SUBCOMPONENT TESTING OF TRAILING EDGE PANELS IN WIND TURBINE BLADES

Kim Branner[1], Peter Berring[1] and Philipp Ulrich Haselbach[1]

[1]Department of Wind Energy, Technical University of Denmark
P.O. Box 49, Frederiksborgvej 399, DK-4000 Roskilde, Denmark, Country
Email: kibr@dtu.dk, Web Page: http:// www.vindenergi.dtu.dk

Keywords: Substructure testing, Finite element analysis, Wind turbine blade, Trailing edge

Abstract
This paper proposes a static subcomponent test method designed to check the compressive strength of the trailing edge region in wind turbine blades under a simplified loading. The paper presents numerical simulations using the proposed subcomponent test method and discusses its ability to be used for checking the compressive strength of the trailing edge region in wind turbine blades.

1. Introduction

For the first time the new DNV GL rotor blade standard DNVGL-ST-0376 [1] makes it possible to use subcomponent testing as part of a blade certification [2]. However, it is not clear how subcomponent testing should be done in order to be used in certification. This paper proposes a static subcomponent test method designed to check the compressive strength of the trailing edge region under a simplified loading.

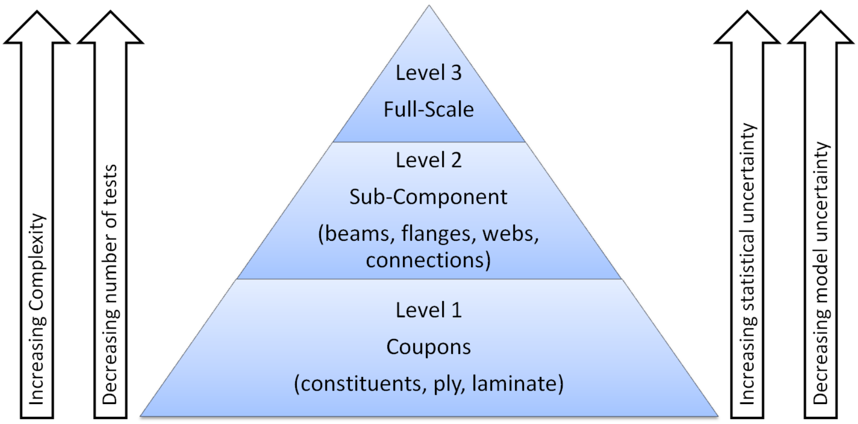

Figure 1. The test pyramid illustrating tests performed for assessment of the load bearing capacity of wind turbine blades.

The design of wind turbine blades incorporates tests on different scales as shown in Figure 1. Test of material coupons (level 1) is performed in order to determine material properties, while full-scale blade tests (level 3) is performed on typically one or two blades in order to verify that the blade type have the load carrying capability and service life provided for in the design. For certification normally only material coupon tests and full scale blade tests are performed while no sub-component tests are

Excerpt from ISBN 978-3-00-053387-7

performed. The new DNV GL rotor blade standard now opens up for this, which also is further described in [3].

At coupon level, small tests specimens with the basic material are tested in order to determine the material properties and their statistical characteristics in both ultimate and fatigue limit states. The test specimens at coupon level are normally relative inexpensive to produce and test by which many repetitions can be performed if beneficial [5].

At full-scale level normally one or two prototypes of the blade are tested both dynamically and statically following the requirements in the IEC 61400-23 standard [4] on full-scale testing. Full-scale tests are very expensive and time-consuming due to the cost of a blade itself and the fact that dynamic tests can require several months to complete for large blades. Furthermore, full-scale tests are usually performed at the end of the design process as a last verifications step. Therefore, design iterations at this stage can be extremely expensive and delay the time-to-market significantly.

Sub-component tests in contrast can be used to determine the structural response and load bearing capacity of selected parts or sections and to verify computational models for potential critical details.

The paper presents numerical simulations using the proposed subcomponent test method and discusses its ability to be used for checking the compressive strength of the trailing edge region in wind turbine blades.

2. Trailing edge failure of full blades

The blade is modeled in MSC Patran/Marc with 20-noded layered continuum elements. The model is densely discretized with a characteristic element size of 40mm and the entire model consists of approximately 83600 elements. A moment- and shear force distribution is generated by applying four point loads along the blade at 13.2m, 18.6m, 24.9m and 28.75m from the root. These are the same positions where loads are applied at the full scale blade test in the test facility.

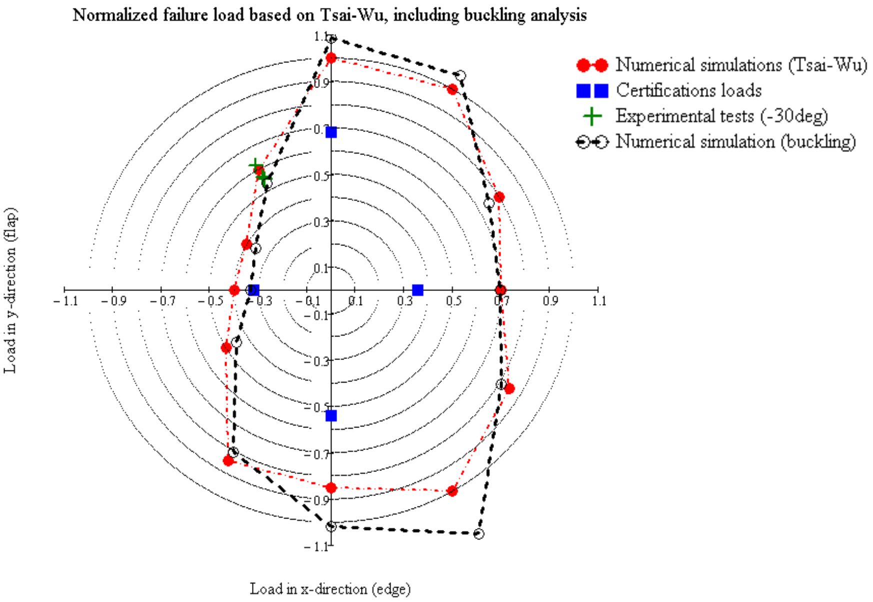

Figure 2. Load carrying capacity envelope for the 34m blade based on Tsai-Wu failure criteria and non-linear buckling analyses.

To predict the most critical load direction for the blade a parameter study is performed. For this purpose, the four load points used in the experiments, is rotated 360 degrees in steps of 30 degrees. At each direction the loading is increased until failure is predicted, either by exceeding the Tsai-Wu failure criteria or a non-linear buckling analysis. The failure loads for different load directions are then plotted as load carrying capacity envelopes as shown in Figure 2.

It is seen from Figure 2 that the blade is strongest in the flapwise direction and weakest when loaded towards the trailing edge. When the blade is loaded in the leading towards trailing (LTT) load direction, the trailing edge comes in compression and waves are forming in the trailing edge region of the blade as seen in Figure 3. As it can be seen from Figure 2 buckling is the pronounced failure mechanism for this blade in most load directions.

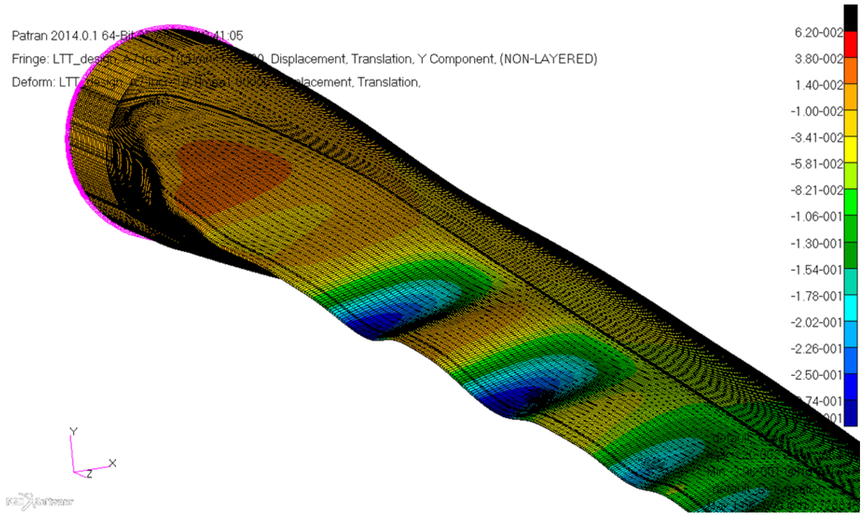

Figure 3. The numerical response of the blade subjected to leading towards trailing (LTT) load direction.

One of the most pronounced waves occur at 14.5 m from the root. This is the second wave from the root shown in Figure 3. As loading is increased these waves or buckles leads to failure in the laminate on the pressure side close to trailing edge adhesive joint as shown in Figure 4.

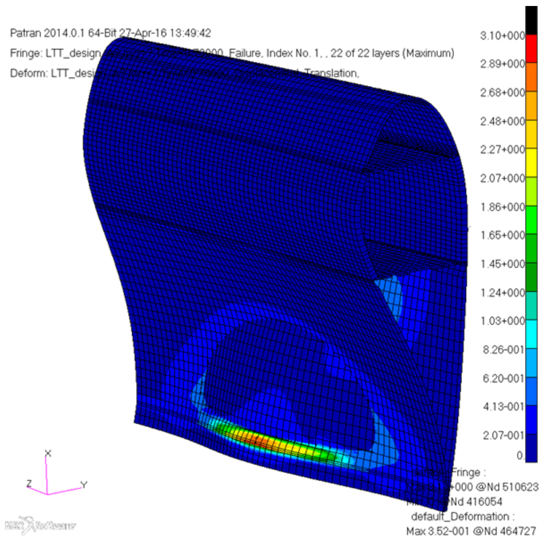

Figure 4. Failure computed by the Tsai-Wu failure criteria occur at 14.5 m from root. The blade is loaded in the LTT load direction.

Excerpt from ISBN 978-3-00-053387-7

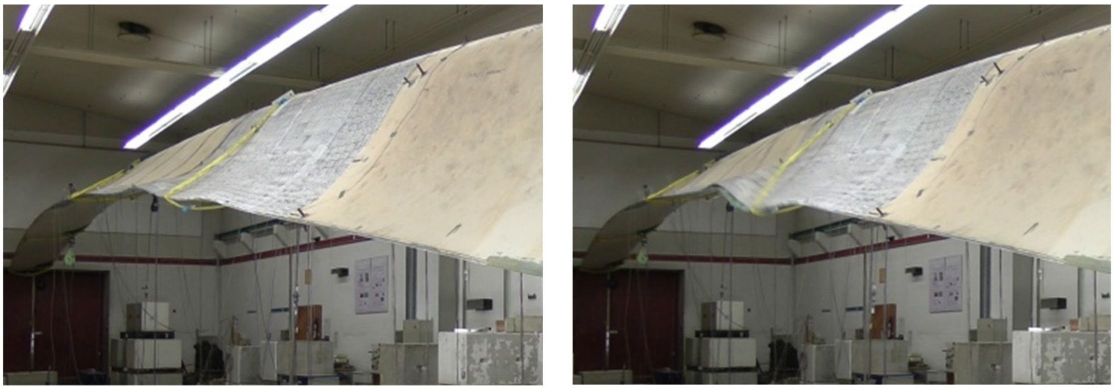

Figure 5. 34m SSP Technology blade tested to failure by loading 30° to the flapwise direction.

The accuracy of the numerical prediction method and the model reliability to predict ultimate failure was compared to results from three full-scale tests performed in the project [5]. Three 34m SSP Technology blades were tested to failure by loading the blades in an angle of 30° to the flapwise direction. In the test facility the blades were tested by pulling vertically towards the floor. This means that, compared to a flapwise load case with the pressure side towards the floor, the blade is rotated 30° so the trailing edge becomes closer to the floor. For all three blade tests pronounced buckling waves in the trailing edge region occurred before ultimate failure occurred as shown in Figure 5. The failure of the three blades is marked with crosses in Figure 2. The average failure load for the three blade tests is 58% of the predicted maximum strength in flapwise direction and very close to the predicted failure load. The three performed full-scale tests and analyses of the failure sequence are further described in [6-9]. The importance of using non-linear finite element analysis for the same blade in the certification process is analyzed in [10].

The three full scale blade tests were conducted in a load direction angle of 60° from LTT towards the load direction suction side towards pressure side (STP). This load direction is too far away from the LTT direction in order to be tested with the proposed subcomponent test method. However, the observed failure mechanism in the full scale tests is similar to what is observed in the LTT simulations.

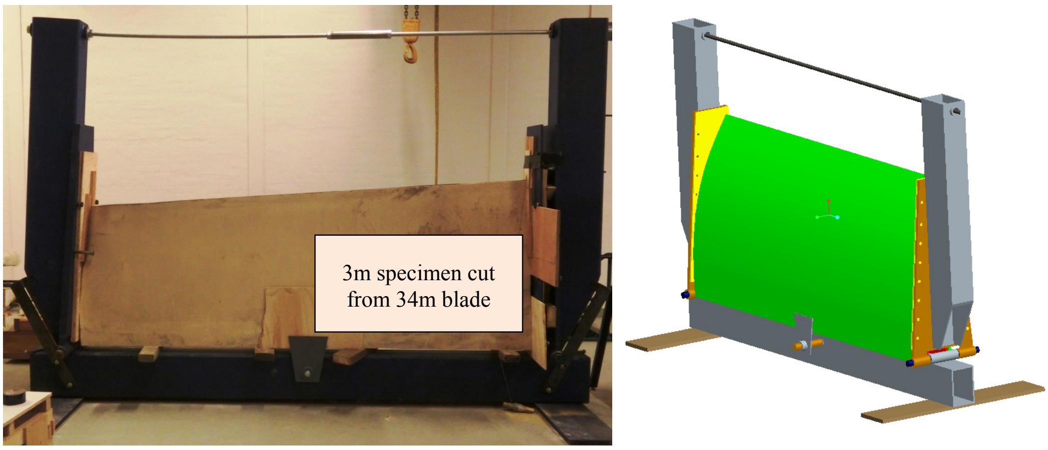

Figure 6. Trailing edge panel cut from SSP Technology 34m blade from approximately 26m to 29m from blade root inserted in test rig.

Excerpt from ISBN 978-3-00-053387-7

3. Proposed subcomponent test method

A test rig for subcomponent testing of trailing edge panels and adhesive bonds has been developed and constructed at DTU (Figure 6). The test rig is designed for testing cut-outs of the same blades tested in full-scale. The cut-outs consist of the trailing edge panels, the shear web closest to the trailing edge and part of the caps. The specimen is loaded by means of driving the top of the two vertical frames towards each other forcing a linear varying compressive displacement on the specimen. The forced compressive displacement is then zero at the hinges, which is placed at the elastic center of the different test specimens and maximum at the trailing edge. This will then mimic an edgewise bending moment on the section. The load history is monitored by a load cell.

The idea with the subcomponent tests is to mimic the compressive loading of the trailing edge panels and bondline, which this region is subjected to under predominantly edgewise loading in full-scale tests. The subcomponent test method is designed to test the trailing edge region in load directions with pronounced leading towards trailing (LTT) loading and with some flapwise loading as well. It is assumed that a minor bending moment generated by asymmetric loading can be applied to trigger the buckling waves in the trailing edge region as observed in numerical analyses and full-scale tests.

A preliminary test of a blade subsection from 26-29m was performed by using the test rig (Figure 6). The test showed that the test setup functioned, but led to failure close to the boundary region at the smaller blade cross section end at 29m. Currently, the test rig is being upgraded and made ready for further subsection tests, including the section analyzed here.

4. Comparison between full blade and subcomponent test

In order to study the similarity between full scale blade testing and the proposed subcomponent test method, a subcomponent test specimen representing the blade section between 13m to 16m from blade root is simulated and analyzed. This test specimen has a critical buckling wave observed at 14.5m in the full blade simulation, which is at the center of the test specimen.

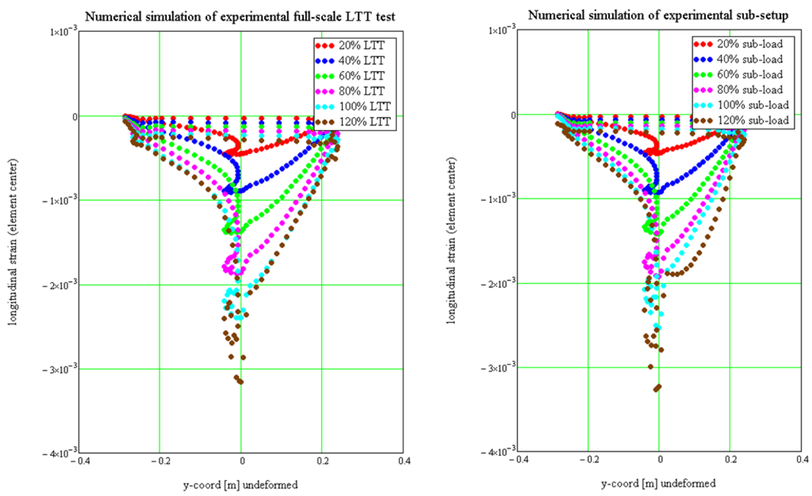

Figure 7. Comparison of strain level at 14.5m from root between simulation of full-scale test (LTT) and sub-component testing.

The longitudinal strain response at different load levels is compared at the 14.5m section between the simulation of full-scale test (LTT) and the similar sub-component testing of the same section. The results are shown in Figure 7. A load level of 100% load corresponds to the certification load in LTT. The certification loads are shown as blue squares in Figure 2. The strain responses seen at low load

Excerpt from ISBN 978-3-00-053387-7

levels are very similar to between numerically modelled sub-component specimen and the full-scale model, while the strain response differs slightly more at higher load levels, particularly on the pressure side close to the trailing edge.

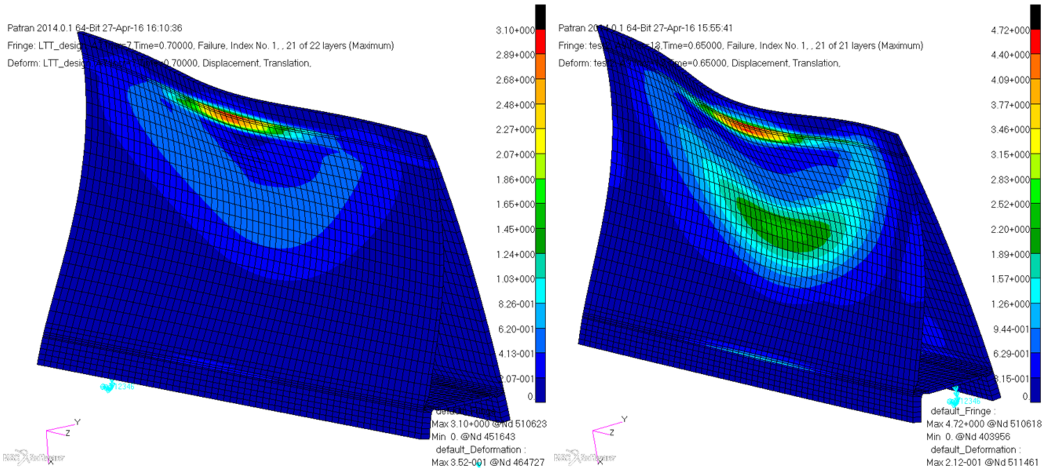

Figure 8. Comparison of failure mode between simulation of full-scale test (LTT) and sub-component testing. Failure is computed by the Tsai-Wu failure criteria.

Failure computed by the Tsai-Wu failure criteria is shown in Figure 8 for the 13-16m section. The figure shows the simulation of the subcomponent test to the right and the identically section of the blade as part of the full-scale model to the left. The failure occurs in both cases at approximately 14.5m from the root in the single skin between the trailing edge joint and the sandwich panel on the pressure side. Failure was predicted to occur at 130% of the LTT certification test load for the simulation of the full blade test and at load level of between 120% and 125% for the simulation of the subcomponent test.

5. Discussion and conclusions

The finite element simulations show that the proposed static subcomponent test method is promising in obtaining a test of the compressive strength of the trailing edge region under a simplified loading. It is overall found that the failure load and failure mode is very similar to full blade test for the analyzed test specimen.

Both at full-scale blade level as well as at subcomponent test level, the critical region is the transition region between the pressure side sandwich panel and the trailing edge adhesive bound. Failure occurred in the laminate area, between these two parts. This conclusion based on the numerical results is in agreement with the first preliminary subcomponent test conducted at DTU Wind Energy.

The vision is that the subcomponent test method can be used to further study the structural behavior and failure of trailing edge adhesive bonds and the surrounding structure [8,11,12]. It is also obvious to use the test method to study the effect of delaminations and debonding in this region [13,14].

Acknowledgments

The work presented in this paper has partly received funding from the European Community's Seventh Framework Programmed under funding scheme: Combination of CP & CSA with grant agreement No. 609795 (IRPWIND).

Excerpt from ISBN 978-3-00-053387-7

The work is also partly supported by the Danish Energy Agency through the Energy Technology Development and Demonstration Program (EUDP 2010), grant no. 64011-0006. The supported project is named Experimental Blade Research Phase 2 (EBR2), and the financial support is greatly appreciated.

The authors will also like to thank SSP Technology A/S for providing blades for testing as part of the EBR2 project and for being very supportive for our ongoing research in improving design and testing methods for wind turbine blades.

References

[1] DNV GL AS. *Rotor blades for wind turbines*. Standard, DNVGL-ST-0376, Edition December 2015.
[2] S. Pansart. A new rotor blade standard for high product quality and flexible certification. Poster, *EWEA 2015*, European Wind Energy Association (EWEA), 17 - 20 November 2015, Paris, France.
[3] J.D. Sørensen, K. Branner, and H.S. Toft. *Milestone 6: Recommendations for future sub component tests. EUDP: Experimental Blade Research – Phase 2 (EBR2)*. Report: Aalborg University & DTU, October 2013.
[4] IEC 61400-23. *Wind turbines - Part 23: Full-scale structural testing of rotor blades*. Edition 1.0, 2014-04-08, TC/SC 88, IEC, Geneva, Switzerland.
[5] M.A. Eder, K. Branner, P. Berring, F. Belloni, H. Stensgaard Toft, J.D. Sørensen, A. Corre, T. Lindby, A. Quispitup, and T.K. Petersen. *Experimental Blade Research - phase 2.* DTU Wind Energy. 108 p., report no. E-0083, 2015.
[6] A. Roczek-Sieradzan, M. Nielsen, K. Branner, F.M. Jensen, and R.D. Bitsche, "Wind Turbine Blade Testing under Combined Loading," in: *Proc. of 32nd Risø International Symposium on Materials Science*, 5-9 September 2011, Roskilde, Denmark.
[7] M.A. Eder and R. D. Bitsche, "Fracture analysis of adhesive joints in wind turbine blades," *Wind Energy*, vol. 18, no. 6, pp. 1007–1022, Jun. 2015.
[8] P.U. Haselbach, M.A. Eder, and F. Belloni, "A comprehensive investigation of trailing edge damage in a wind turbine rotor blade," *Wind Energy*, 2016.
[9] P.U. Haselbach and K. Branner, "Initiation of trailing edge failure in full-scale wind turbine blade test," *Eng. Fract. Mech.*, 2016.
[10] M. Rosemeier, P. Berring, and K. Branner, "Non-linear ultimate strength and stability limit state analysis of a wind turbine blade," *Wind Energy*, vol. 19, no. 5, pp. 825–846, May 2016.
[11] M.A. Eder, R.D. Bitsche, M. Nielsen, and K. Branner, "A practical approach to fracture analysis at the trailing edge of wind turbine rotor blades," *Wind Energy*, vol. 17, no. 3, pp. 483–497, Mar. 2014.
[12] M.A. Eder, R.D. Bitsche, and F. Belloni, "Effects of geometric non-linearity on energy release rates in a realistic wind turbine blade cross section," *Compos. Struct.*, vol. 132, pp. 1075–1084, 2015.
[13] H.S. Toft, K. Branner, P. Berring, and J.D. Sørensen, "Defect distribution and reliability assessment of wind turbine blades," *Eng. Struct.*, vol. 33, no. 1, pp. 171–180, 2011.
[14] P.U. Haselbach, R.D. Bitsche, and K. Branner, "The effect of delaminations on local buckling in wind turbine blades," *Renew. Energy*, vol. 85, pp. 295–305, 2016.

Excerpt from ISBN 978-3-00-053387-7