Testing & modelling of composite substructures: opportunities and challenges

T. Laux[1a], R. Cappello[1], J.S. Callaghan[2], S.W. Boyd[3], D.A. Crump[3], A.F. Robinson[3], O.T. Thomsen[1], J.M. Dulieu-Barton[1,3]

[1]Bristol Composites Institute, Faculty of Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 ITR, UK, [2]Nuclear Futures Institute, School of Computer Science and Engineering, Bangor University, Bangor, Gwynedd, LL57 2DG, UK, [3]School of Engineering, Boldrewood Innovation Campus, University of Southampton, Southampton, UK

[a]tobi.laux@bristol.ac.uk

The evaluation of composite materials and structures at the higher length scales, i.e. on the subcomponent level, provides the opportunity to investigate complex structural interaction effects, particularly on the failure behaviour, which is neither possible on the coupon nor efficient on the full structural scale. While coupon-scale testing and modelling fail to capture material and structural scaling effects intrinsic to laminated composites, the full-scale is too resource intensive, both physically and virtually. With sophisticated 'virtual testing' techniques, usually based on the Finite Element (FE) method, set to replace physical testing in the design, development, and certification of high-performance structures, complex, information-rich, multi-instrumented experiments that can challenge and thus scrutinise model predictions on the higher structural length scale, are urgently needed [1]. However, testing and modelling at the subcomponent scale is conceptually challenging and no consensus has been reached on how model validation should be conducted. In previous research [2], [3], it has been demonstrated that full-field imaging techniques such as Digital Image Correlation (DIC) and infrared (IR) imaging for Thermoelastic Stress Analysis (TSA), in combination with full-field data fusion procedures, can unlock the potential of subcomponent testing for structural evaluation and model validation. Full-field imaging is attractive, as the non-uniform deformation and stress states that often occur in multiaxial subcomponent tests can be captured and compared to the model predictions. The presentation aims to demonstrate how full-field imaging and data fusion techniques can be employed for the comprehensive and quantitative assessment of large composite subcomponents. Data fusion techniques for integrated testing and modelling based on full-field imaging [2], [4] are applied to the evaluation of a composite wind turbine blade (WTB) spar cap to web T-joint subcomponent, subjected to realistic multiaxial loading conditions, as shown in Figure 1. The experiments were conducted using the Structures 2025 facility in the Large Structures Testing Laboratory (LSTL), of the National Infrastructure Laboratory, at the University of Southampton. The imaging set-up consisted of 8 DIC cameras and two IR cameras and is shown in Figure 1 (c). Two regions of interests were defined for imaging in the joint regions on both sides of the specimen, as shown in the overview of experimental results given in Figure 2. The experimental results will be presented, which highlight the challenges associated with imaging of large structures. Figure 2 (a) shows DIC ε_y strain maps taken on both sides of the specimen, clearly capturing the T-joint deformation dominated by transverse web and flange bending strains. Figure 2 (b) shows TSA results evaluated at two different load steps, further revealing stress redistributions associated with the occurrence of damage. Lastly, Figure 2 (c) shows the specimen after final failure, associated with delamination of the joint at the flange on side 2 of the specimen, as indicated in Figure 1 (c). The large, structural-level

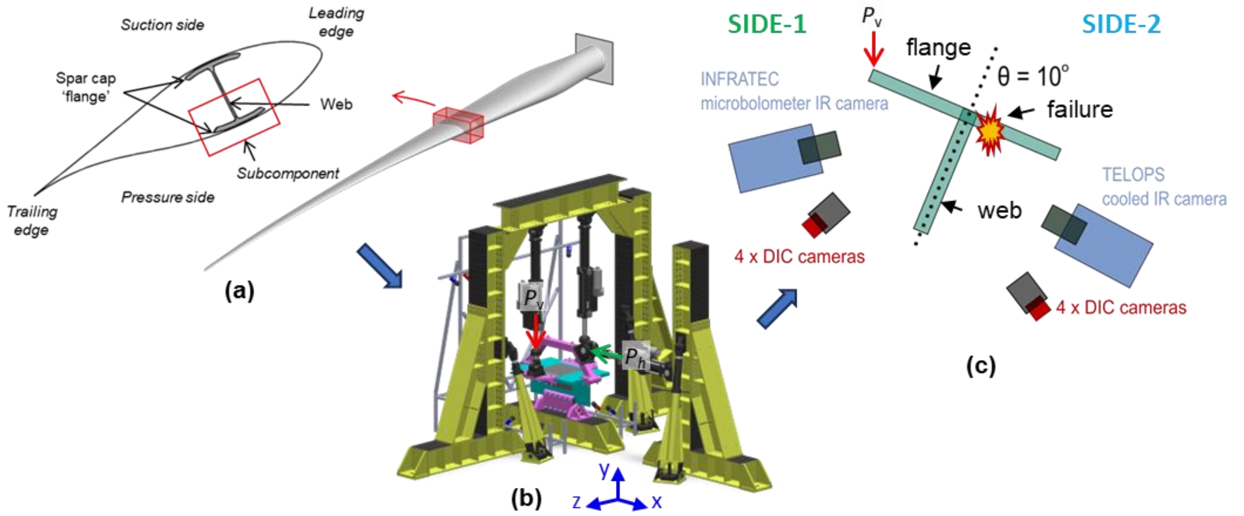

Fig. 1: Test overview: (a) definition of wind turbine blade subcomponent, (b) specimen and multiaxial loading rig with vertical actuators/loads (P_v), horizontal load (Ph), and definition of global coordinate system (x,y,z), and (c) multicamera imaging set-up for stereo DIC and TSA.

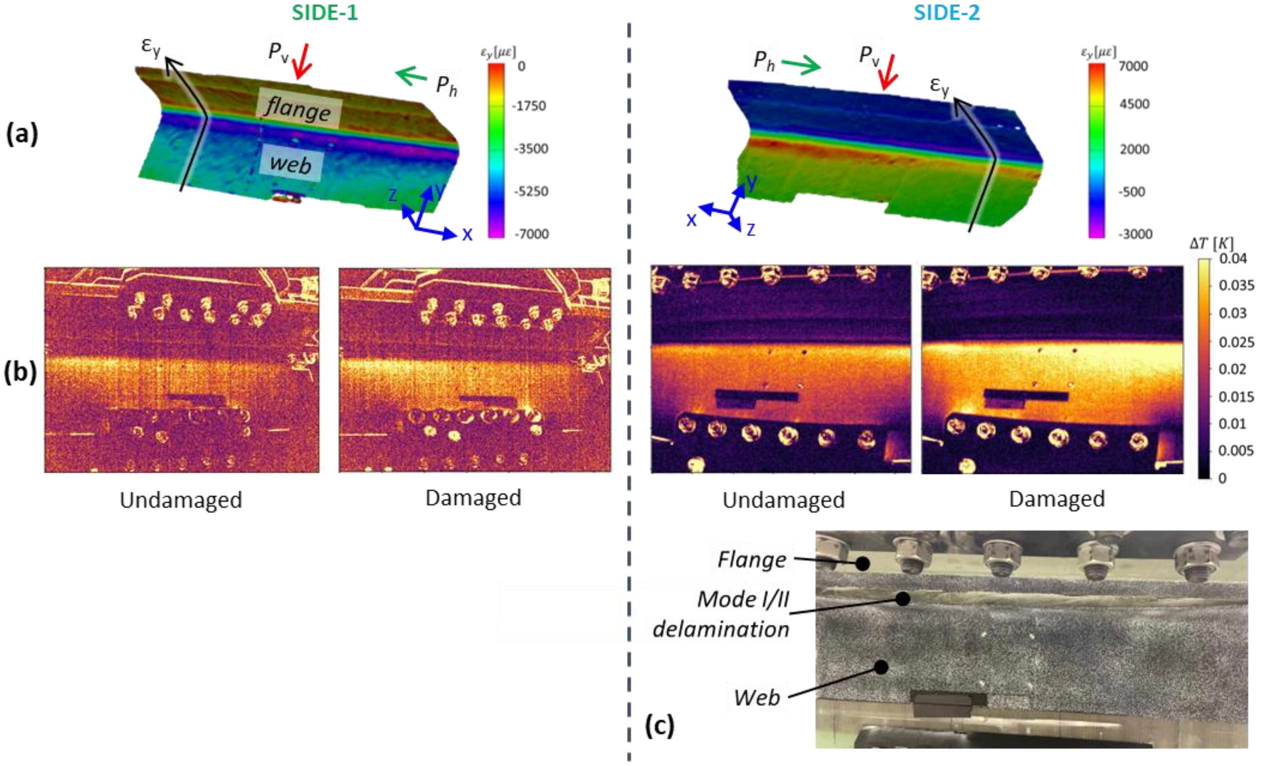

Fig. 2: Snapshot of experimental results: (a) Full-field DIC strain maps just before ultimate failure, (b) TSA *ΔT* maps before and after damage initiation on both sides of the specimen, and (c) ultimate delamination failure mode.

delamination (see Figure 2 (c)) is likely to be driven by a combination of in-plane fracture mode II shear stresses and tensile mode I peeling stresses. The complex stress interaction that has led to the failure, in association with the information-rich data obtained, is ideally suited to challenge, assess, and validate the predictive capability of advanced Finite Element (FE) model predictions on the subcomponent level. Therefore, a FE model of the WTB subcomponent experiment was generated in the commercial software Abaqus to predict the progressive interface failure observed.

It is shown that the information-rich experimental data enables a holistic and quantitative assessment of the model with regards to material properties, specimen geometry, boundary conditions, and constitutive models and failure criteria. Moreover, the current state-of-the-art regarding the capabilities of full-field imaging and data-fusion approaches are demonstrated.

References

[1] M. G. Ostergaard, A. R. Ibbotson, O. Le Roux, and A. M. Prior, “Virtual testing of aircraft structures,” *CEAS Aeronaut J*, vol. 1, no. 1–4, pp. 83–103, Sep. 2011, doi: 10.1007/s13272-011-0004-x.

[2] J. S. Callaghan, D. Crump, A. S. Nielsen, O. T. Thomsen, and J. M. Dulieu-Barton, “Quantitative Full-Field Data Fusion for Evaluation of Complex Structures,” *Exp Mech*, no. 0123456789, 2023, doi: 10.1007/s11340-023-00973-8.

[3] T. Laux *et al.*, “Testing of a wind turbine blade spar cap to web joint subcomponent subjected to multiaxial loading,” in *23rd International Conference on Composite Materials (ICCM23)*, Belfast, 2023.

[4] P. Lava, E. M. C. Jones, L. Wittevrongel, and F. Pierron, “Validation of finite-element models using full-field experimental data: Levelling finite-element analysis data through a digital image correlation engine,” *Strain*, vol. 56, no. 4, pp. 1–17, 2020, doi: 10.1111/str.12350.