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Characterisation of the rotational stiffness and strength of web-flange junctions of pultruded GRP WF-sections via web bending tests

G.J. Turvey*, Y. Zhang

Engineering Department, Lancaster University, Bailrigg, Lancaster LA1 4YR, UK

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Abstract

Three-point flexure tests on the webs of 12 pultruded Glass Reinforced Plastic (GRP) Wide Flange (WF) specimens are described. The webs of the specimens were tested with their ends either simply or semi-rigidly supported. Dual knife-edge fixtures and rigid steel supports were designed and fabricated to simulate these support conditions. A series of low load tests were carried out on the webs of the WF specimens for both types of end conditions and deflections and strains were recorded at mid-span. Using simple beam analysis models in conjunction with the test data, both the transverse elastic modulus of the web and the rotational stiffness per unit length of the web-flange junctions of each specimen were determined. The webs of five of the specimens were failed under simply supported end conditions and the remaining seven under semi-rigid end conditions. From these failure tests the initial failure strengths of the web-flange junctions and the ultimate bending strengths of the webs were determined. The failure loads and modes of failure for both sets of end conditions have also been quantified.

Keywords: Mechanical properties; Mechanical testing; Polymer-matrix composites (PMCs); Pultrusion; Strength

1. Introduction

Over the past decade and a half the use of fibre-reinforced polymeric composite materials, in the form of pultruded GRP beams and columns, in infrastructure applications has increased substantially. The strength to stiffness ratio of the GRP of these structural elements is much higher than that of aluminium or steel. In consequence, pultruded GRP structural elements are much more prone to becoming unserviceable due to instability than similar sized elements made of steel or aluminium. It is, therefore, less than surprising to realise that over the same time period a considerable amount of research has been undertaken to develop knowledge and understanding of the buckling response-local and overall-of pultruded GRP beams and columns. Thus, today, their initial elastic buckling response is reasonably well understood and documented (see, for example, [1–9]). Nevertheless, gaps remain in our knowledge and understanding of a number of factors which influence their buckling response. For example, in the case of the compression flange of a WF beam or the flanges of a WF column, the rotational stiffness of the web-flange junction has a significant effect on the local buckling stress. However, as far as the authors are aware, this stiffness has only been quantified by indirect means (see [10,11]) and, moreover, its rotational or bending strength has not been determined.

As already mentioned, buckling research on pultruded GRP structural elements has been focused primarily on their initial bucking response and very little attention has been paid to the ultimate failure or collapse response of, for example, beams and columns. To date, only a handful of studies [12–14], which are partly or solely concerned with failure, have been reported on beams. Research on column failure is similarly scant [15–17]. From the limited information that is available, it is clear that GRP beams and columns fail in a brittle manner. The collapse mechanisms, which are not yet fully understood, often appear to involve failure of the web-flange junction(s). Moreover, the few attempts to model the collapse behaviour of pultruded GRP beams (see, for example, [13,14]) have assumed that the failure strengths of the web-flange

* Corresponding author.
E-mail address: g.turvey@lancaster.ac.uk (G.J. Turvey).

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junctions of pultruded GRP profiles are the same as those obtained from tests on coupons cut out of the *flat* parts of the web and/or flanges of the profiles. Several researchers (Bank, Zureick, Barbero and Mottram, to name but a few) have recognised that the mechanical properties of pultruded profiles may vary around the cross-section because of the constraints imposed by the cross-sectional shape on the placement of the fibre reinforcement (rovings and CFM (Contiuous Filament Mat)) and in [11] a theoretical study is presented of the implications of this variability on the local buckling response of pultruded GRP beams.

It is the authors' view that the assumption in [13,14], viz. that the mechanical properties of the flat parts of the web and flanges are the same as those of the web-flange junction, is likely to be unconservative, simply because coupons cut from the flat parts will have a more uniform fibre architecture. The architecture of the web-flange junction is different in a number of respects. First, there is a triangular shaped *core* of rovings at the centre of the junction. Second, the curvature of the fibre architecture is both zero and finite within the junction region, whereas the curvature of the fibre architecture in the coupon is zero. And third, there is more evidence of wrinkling of the CFM in web-flange junctions than in flat coupons. These differences constitute the principal reasons why it is important to characterise the strengths of web-flange junctions of pultruded GRP profiles. Only through the acquisition of such strength data will it be feasible to develop accurate and reliable numerical models for predicting the failure of pultruded GRP beams and columns. These models are required to underpin the development of a future limit state design code, the forerunner of which may be regarded as the *EUROCOMP Design Code and Handbook* [18], and they will grow in importance as the use of structural pultrusions in infrastructure increases in the years ahead.

About 3-years-ago the authors recognised the need to embark on a programme of research to try to characterise the stiffness and strength of web-flange junctions subjected to a number of basic load types. Their first research investigation was to quantify the tensile strengths of the web-flange junctions of two sizes of pultruded GRP WF profile. The results of this study were reported recently [19]. This was followed by a second study [20], which was concerned with quantifying the shear strengths of the web-flange junctions of the same two sizes of WF profile.

The present study represents an extension of the earlier work reported in [19,20] and is concerned with quantifying the rotational stiffness and strength of the web-flange junctions of the larger WF profile used in the previous two studies. Two test rigs have been developed for testing the web of the WF profile as a beam in three-point bending. One rig simulates simply supported conditions at the ends of the web and the other simulates clamped flanges. Details of the test rigs are presented. The instrumentation of the WF test specimens and the test procedure are also described. Simple analytical models, based on simply supported and semi-rigidly supported beams with a vertical point load applied at mid-span are introduced. The models have been used to analyse the data obtained from tests on the webs of 12 cross-section specimens of a 203×203×9.5 mm WF profile and to derive the rotational stiffnesses and strengths of their web-flange junctions and the transverse elastic moduli of their webs. The junction strengths are shown to be somewhat higher than the *minimum* transverse flexural strength value given in the manufacturer's design manual [21] for this size of pultruded GRP profile. In contrast, the transverse moduli values are significantly higher than the *minimum* value given in [21].

2. Test specimen details

The bending test specimens were prepared from an EXTREN® 500 series pultruded GRP 203×203×9.5 mm WF profile. (Note: reference to a trademark is solely for the purposes of factual accuracy. No endorsement whatsoever is implied.) The profile was cut transversely into 25, 40, 25, 40,…, mm widths to provide a total of 12 specimens. The six 25 mm wide specimens comprised the first group of specimens and were labelled I8-BH1.1-m (m = 1–6). Likewise, the six 40 mm wide specimens comprised the second group of specimens and were labelled I8-BH1.2-m (m = 1–6). Six 8 mm diameter holes were drilled through each of the flanges of each specimen in order to accommodate the end fixtures used to simulate simply supported and clamped flange conditions at the ends of the web. A sketch of a typical specimen is shown in Fig. 1.

The average dimensions of each test specimen were determined from measurements taken at several locations on the cross-section, as shown in Fig. 2. The average

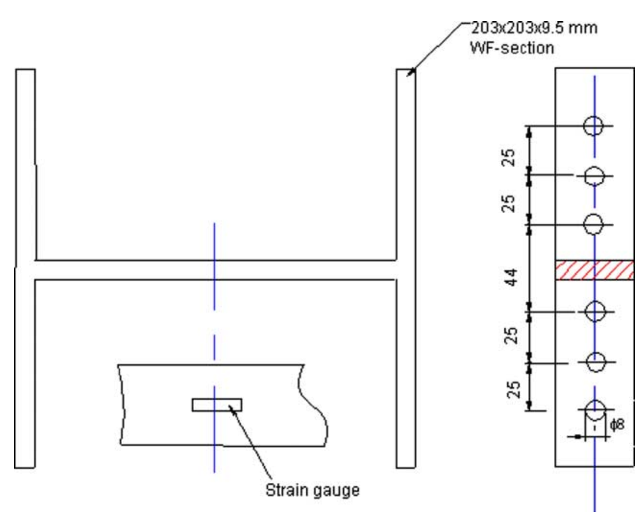

Fig. 1. Sketch of a 203×203×9.5 mm WF specimen used in the three-point flexure tests showing the positions of the bolt holes in the flanges and the location of the strain gauge at the centre of the web (all dimensions in millimetres).