UpWind

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"Integrated Wind Turbine Design"

Guidelines for design, stress analysis and testing of a structural blade detail

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1. INTRODUCTION

One of the main aims of the subcomponent testing and modelling efforts in WP3 of UPWIND was, to help improve reliability of wind turbine blade design. This implies that the test results and models need to be 'translated' in recommendations that aid the work of the designer. A similar effort was made near the finalization of the OPTIMAT project, see [1]. Recommendations from the general work in WP3 are found in [2].

This report presents the design and test recommendations and guidelines resulting from the work on subcomponents in UPWIND WP3.

Within the frame of Task 3.1 "Applied (phenomenological) material model" of work-package WP3 "Rotor Structure and Materials" of the UPWIND project tests on subcomponents of wind turbine blades were planned according to the DPA of WP3. A structure, representing a structural blade detail was selected, designed, manufactured, tested, assisted with NDT methods, and analysed, to come up with improved understanding of the structural behaviour of this detail.

The main objective of the subcomponent programme was:

To develop a cost-effective test representative of (a) blade structural detail(s).

Such a subcomponent can be used for various purposes, such as:

- Experimental validation of design details
- Optimisation of structural details
- Validation of (numerical) models
- Material tests (stress states and failure modes)
- Uncertainty analysis
- Investigating influence of manufacturing methods
- Testing and validation of repair methods
- Complementing full-scale blade tests

In the UPWIND programme a generic subcomponent was designed. 'Generic' in this case means both that this particular subcomponent did have similarities with a load-bearing spar representative of a blade, but did not reflect any particular proprietary blade design, and that the beam could be used to study the effect of small variations in configuration, e.g. damage induced in the web or bonding lines.
The UPWIND I-beam was designed to favour failure in the bondline between spar caps and web. Two different bondline geometries were compared. Bondline strengths achieved in the subcomponent tests were compared to material properties acquired for the bondline adhesive using various material tests. Numerical models were used to predict bondline stresses, strains and failure modes. Model predictions were verified in the subcomponent experiments.

In the design process of a blade, subcomponents can also be of great value to study the specific structural design details. This way subcomponents can be used to compare and validate different designs without manufacturing and testing the actual blade.

2. RECOMMENDATIONS

2.1 SUBCOMPONENT DESIGN

For a cost effective subcomponent test complex tests setups should be avoided. Preferably the subcomponent is designed in such a way that it can be tested in a standard load frame of average capacity. For design details that are shared by many blade designs, standard subcomponents can be used to simplify the design process and to generate data which is of use to many blade designs.
Full scale subcomponents are most desirable to avoid (unanticipated) scale effects in the experiments; however for large structures this may affect the benefits of using subcomponents. When scale effects

are expected to be limited and can be quantified, scaled subcomponents can be used to enable less complex test setups and allow for testing larger series.

Recommendation 1. Include design and modelling of, and tests on subcomponents as an intermediate step between coupon tests and full-scale tests to develop and validate critical structural blade details.

Recommendation 2. For cost effectiveness and reproducibility of the subcomponent experiments, testing in a standard 100 kN maximum capacity test frame is recommended. If this requires scaling down of the subcomponent the scale effects should be quantified.

Recommendation 3. For consistency and efficiency, standard subcomponent geometries should be developed and established for critical blade sections. For details that do not allow a generic subcomponent design, guidelines regarding size, boundary conditions, minimum test area etc. should be developed.

2.2 SUBCOMPONENT MODELLING

For analysis of the UPWIND subcomponent different models were developed [3]–[5]. Initially the scatter on the predictions was large. Agreement in terms of load, displacement and strains with an actual experiment was not acceptable. When evaluating the discrepancies between the predictions from the different models and the static test results, the availability of good material data for relevant loading directions of the constituents turned out to be a key factor for reliable modelling. For complex subcomponents with a large number of constituents, the important material parameters can be identified though their influence on the model predictions for deformation and failure mode.
For the bondline in the upwind subcomponents the failure modes could be predicted quite satisfactory using elements based on cohesive laws.

Recommendation 4. For input of the model, reliable material properties (e.g. strength, stiffness) for all constituents of the subcomponent should be obtained. For complex subcomponents the key material parameters can be identified by sensitivity analysis on the model.

Recommendation 5. For correct modelling of bondline failure modes, the use of cohesive laws is recommended.

Recommendation 6. Verify numerical models by comparing predictions for stiffness and deformation to experimental data from the subcomponent experiment.

2.3 SUBCOMPONENT TESTING

A total of 44 generic I-beams were distributed along the different test facilities. The beams consisted of 24 beams with a symmetric cross section and 20 asymmetric cross sections. Different test methods and test set-ups were used for testing the I-beams. In all cases, actuator displacement, force and strains at several locations were recorded. In some cases, full field measurement techniques were used (e.g. digital image correlation, thermo-elastic stress analysis, acoustic emitters). More details on the beam tests can be found in [6]-[14].
The suitability of measurement methods can also be dependent on the design of the subcomponent. For e.g. a full field strain measurement technique, an unobstructed view on the area of interest must be available. For this purpose subcomponents can actually be of additional value because measurements that cannot be made on an actual blade can be made possible by the use of subcomponent testing.

Recommendation 7. Create a section with constant loading in the subcomponent to test a bigger material volume. This can be done by varying loading, geometry and lay-up, depending on the properties of interest.

Recommendation 8. Selection of the test setup and measurements should be based on both the validation of the structural integrity of the subcomponent as well as the validation of numerical models.

Recommendation 9. To avoid undesired failure, load introduction points and supports should be carefully designed and considered early in the design process of the subcomponent.. If necessary, reinforcements should be implemented.

Recommendation 10. For areas of specific interest, a combination of local (strain gauge) and full-field (digital image correlation, thermo-elastic stress analysis) strain measurements should be used.

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