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Effects of Bonded Splice Joints on the Flexural Response of Pultruded Fibre Reinforced Polymer Beams

G. J. Turvey[1, a]

[1]Engineering Department, Lancaster University, Bailrigg, Lancaster, LA1 4YR, UK

[a]g.turvey@lancaster.ac.uk

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Abstract. Three Pultruded Fibre Reinforced Polymer (PFRP) 152 x 152 x 6.4mm Wide Flange (WF) beams were fabricated with a central two-plate splice joint. The 6.4mm thick PFRP splice plates were 210, 410 and 610mm long. Each beam was tested in symmetric four-point bending about its major and minor-axis and deflections, rotations and surface strains were recorded. Beam transverse stiffnesses, support rotations and splice rotational stiffnesses were quantified and compared with theoretical predictions. Predicted deflections were 3.5% to 18.5% larger and support rotations were 10% smaller to 14.2% larger than the experimental values. Splice end rotations were generally poorly predicted.

Introduction

The use of PFRP profiles in structural frameworks has been increasing over the past decade and a half. There are a number of reasons for the increasing structural use of PFRPs. The first is greater awareness amongst the civil and structural engineering design community of the potential of PFRPs, especially their positive attributes of low self-weight and high corrosion resistance. Another important factor is the increasing volume of data reported on the structural performance of PFRPs. Thus, even though there are no statutory design codes for PFRPs, sufficient data/guidance exists on the load – deformation response of structural elements and bolted joints to enable PFRP frames to be designed by adapting the Simple Design Method developed for steel frames.

Despite the existence of useful information on bolted tension and beam-to-column joints [1,2] and bonded tension joints [3,4], improved understanding of the behaviour of PFRP joints is still required. This is mainly because PFRPs are orthotropic elastic brittle materials with low through-thickness strength. Moreover, future research should also take account of the difference between the respective dominant design criteria for steel and PFRP structures, namely strength and stiffness.

Much of the bonded joint research has been focused on ultimate strength, but joint stiffness may be equally important for PFRP frames. Furthermore, as is clear from [3,4], most research on bonded PFRP joints has been concerned with their behaviour in tension. Flexural behaviour of bonded PFRP joints remains to be addressed. Such joints, known as splice joints, are used to join PFRP profiles end-to-end to produce continuous beams or to repair damaged beams.

The objective of this paper is to describe an investigation of splice joints in PFRP beams. Details are given of bending tests on three bonded splice joints connecting the ends of PFRP WF profiles. Deformation data (deflections and rotations) are presented which enable the transverse stiffnesses of the beams and the rotational stiffnesses of the splice joints to be quantified. Formulae are given for the calculation of beam deformations and their accuracy is quantified by comparison with the experimental deformations.

Material Properties

An EXTREN® 500 series 152 x 152 x 6.4mm WF section (Note: Reference to a trade name is solely for the purposes of factual accuracy.) was selected for the beams. The same series 6.4mm thick plate section was used for the splices.

The *minimum* longitudinal elastic moduli of the WF and plate sections are given in [5] as 17.2kN/mm^2 and 12.4kN/mm^2 respectively. Elastic moduli determined from tension tests on coupons cut longitudinally out of the web and flanges of WF and plate sections are often as much as 20% higher than the minimum values.

Splice Joint Fabrication Details

Three nominally identical 152 x 152 x 6.4mm WF profiles were each cut to a length of 3.1m. Each beam was then cut in half. Six rectangular splice plates - two for each beam - were cut out of the 6.4mm thick plate material such that their longer sides were parallel to the pultrusion direction. The plates were nominally 152mm wide, i.e. equal to the width of the flanges of the WF profiles. The lengths of the pairs of splice plates were 210mm, 410mm and 610mm.

The beam splice joints were fabricated in stages. The whole of one surface of each splice plate was abraded with sandpaper to remove the surface veil. The outer surfaces of the top and bottom flanges at each end of the beam halves were similarly abraded over a length slightly greater than the half-length of the splice plate. Resin dust was then removed from the abraded surfaces. Adhesive tape was applied to the edges of the splice plates, the edges and ends of the abraded flanges and also across the width of the flanges at the ends of the splices. The purpose of the tape was to define the bond areas and to facilitate removal of adhesive spew after bonding. The beam halves were then aligned lengthwise (flanges upright) on two trestle tables so that their ends were 10mm apart and bond areas were accessible between the ends of the tables. A two-part adhesive (Araldite® 2015) was then applied to the abraded surfaces of the splice plates and the beam flanges. Several 1mm diameter wire spacers were placed in the adhesive applied to the splice plates to ensure uniform bond thickness. Thereafter, the splice plates were brought into contact with the flanges, adjusted to ensure correct positioning and then clamped in position. After about one hour the adhesive spew was removed and the splice joint was left to cure for a further 23 hours. After curing the clamps were removed and the joint was inspected visually.

In this manner the two halves of each beam were reconnected to create three beams with two-plate splice joints of lengths, 210mm, 410mm and 610mm (including the 10mm gap between the ends of each half beam) at their centres.

Test Setup, Instrumentation and Test Procedure

The three beams with two-plate splice joints were tested in a symmetric simply supported four-point bending arrangement, as shown in Fig. 1, so that the splice joint was subjected to pure bending.

Fig. 1 also shows part of the instrumentation used to record deformations during the four-point flexure tests. A dial gauge with 50mm travel and a displacement resolution of 0.01mm was used to record the mid-span deflection at E. Four electronic clinometers each with a rotation range of 60^o and an angular resolution of 0.001^o were fixed to the longitudinal centreline of the beam web. Two of the clinometers were located above the simple supports at A and B. The other two were located in line with the ends of the splice plates at C and D. Not shown on Fig. 1 are four uniaxial strain gauges (gauge length 10mm and gauge resistance 120 Ohms) which were bonded to the outer surfaces of the top and bottom splice plates at mid-span. They were inset 10mm from the longitudinal edges of the splice plates with their sensitive axes parallel to the length of the beam. Thus, mid-span deflections, splice plate surface strains, support rotations and splice end rotations could be recorded throughout each spliced beam test.

As the design of PFRP structures tends to be dominated by serviceability rather than ultimate limit state criteria, it was decided to carry out four-point flexure tests only up to the deflection limit state. This had the advantage that it was unlikely that the spliced beams would be damaged during testing, so that repeat tests would be possible and that other types of test (not reported here) could be carried out on the same beams. The deflection limit chosen for the four-point flexure tests was set at

1/200th of the span for the major-axis tests. This value is slightly larger than that given in [6]. The value was reduced by 1/3rd for the minor-axis tests.

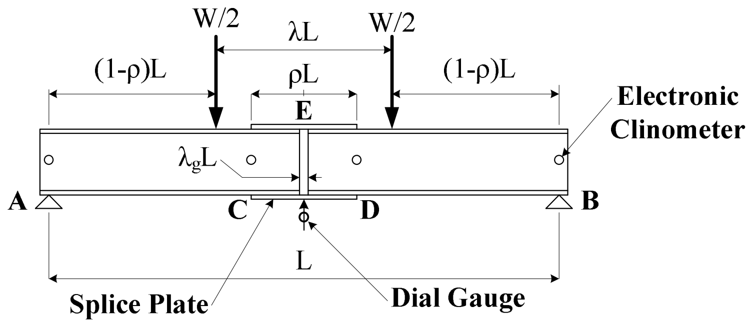

Fig. 1: Four-point bending test setup for a simply supported beam with a central two-plate splice joint.

The beams were loaded such that the deflection at mid-span increased in 2mm/1mm increments and at each deflection increment the load, rotations and strains were recorded. When the maximum deflection was reached (15mm for major and 10mm for minor-axis flexure respectively) the beam was unloaded in 3mm/2mm decrements. Each beam was subjected to three load – unload tests. The load - deflection responses were linear with good repeatability, as were the load - end rotation responses. However, the repeatability of the moment - splice end rotation responses showed some scatter. The strains recorded by individual gauges on the outer surfaces of the top and bottom splice plates showed good repeatability. Average top surface strains were about 50% of the bottom surface strains for the two longer splice joints and only 21% for the shortest splice joint. Strains recorded at opposite edges of the same splice plate sometimes differed significantly. Unsurprisingly, the correlation between experimental and theoretical strains was poor. Space limitations preclude a discussion of possible reasons for the poor strain correlations.

Test Results

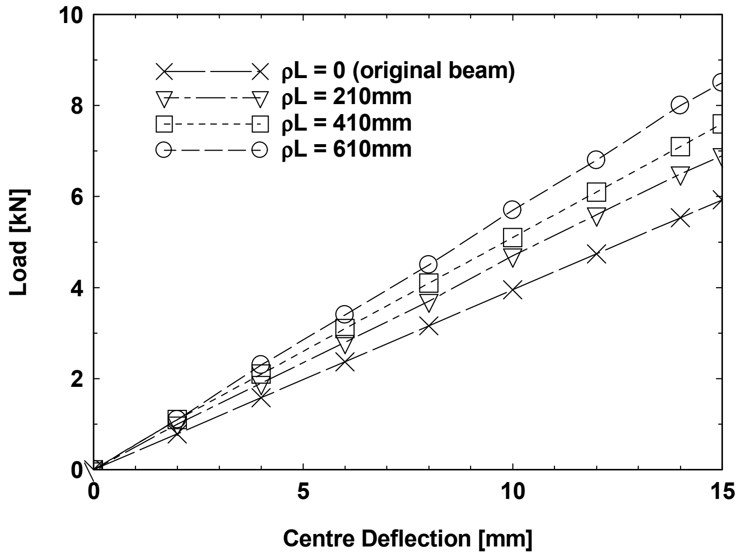

Fig. 2: Comparison of the load – deflection responses of beams with two-plate splice joint lengths of 210mm, 410mm and 610mm (bending about the major-axis).

The load – centre deflection responses of the three spliced beams are compared with the calculated response of the original beam in Fig. 2. It is evident that the response is linear for all of the beams up to the deflection limit and that they are stiffer than the original beam. Straight line fits to the load – deflection/support rotation/splice end rotation data obtained from the tests have enabled the transverse stiffnesses of the spliced beams and the rotational stiffnesses of the splice joints to be determined with respect to their major and minor-axes. These stiffnesses are given in Table 1.

Table 1

Transverse stiffnesses of spliced beams and rotational stiffnesses of two-plate bonded splice joints

Length of Splice Joint [mm]	Major-Axis Transverse Beam Stiffness [kN/mm]	Minor-Axis Transverse Beam Stiffness [kN/mm]	Major-Axis Splice Rotational Stiffness [kNm/mrad]	Minor-Axis Splice Rotational Stiffness [kNm/mrad]	Major-Axis Splice Rotational Stiffness/Unit Length [kNm/m/mrad]	Minor-Axis Splice Rotational Stiffness/Unit Length [kNm/m/mrad]
210	0.473	0.138	0.767	0.255	3.652	1.214
410	0.505	0.150	0.700	0.154	1.707	0.376
610	0.569	0.183	0.627	0.144	1.028	0.236
0	0.395	0.126	-	-	-	-

Spliced Beam Analysis

The deformation behaviour of a simply supported beam with a splice joint at mid-span, shown in Fig. 1, may be analysed using simple beam bending theory in conjunction with Mohr's Moment-Area theorems and the Method of Transformed Sections [7]. Hence, using the notation in Fig. 1, the expression for the mid-span deflection may be written as:-

$$\delta_E = \frac{WL^3}{96EI}(1-\lambda)\left\{\left(2+2\lambda-6\rho-\lambda^2+3\rho^2\right)+3\frac{\rho(1-\rho)}{(1+\phi_I)}\right\}. \tag{1}$$

Likewise, the expressions for the support and splice end rotations may be written respectively as:-

$$|\theta_A| = |\theta_B| = \frac{WL^2}{16EI}(1-\lambda)\left\{(1+\lambda-2\rho)+2\frac{\rho}{(1+\phi_I)}\right\}. \tag{2}$$

$$|\theta_C| = |\theta_D| = \frac{WL^2}{8EI}\frac{\rho(1-\lambda)}{(1+\phi_I)}. \tag{3}$$

In Eqs. (1) – (3) I and ϕ_I denote respectively the second moment of area of the original PFRP section and the additional second moment of area factor due to the two splice plates.

The geometries of the original and transformed cross-section for major-axis bending are shown in Figs. 3(a) and 3(b) respectively. λ_b, λ_f and λ_w denote the ratios of the flange width, flange thickness and web thickness respectively to the depth of the WF cross-section. Similarly, β_a and β_p denote the ratios of the adhesive and splice plate thickness respectively to the flange thickness. In addition, γ_a and γ_p denote the ratios of the adhesive elastic modulus and the longitudinal splice plate modulus respectively to the longitudinal elastic modulus of the beam. The values of these factors for the 152 x 152 x 6.4mm WF and 6.4mm plate sections and the 1mm thickness of the adhesive layers are:-

$$\lambda_b = 1; \lambda_f = \lambda_w = 0.42; \beta_a = 0.156; \beta_p = 1; \gamma_a = 0.174; \gamma_p = 0.721. \quad (4)$$

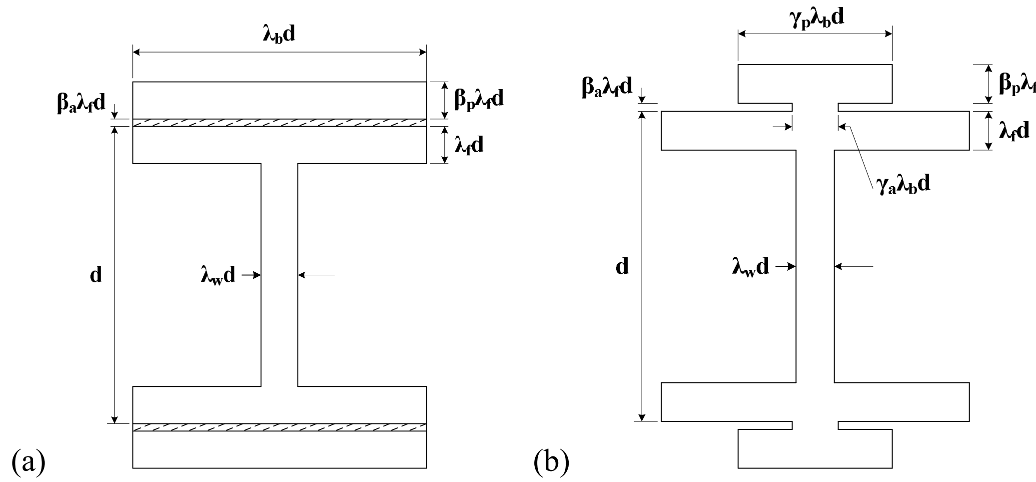

Fig. 3: (a) Section through the splice joint and (b) transformed section

Expressions have been derived for both I and ϕ_I in terms of the lambda, beta and gamma factors for both major and minor-axis flexure. Ignoring the effect of the adhesive layers of the splice joint, i.e. setting $\beta_a = 0$, the values of the additional second moment of area factors ϕ_I were evaluated as:-

$$\phi_I = 0.748(\text{major-axis}); \phi_I = 0.720(\text{minor-axis}). \quad (5)$$

Using these values together with values of $\lambda = 0.267$ and $\rho = 0.070, 0.137, 0.203$ for each of the three splice lengths, the mid-span deflection, end rotation and splice end rotation at E, B and D respectively were evaluated for the maximum load of each test. These values are compared with the experimental values in Table 2.

Table 2

Comparison of experimental and theoretical deflections and rotations for simply supported beams with a central two-plate splice joint

(a) Major-Axis Bending

Maximum Load (W) [kN]	Splice Plate Length (ρL) [mm]	Centre Deflection (δ_E) [mm]	Support Rotation ($\lvert\theta_A\rvert,\lvert\theta_B\rvert$) [mrad]	Splice End Rotation ($\lvert\theta_C\rvert,\lvert\theta_D\rvert$) [mrad]
8.5	610	17.41 (16.1%) 15.00	19.09 (14.2%) 16.71	4.065(8.1%) 3.761
7.6	410	16.68 (11.2%) 15.00	17.96 (11.0%) 16.18	2.443 (-17.2%) 2.950
6.9	210	16.23 (8.2%) 15.00	17.11 (5.0%) 16.30	1.136 (-45.8%) 2.095

(b) Minor-Axis Bending

Maximum Load (W) [kN]	Splice Plate Length (ρL) [mm]	Centre Deflection (δ_E) [mm]	Support Rotation ($\|\theta_A\|,\|\theta_B\|$) [mrad]	Splice End Rotation ($\theta_C\|,\|\theta_D\|$) [mrad]
1.9	610	12.27 (18.5%) 10.00	13.43 (-5.3%) 14.14	2.896 (-23.5%) 3.578
1.5	410	10.36 (3.6%) 10.00	11.14 (-10.0%) 12.25	1.537 (-61.8%) 2.487
1.4	210	10.35 (3.5%) 10.00	10.90 (-8.6%) 11.84	0.735 (-86.5%) 1.371

Note: Experimental values are the average values for the third test and are the lower values in each row. (..%) = [(theory – experiment)/experiment] x 100.

Concluding Remarks

The test results show that the transverse stiffnesses of all the spliced beams are greater than the original beam for both major and minor-axis flexure and that transverse stiffness increases with splice length. In contrast, splice rotational stiffness decreases with increasing splice length.

Finally, the closed-form equations, developed for four-point flexure of simply supported beams with central two-plate bonded splice joints have been shown to provide good to reasonable estimates of mid-span deflection and support rotation, but poor estimates of splice joint rotation.

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References

[1] G.J. Turvey: Prog. Struct. Eng. Mat. Vol. 2 (2000), p. 146

[2] G.J. Turvey and C. Cooper: Proc. I.C.E. (Struct. & Build.) Vol. 157 (2004), p. 211

[3] T. Keller and T. Vallée: Comp. Pt. B (Eng.) Vol. 36 (2005), p. 331

[4] T. Keller and T. Vallée: Comp. Pt. B (Eng.) Vol. 36 (2005), p. 341

[5] Anon: *EXTREN Fiberglass Structural Shapes Design Manual*, Strongwell, USA (1989).

[6] J.L. Clarke: *Structural Design of Polymer Composites: EUROCOMP Design Code and Handbook*, E & F N Spon, London (1996).

[7] J. Case and A.H. Chilver: *Strength of Materials*, Edward Arnold, London (1959).