Full field imaging techniques for high fidelity testing of a structural subcomponent

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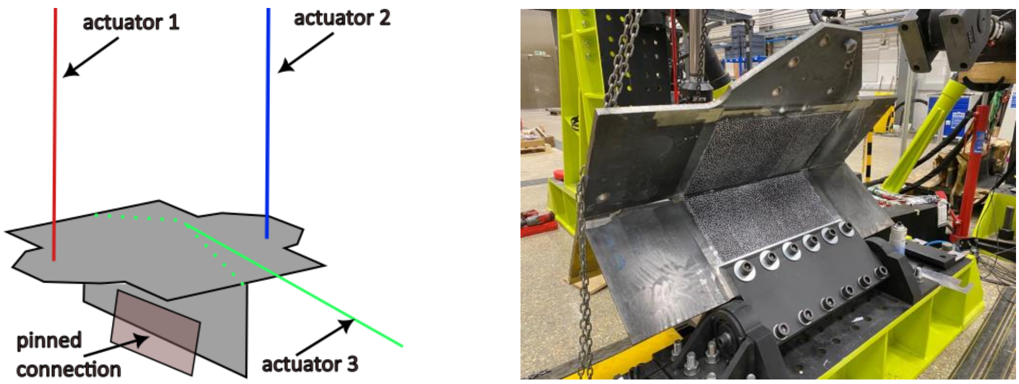
Abstract. The implementation of an experimental imaging setup to obtain detailed information on the mechanical behaviour of a large structural subcomponent is presented. Specifically, a T-Joint that is representative of a part of a Wind Turbine Blade (WTB) cross-section is studied. To refine the setup, a steel specimen is employed. Thermoelastic Stress Analysis (TSA) is combined with Digital Image Correlation (DIC) to obtain stresses and measure displacements, respectively, within the structure. These data are subsequently used to validate a numerical model of the analysed component.

Introduction

Experimental procedures to test large structures in the context of certification and validation are often challenging. Traditional testing procedures can be time-consuming, costly, and may not capture the full range of stress states and failure modes that a structure may experience during its in-service life. In recent years, research efforts focused on improving the accuracy and efficiency of testing procedures at different scales to speed up certification processes (the so-called testing pyramid). One such approach is the use of representative substructures, which can shorten testing procedures while still capturing key stress and failure characteristics. Additionally, the use of different experimental full field techniques, such as Thermoelastic Stress Analysis (TSA) and Digital Image Correlation (DIC), in combination with numerical modelling can provide rich datasets. The fusion of such different datasets can provide a more comprehensive understanding of structural performance under load. To demonstrate the effectiveness of this approach, a high-fidelity testing procedure for a structural subcomponent is presented. The chosen substructure is a spar cap to web T-joint of a Wind Turbine Blade (WTB) [1]. To tune the experimental setup in preparation for testing the composite WTB component, a steel T-joint with equivalent stiffness is used. In this way, the accuracy and precision of the image based measurements can be ascertained prior to testing the WTB component. Furthermore, Finite Element (FE) model predictions are correlated with the experimental data, both in terms of displacement/strains/temperature variation (or First Stress Invariant – FSI), to validate the testing procedure.

Experimental setup

A custom testing rig (schematized in Figure 1a) specifically designed to apply multiaxial loading to complex structures is set-up in a configuration to apply representative service loads to a WTB subcomponent. Two vertical actuators (1 and 2) are employed to apply bending and compression in the flange and the web, while a third horizontal actuator (3) allows the application of shear loading in the web. The loading system is part of the Structures 2025 facility in the Large Structures Testing Laboratory (LSTL) at the University of Southampton. The internal joint area was selected as the Region of Interest (ROI) for the experimental techniques, as shown in Figure 1b.



(a) (b)

Figure 1 – Experimental set-up: a) Schematic representation of the T-Joint and the three actuators and b) ROI with speckles applied.

Firstly, a measurement area, of 500 x 400 mm was cleaned and prepared with a thin coating of matt black paint, to provide an increased and uniform infrared emissivity for the thermal analysis. A computer-generated random speckle pattern (speckle size of 2.5 mm) was then applied using white matt paint and a stencil, for

DIC. Additionally, five aluminium foil markers were positioned in known locations on the specimen for physical reference and visibility in both DIC and TSA images.
The flange is bent applying a force through actuator 1, in load control, while actuator 2 is kept in displacement control. The shear load applied with actuator 3 is not included in the present study.
A stereo pair of FLIR blackfly cameras with 8 MP sensor with 25 mm Computar V2528 lenses were used to capture white light images. DIC was performed using the commercial software MatchID. Images were captured during a load ramp from 0 to 16 kN using a frame rate of 0.5 Hz.
A photon detector Telops FAST M2K infra-red camera fitted with a 13 mm lens was used to capture images at 50 Hz for the TSA. The structure was cyclically loaded at 0.5 Hz with 8.5 kN mean and 8 kN amplitude. The linear elastic finite element model includes a custom user subroutine that evaluates the thermoelastic effect and the heat transfer, both in-plane and through-the-thickness of the structure [2]. The boundary conditions and loads in the model were defined to match the experimental testing conditions.

Results and discussion

Full field experimental maps related to the sum of the principal stresses were obtained using TSA and are shown in Figure 2a in terms of the thermoelastic temperature change (ΔT). The stress distribution in the joint is clearly visible, which compares well with the equivalent data obtained from the model shown in Figure 2b. Figure 2c shows the temperature variation along a line through the centre of the specimen (white dotted lines in Figures 2a and b), showing a close match between numerical and experimental data. The good comparison demonstrates that at the low loading frequency adiabatic conditions are met and the non-uniform stress state which includes in-plane and through-thickness temperature gradients does not cause heat transfer.

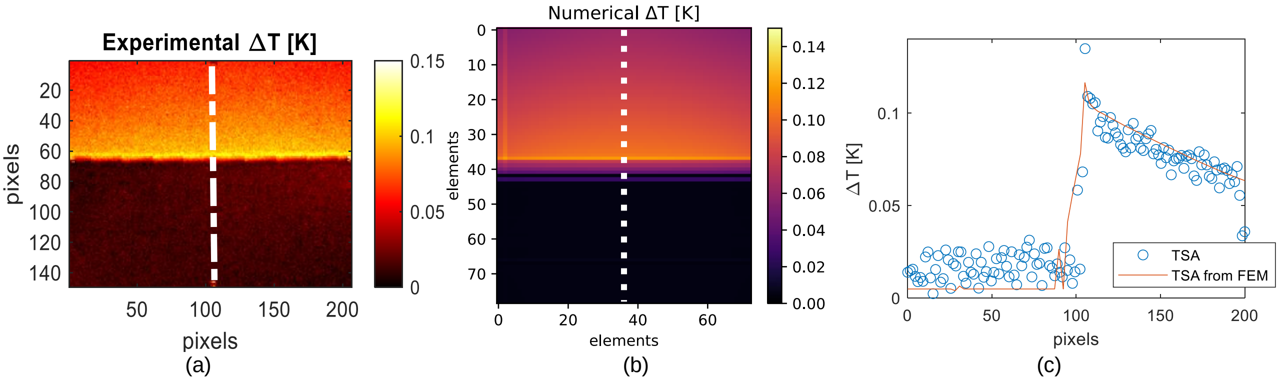


Figure 2 – a) Experimental ΔT b) Numerically obtained ΔT c) comparison between experimental and numerical data. Same scale is applied.

The displacement magnitude captured using DIC and predicted using the FE model are shown in Figures 3a and b, respectively. The qualitative comparison shows good agreement, verifying the applied model boundary conditions and modelling assumptions.

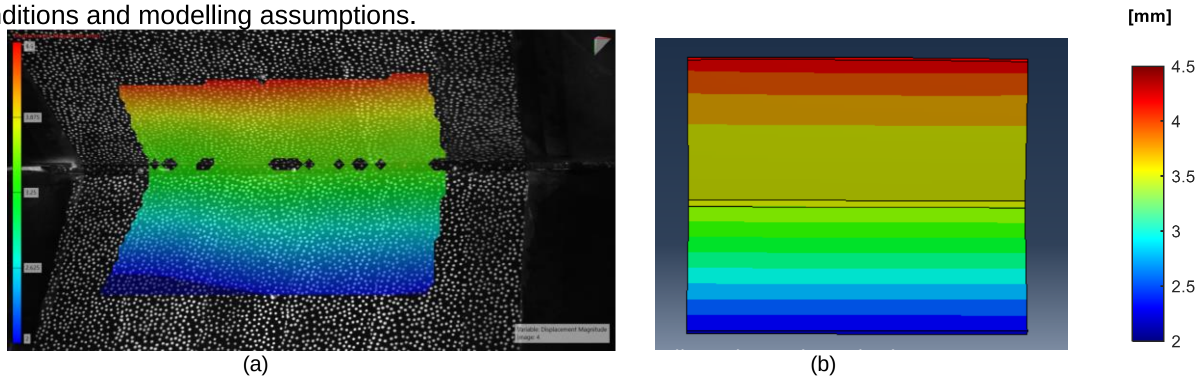


Figure 3 – Qualitative comparison between a) Experimental and b) Numerical displacement magnitude maps. Same scale is applied.

Conclusion

The combination of TSA, DIC, and FE modelling offers a powerful tool for studying complex stress fields. The approach can provide valuable insights into the mechanical performance of structural components. The imaging setup, developed and applied to a steel specimen, can be used to analyse more complex materials, such as composites, commonly used in wind turbine blades and retrieve meaningful information about the mechanisms of failure in real-world applications.

References

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