of the connection area due to eccentric effect and resulted in reducing bolted joint strength.

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