ICCM24 24TH INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS
AUG 4-8, 2025 • BALTIMORE CONVENTION CENTER • BALTIMORE, MARYLAND

A NEW TEST FOR THE MECHANICAL CHARACTERISATION OF COMPOSITE PULTRUDE RODS UNDER COMPRESSION

G. Quino[1,2], C. Zhao[1], B. Zhang[2], P. Robinson[1], and R. S. Trask[2]

[1]Department of Aeronautics, Imperial College London
Exhibition road, SW7 2AZ, London, United Kingdom
Email: g.quino-quispe@imperial.ac.uk, web page: https://www.imperial.ac.uk/aeronautics/

[2]Bristol Composites Institute, University of Bristol
University walk, BS8 1TR, Bristol, United Kingdom
web page: www.bristol.ac.uk/composites

Keywords: CFRP; test method; compression; 4-point bending; pultrusion; DIC

ABSTRACT

Traditional direct compression tests on pultruded rods typically generate stress concentrations around the gripping regions, preventing accurate measurement of the true compressive strength. This paper introduces the 'cradle test', a novel experimental methodology designed to better characterise the compression performance of such materials. The setup consists of a polymeric beam that 'cradles' a pultruded rod, which is adhesively bonded to the beam. The method produced consistent failure within the gauge length and clear evidence of compression-dominated failure modes. A complementary technique based on full-field digital image correlation (DIC) strain measurements was also developed to obtain the complete strain *vs*. stress response. The approach is extendable to the characterisation of other materials.

1 INTRODUCTION

Composite pultruded rods can be key in the manufacture of components and structures with enhanced compression performance, as they typically exhibit reduced fibre misalignment [1]. However, measuring their compressive behaviour is challenging. Traditional compression testing methods, such as direct compression, often fail to produce consistent failure within the gauge length [2], [3].

We propose the 'cradle test' as a new method for characterising the mechanical response of fibre composite pultruded rods under uniaxial compression [4], [5]. The test gradually generates compression on the pultruded rod by applying four-point bending on a polymeric beam to which the rod is bonded to.

In the following sections a summary of the experimental methodology and some key results will be presented. Further details on the experimental methodology, data processing and results can be found in the full journal article published by the authors [4].

2 EXPERIMENTAL

2.1 Materials and specimen design

The material system characterised in this study was a commercially available carbon fibre/epoxy pultruded rod with a diameter of 0.8 mm. The fibre volume fraction was within the range of 49-55%, measured from micrographic images of the rods' cross sections. Tensile experiments on these rods showed that their elastic modulus was 134.1±4.5 GPa. This modulus value will later serve as validation of the results.

Figure 1a shows a schematic of the cradle test specimen assembly. The design of the specimen was conducted with a combination of analytical and FEA computational tools, such that: (i) The cradle

behaves linear and does not fail before the rod; (ii) buckling is prevented; (iii) rod bending is reduced; and (iv) strains on the cradle are measurable. The cradle test beams were fabricated from 15 mm thick polycarbonate (PC) plates. Load and supports spans were selected as $L = 120$ mm and $D = 60$ mm, respectively. The final dimensions of the cradle that met the design requirements are shown in Figure 1b.

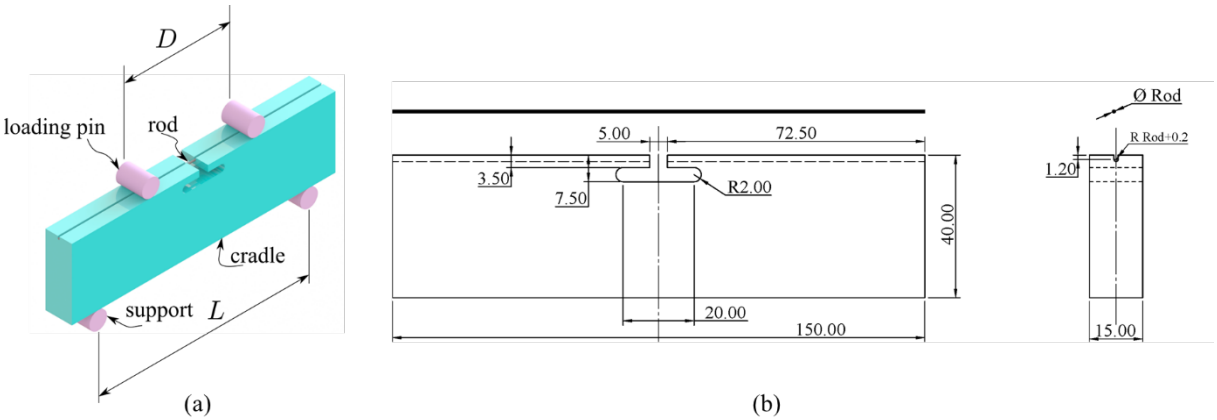


Figure 2: Cradle test design: (a) Schematic, and (b) Dimensions of the cradle test assembly.

2.2 Experimental setup

The setup, shown in Figure 2, included two cameras to image the speckled surfaces of the cradle (camera 1) and the pultruded rod (camera 2). Speckle patterns were carefully prepared to enhance the accuracy of DIC [6]. For the cradle, the 'tattoo speckle' pattern was used to provide optimal speckle sizes for the specific optical setup [7]. The experiment was conducted under displacement control at 0.18 mm/min, ensuring quasi-static loading of the specimen.

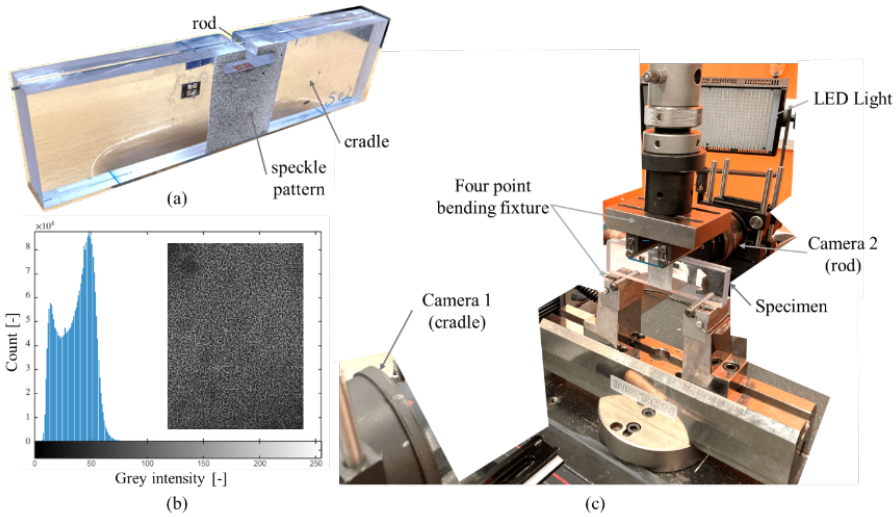


Figure 2: Prepared specimen and the loading rig and acquisition setup.

2.3 Data reduction method

By prescribing force equilibrium in the x-direction in the free body diagram shown in Figure 3, the resultant force across the cradle's midplane is equal to the absolute value of the compressive force on the pultruded rod F^r. FEA simulations demonstrated that the horizontal component of the reaction forces on the loading and supporting pins had negligible influence; therefore, they were excluded from the analysis. The compressive force acting on the rod can therefore be calculated by assuming plane stress, elasticity, and the integration of the DIC strain field of the cradle along the midplane path as shown in

equation (1).

$$F^r \approx -b \int_0^h \frac{E}{1-\nu^2} \varepsilon_{xx}^c(y) + \frac{\nu E}{1-\nu^2} \varepsilon_{yy}^c(y) dy, \quad (1)$$

where $\varepsilon_{xx}^c(y)$, and $\varepsilon_{yy}^c(y)$, are the x-, and y-strain components on the surface of the cradle along the midplane path; b is the width of the cradle (15 mm), and h is the length of the midplane path. The strain history of the rod ε^r was obtained using DIC on the images acquired by camera 2. Finally, F^r and ε^r were combined to produce the strain vs. stress curves. Figure 4 summarises the data reduction process.

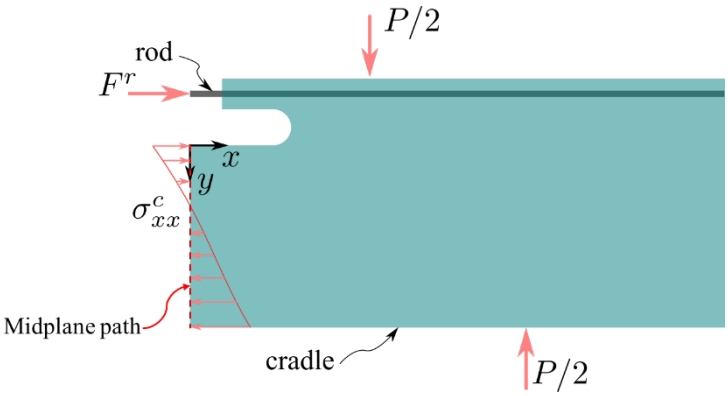


Figure 3: Free body diagram of half of the specimen.

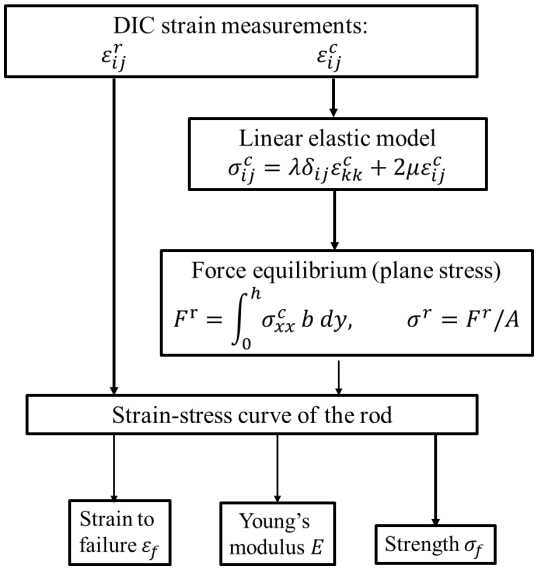


Figure 4: Flow chart of the data reduction process.

4 RESULTS

A typical displacement *vs*. load curves, and DIC strain fields measured in the experiment are shown in Figure 4a. Compression failure, away from the gripping region was consistently obtained across experiments (Figure 4b). From all tests, the DIC reconstructed strain *vs*. stress curves are shown in Figure 5. The average of the obtained elastic moduli was E=133.0 ± 11.3 GPa, close to the 134.1 ± 4.5 GPa measured from uniaxial tensile tests, validating the experiment and methodology. The average strain to failure was 1.16 ± 0.13%. The SEM images shown in Figure 6 showed fibre kink bands, a characteristic feature of compression failure.

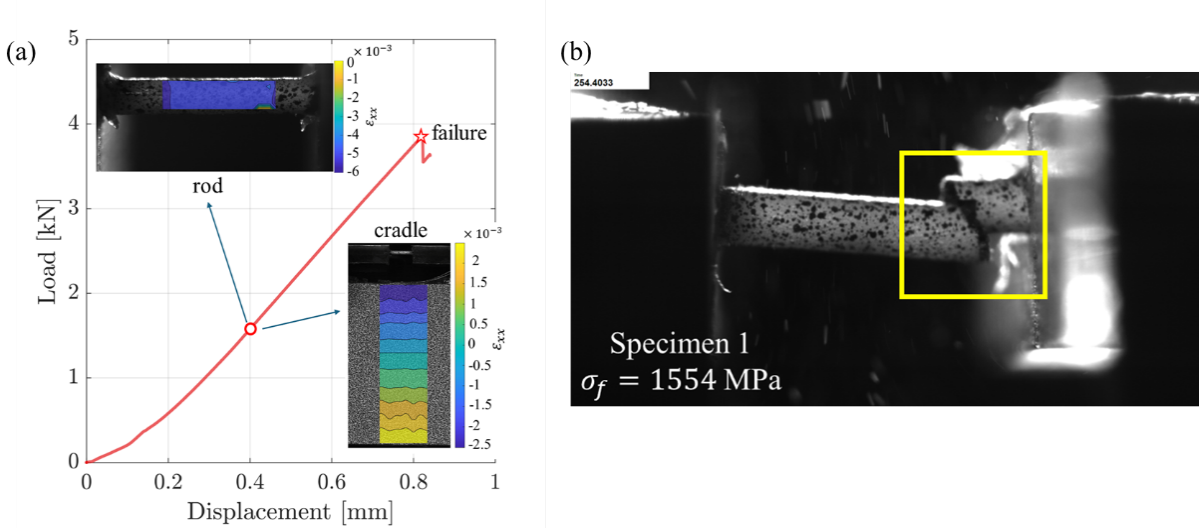


Figure 4: Data from a typical test: (a) Displacement-load curve and strain maps; and (b) pultruded rods failure mode.

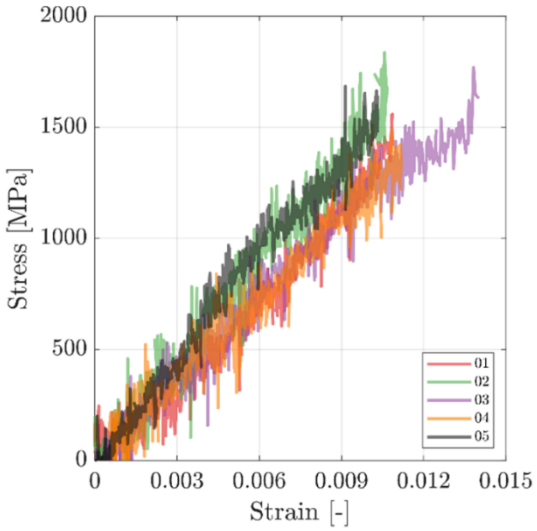


Figure 5: Strain-stress curves of all specimens

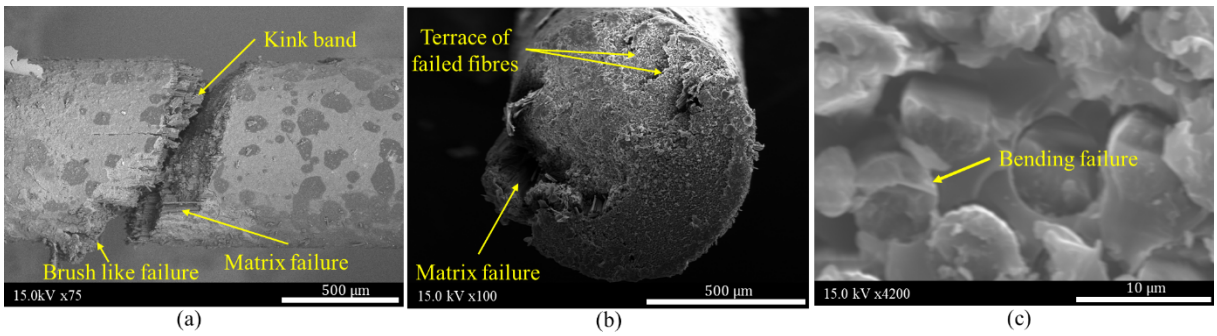


Figure 6: SEM micrography images: a) Full image of a failed specimen, b) Failure surface of another representative sample, and c) Individual failed fibres showing bending failure.

5 CONCLUSIONS

In this work, we presented and validated the ‘cradle test’, a novel methodology for characterising the compressive mechanical behaviour of pultruded rods. The main conclusions are:

- The new method simplifies specimen preparation and test setup and ensures compressive failure within the gauge length.
- The methodology can reconstruct the compressive strain vs. stress curves.
- The failure planes were located far from the bond region, suggesting mitigation of stress concentrations at gripping zones.

Further work is required to reduce the noise in the reconstructed stress, coming from the integration of the DIC strain field. The method will be used to rank various new material systems produced by pultrusion.

ACKNOWLEDGEMENTS

The authors kindly acknowledge the funding for this research provided by UK Engineering and Physical Sciences Research Council (EPSRC) programme Grant EP/T011653/1, Next Generation Fibre-Reinforced Composites (NextCOMP): a Full-Scale Redesign for Compression a collaboration between Imperial College London and the University of Bristol.

For the purpose of open access, the authors have applied a Creative Commons Attribution (CC BY) license to any author accepted manuscript version arising. Supporting data can be requested from the corresponding author but may be subject to confidentiality obligations or all underlying data to support the conclusions are provided within the manuscript or supplementary information.

REFERENCES

[1] N. Jeppesen, L. P. Mikkelsen, A. B. Dahl, A. N. Christensen, and V. A. Dahl, "Quantifying effects of manufacturing methods on fiber orientation in unidirectional composites using structure tensor analysis," *Compos Part A Appl Sci Manuf*, vol. 149, p. 106541, Oct. 2021, doi: 10.1016/j.compositesa.2021.106541.

[2] C. Soutis, "Compression testing of pultruded carbon fibre-epoxy cylindrical rods," *J Mater Sci*, vol. 34, pp. 3441–3446, 2000, [Online]. Available: https://link.springer.com/article/10.1023%2FA%3A1004832606677

[3] S. R. Vankar, A. N. Kaore, and C. S. Yerramalli, "Methodology for testing the compressive strength of pultruded composites," *Journal of Reinforced Plastics and Composites*, vol. 42, no. 11–12, pp. 544–557, Jun. 2023, doi: 10.1177/07316844221133293.

[4] C. Zhao, G. Quino, B. Zhang, P. Robinson, and R. S. Trask, "The cradle test: A new experiment to characterise the compression response of pultruded rods," *Compos Part A Appl Sci Manuf*, vol. 197, p. 109054, Oct. 2025, doi: 10.1016/j.compositesa.2025.109054.

[5] G. Quino, P. Robinson, and R. S. Trask, "Design of a bending experiment for mechanical characterisation of pultruded rods under compression," *Proceedings of the 20th European Conference on Composite Materials*, vol. Vol 3-Char, pp. 167–172, 2022, doi: 10.5075/epfl-298799_978-2-9701614-0-0.

[6] G. Quino, "Impact damage analysis of composite structures using digital image correlation," in *Non-destructive Testing of Impact Damage in Fiber-Reinforced Polymer Composites*, Elsevier, 2024, pp. 69–86. doi: 10.1016/B978-0-443-14120-1.00003-0.

[7] G. Quino *et al.*, "Speckle patterns for DIC in challenging scenarios: rapid application and impact endurance," *Meas Sci Technol*, vol. 32, no. 1, p. 015203, Jan. 2021, doi: 10.1088/1361-6501/abaae8.