Full-field evaluation of a the load response of a wind turbine blade substructure

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Abstract

A composite wind turbine blade (WTB) substructure is analysed using full-field experimental techniques thermoelastic stress analysis (TSA) and digital image correlation (DIC) and compared to a high-fidelity finite element (FE) numerical model. This is the first step in developing a methodology for high-fidelity evaluation of WTB substructures, by integrating complex numerical modelling with data-rich experimental testing, which is expected to significantly reduce design and certification time and costs for wind turbine blades. The paper describes an initial study that is conducted on a “T-joint” of a WTB substructure, which was loaded in tension in a three point bend (3PB) configuration.

Introduction

The load response and failure mechanisms of wind turbine blade substructures are generally not well understood, and current certification only requires testing of material coupons and full-scale blades following the well-established ‘building block’ approach ([1],[2]). Material failure criteria do not necessarily predict failure on the structural scale level, and full-scale computational blade models lack detail due to computational constraints. Full-scale tests give the designers information regarding the structural behaviour of the blades, however they are costly [3], and primarily conducted to comply with certification requirements. A high-fidelity method is therefore utilised that integrates numerical modelling with testing, whereby the experimental design is defined by extraction of substructure boundary conditions (displacements/loads) by the initial global FE model. Following this, the experimental observations on the substructure scale are correlated with high-fidelity local FE model results in a closed-loop input/feedback loop that is used to inform and further improve the model predictions. The paper focuses on a study of a cross-sectional region of a 59 m wind turbine blade, where the shear web joins the main spar, referred to as the “T-joint”.

Numerical modelling and experimental setup

A refined local FE model was constructed using 20-node solid elements to capture stress and strain distributions in three-dimensions. The geometry was defined by scanning the cross section of the physical T-joint so that the geometry was defined, and then assigning regional material data that was extracted from the global FE model. The T-joint mainly consists of unidirectional and biaxial resin infused glass fibre, with some wooden core materials.

To gain an initial understanding of the load response of the structure, a three point bend (3PB) test in the blade cross sectional plane was designed (***Figure 1***). The load was applied in the direction collinear with the web in the cross-sectional plane. The test rig was designed for the 3PB test to be adjustable, so that it can be used for varying asymmetric geometries accommodating for different boundary condition locations, in both tension and compression loads, which are accommodated for through simple test rig adaptations. Thermoelastic stress analysis (TSA) and digital image correlation (DIC) was used to gain full-field measurements from positive R-ratio cyclic and quasi-static load cases respectively. For TSA a FLIR SC5500-M photon detector was used, and for DIC two Manta G504B monochromatic cameras were used in a stereo configuration.

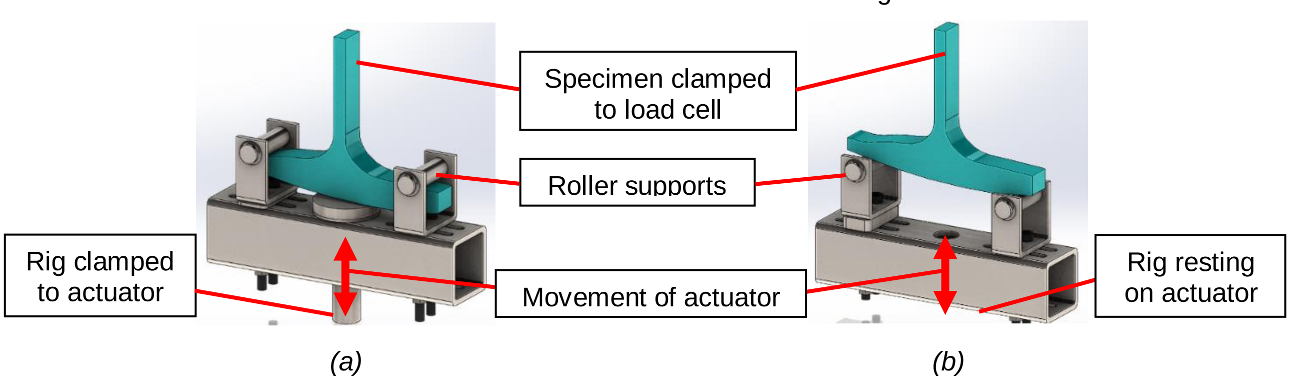
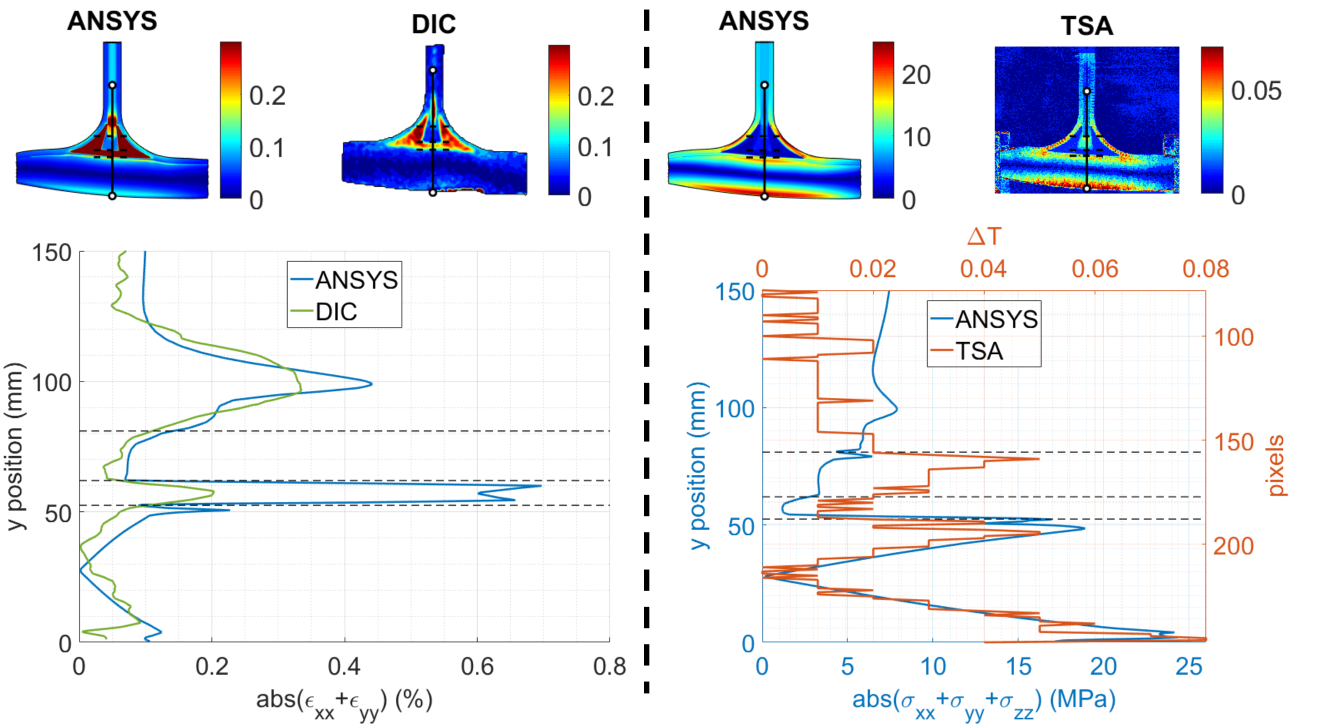


Figure 1*: 3PB load rig configurations – (a) Tension; (b) Compression*

Results

The predicted strain and stress fields and the experimental strain and temperature difference fields generally match well (***Figure 2***). The midline plot demonstrates the close match for the FE-DIC results, although differences can be observed, namely: a non-uniform bending axis, missed laminate detail, and smoothed data from the experimental result; and non-matching stiffness of core material. The FE-TSA midline results show a close similarity by pattern, where the differences in magnitude can be attributed to the effect of the thermoelastic constant which acts like a scaling factor for each material. An inherent feature that is incorporated into the FE model shows a strain concentration and negates a stress concentration that are not captured experimentally, which suggests a mischaracterisation of the feature. Interestingly the strain and stress concentrations are apparent in different regions of the substructure, which gives an indication into the stiffness and strength effects of the load response.



(a) *(b)*

Figure 2: *Numerical and experimental result comparison by surface contours and midline plots – (a) sum of surface in-plane normal strains from FE and DIC; (b) sum of surface normal stresses from FE and change in temperature from TSA*

Conclusions

An initial full-field study of the load response of a WTB substructure has shown a good match between the numerical predictions and experimental results. The results will affect the further development of the numerical modelling framework (global to local high-fidelity), where key geometrical features will be identified with regard to their influence on the onset and progression of damage and failure (i.e. fracture planes, crack initiation zones), as well as allowing for initial model validation. Also, key parameters such as material stiffness have been identified that can be improved by parametric analysis and material characterisation studies. Further testing is ongoing for this substructure, including failure analysis under quasi-static loading, and then later fatigue loading.

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