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Subcomponent testing for wind turbine blades

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Abstract:

A subcomponent which represents a structural detail of a blade can be a cost-effective addition prior to full scale blade tests. Such a subcomponent can be used for various purposes, like material testing, modelling and validation and investigating the influence of manufacturing and repair methods.

A generic I-beam assembly is suggested, which can be tested in e.g. 3- and 4-point bending, as well as statically and in fatigue. Another, more generic subcomponent is a tubular specimen, which was used for obtaining a detailed description of adhesive properties without the effect of sharp edges or other local geometries at corners of the bonded specimens. A brief description of the experiments and results on these subcomponents is presented.

Keywords: *wind turbine blade, subcomponent testing, bond line thickness*

1. Introduction

As rotor blades, wind farm investments and risks get larger, optimal and reliable design becomes more important. Currently, wind turbine blades are designed, based on material characteristics obtained from test coupon data. Consequently, extensive testing programmes, in static and fatigue loading precede the actual production of a new wind turbine blade. Full scale static and fatigue blade tests are required for certification of new blades and when major design, production or material changes are done in existing certified blades.

For these cases, subcomponent testing might fill up the gap between coupon and full scale blade testing because the structural behaviour that is not evident in simple coupons could be obtained with subcomponents. Therefore, a subcomponent which represents a specific structural detail of a blade can be a cost-effective addition to realize a more optimized design.

This way, major changes in e.g. use of new material or production process can be tested before the prototype of a new blade is produced.

2. Purposes of subcomponent testing

Material characterization

Some material characteristics within the blade construction can be obtained from subcomponent testing. For example, an I-beam can provide shear data from the web [1], sandwich panels or other beam-like structures can provide compression data without buckling and bonded tubes under torsion are useful to obtain shear properties of adhesives.

Modelling and validation

Where small test coupons give data essentially based on single-axis tests, subcomponents can provide more realistic input for developing methodologies that predict multi-axial stresses and damage progression. These models still lack the experimental basis from structure-like coupons.

Manufacturing and repair methods

Common manufacturing flaws can be introduced into a subcomponent, such as an I-beam, and subsequently their performance can be determined. Simultaneously, damaged I-beams can be repaired and tested to compare the performance.

The influence of modifications in the manufacturing process, (grinding, curing, bond line thickness, new materials, etc), can be investigated with a subcomponent test programme.

Complementing full-scale blade tests

Data gathered from subcomponents, that (accurately) represent the structural details of the design can improve the design. Unexpected failures or failure modes, not evident in simple coupons, might arise during fatigue testing of subcomponents.

New designed complex structural parts or an improved manufacturing process step could be (re-)tested, prior to a whole new blade manufacturing and testing as the required final verification. By strain/stress analysis in the subcomponent and in the area of the blade it represents, and the analysis of the possible failure during a full-scale test, further improvement of the subcomponents can be achieved.

3. Structural details and subcomponent design

There are several structural details in a blade that can be represented by a subcomponent. Some of these details are schematically indicated in Figure 1.

The first step in representing structural blade details would be to scale-down a turbine blade to a more manageable dimension. As an advantage, lower forces can be applied, but on the other hand, the geometrical complexity remains, making this subcomponent more difficult to manufacture and reproduce. Model blades like this have been extensively tested within the PROFAR project [2].

Also the bolted blade root to hub connection [3] and repaired uni-axial composite specimens [4] were investigated in previous projects. The latter, though, did not deal with the complex three-dimensional stress state in a realistic structural repair.

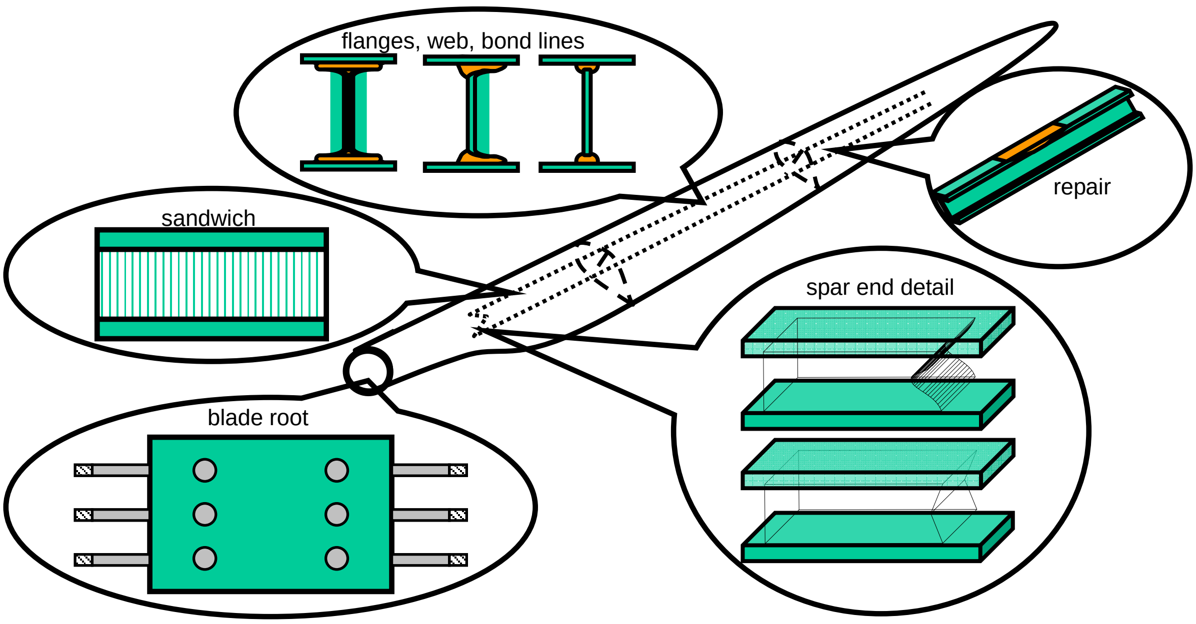

Figure 1: Structural details in wind turbine blade

4. Generic subcomponents

From the description of the various regions of interest in a rotor blade it becomes clear that many different subcomponents are likely to be necessary to evaluate the above (non-comprehensive) structural details. As a consequence, a generic subcomponent design is preferable, without representing a single manufacturer's design philosophy. An I-beam subcomponent could fulfil these requirements. It can be tailored to full-scale blades (e.g. cross sectional dimension variations, reinforcements and sandwich constructions) and/or tested in different test set-ups (e.g. 3-point or 4-point bending).

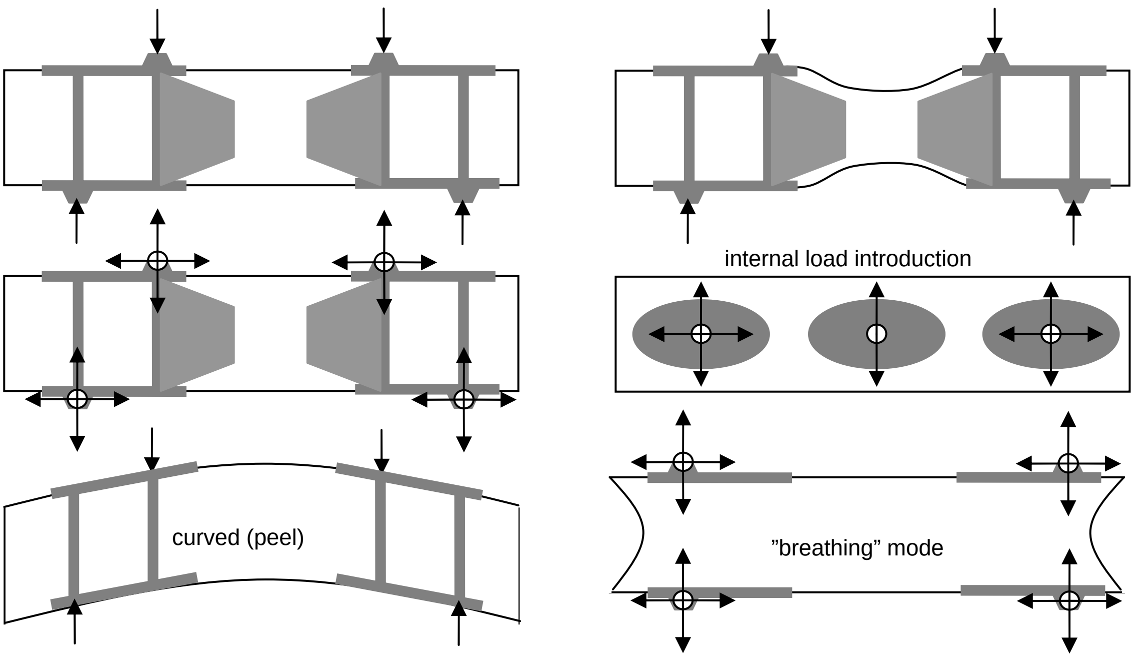

Figure 2: I-beam and test load introduction concepts

Some options for different kind of tests or load introductions can be seen in Figure 2. The I-beams are shown from the side and the grey areas are (possible) reinforced parts. The concept for 3- and 4-point bending is similar, although 4-point bending introduces a clearer loading condition that could prevent failure at the load introduction points and has a larger bending zone than in 3-point bending.

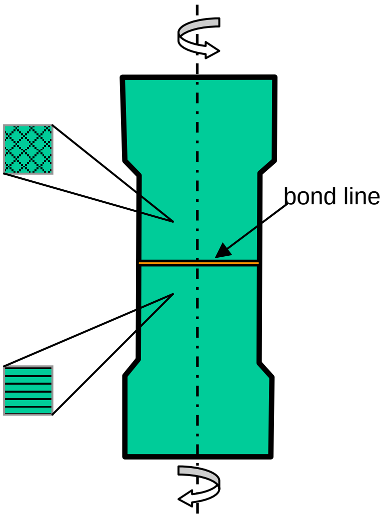

Figure 3: Tubular subcomponent

Another, more generic subcomponent is a tubular specimen, which could be used for biaxial laminate testing but also to obtain a detailed description of adhesive properties. It was proposed to obtain shear properties of a structural adhesive, used by the wind turbine industry, by testing bonded tubes under torsion [5] (Figure 3). This configuration allows to include different adhesive thicknesses and to eliminate effects of sharp corners and other local geometries present in joint configurations commonly used for this purpose, e.g. single lap or strapped joints. Another advantage might be the possibility to re-use the specimens (e.g. remove the tested bond line, and continue with a shorter tube) or test the bond line between two different adherends. Also, fatigue tests could be performed with this configuration, which can include a combination of torsion with axial tensile and compressive loads.

5. Results on selected subcomponent testing

I-beams

I-beams were built from two C-beams as the web (±45° fibres) bonded to flanges (unidirectional fibres) (Figure 4). These subcomponents were tested in 3- and 4-point bending in a 1000 kN axial test frame. The experiments were useful to identify main failure zones and to evaluate the relevance of both tests on blade designs. The 4-point bending test showed the advantage of including a larger bending zone (Figure 5). These subcomponents were found to be a very versatile and promising configuration for obtaining a wide range of mechanical properties of wind turbine blades and should be considered for further research [5].

Figure 4: I-beam built with two C-beams as the web and bonded to flanges

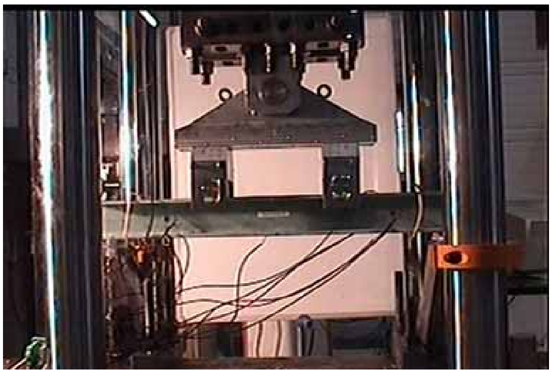

Figure 5: 4-point bending test setup [5]

Tubes

The tubes were manufactured with a Resin Transfer Moulding (RTM) process within a metal mould that ensured a constant thickness along the tube. After infusion and post-curing, the tubes were cut (Figure 3), bonded with the desired adhesive thickness, and tested under torsion in a 250kN / 4kNm axial/torsion test frame and compared with an un-bonded tube and a strapped double-sided joint with sharp corners. This is shown in Figure 6.

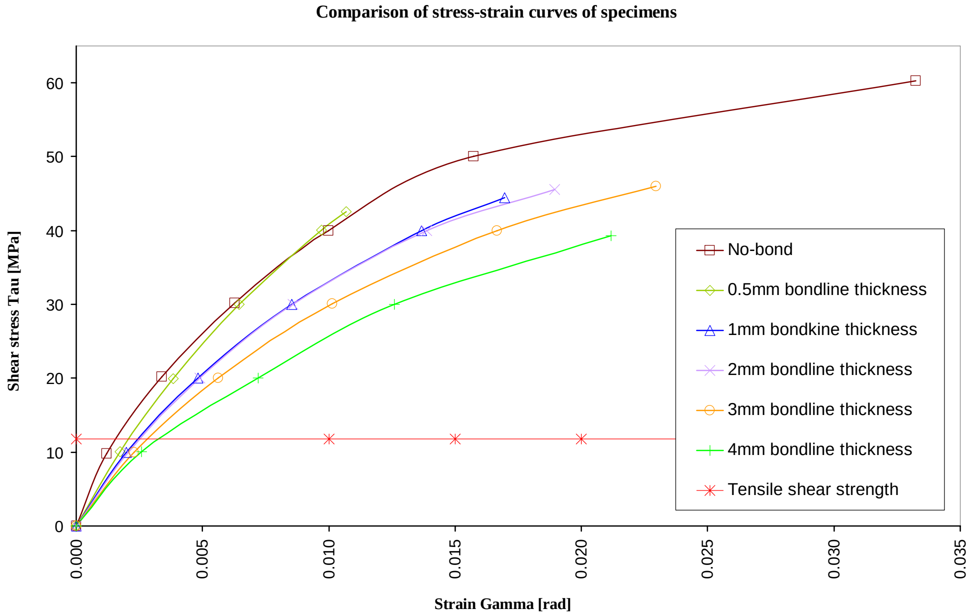

Figure 6: Comparison of bonded and un-bonded tubular specimens with tensile shear test

A remarkably high strength of the tubular specimens was found in comparison to the strapped double-sided joints with sharp corners, concluding that the selected test is a better configuration for obtaining shear properties of adhesives influenced only by the bondline thickness effect.

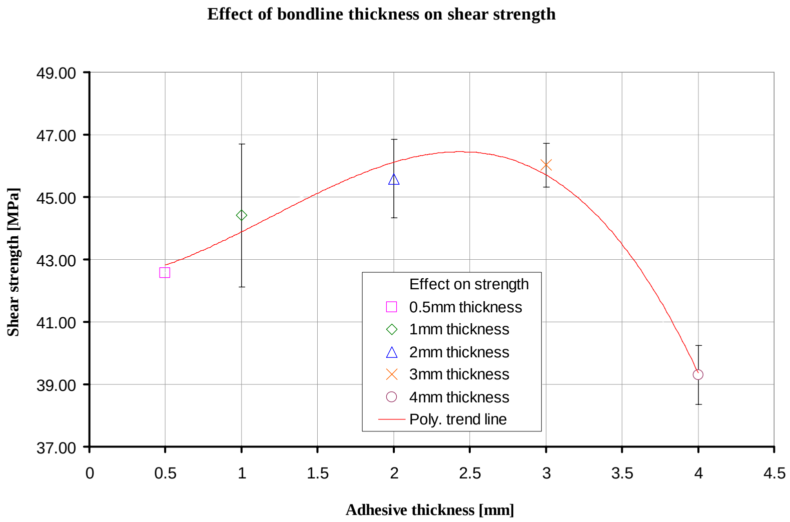

Figure 7: Comparison of shear strengths at different adhesive thicknesses. The error bars show the highest and lowest measurements of a specific adhesive thickness [5]

Different adhesive thicknesses seemed to affected the shear strength and strains of the bondline. Initial results showed higher strength for an adhesive thickness in the range of 2 mm to 3 mm that has to be corroborated with more experiments to confirm this suspected trend. The strain was also affected but the method of measuring the deformation directly in the bondline needs further development (see Figure 7).

6. Concluding Remarks

By testing subcomponents, certain mechanical properties of the materials that were not evident in simple coupons, could be obtained. I-beams are very promising for obtaining a wide range of data and unexpected behaviour of the composite assemblies and should be considered for further research.

The tests on bonded tubes were a successful method for obtaining shear properties of the bondline. These tests seem to show different shear properties with different thicknesses of the adhesive, which should be further investigated. More tests of these subcomponents are required.

7. Acknowledgements

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