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Buckling and progressive failure of trailing edge subcomponent of wind turbine blade

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Abstract:

Subcomponent tests offer promising opportunities for evaluating structural integrity of critical parts that could be difficult to load realistically during full-scale tests. As an important complement to the mandatory full-scale structural tests for certification of wind turbine blades, subcomponent testing has recently been proposed. Nevertheless, challenges still exist in reproducing structural behavior observed in full-scale structural tests by using subcomponent tests, especially when the nonlinear structural response associated with buckling and failure is under concern. This study presents an experimental investigation and numerical simulation on a trailing edge subcomponent cut from a 34 m full-scale composite rotor blade. A particular focus is placed on: 1) the development of an experimental method and test setup for the trailing edge subcomponent, 2) the development of a numerical model capable of capturing multiple structural nonlinearities, including different failure modes occurring at the trailing edge and 3) the buckling, post-buckling and progressive failure response of the trailing edge subcomponent.

The trailing edge subcomponent under study was cut from the full-scale rotor blade in such a way that the cutting line passes through the zero-strain axis of the blade cross section for the leading towards trailing edge (LTT) load case. The zero-strain axis was determined by a finite element analysis where the full-scale blade is subject to the LTT bending load case. A C-shape test rig was used to compress the trailing edge subcomponent to reproduce a strain field as close as possible to the one that the subcomponent would be subjected to if it was situated in the full blade. In order to avoid undesired premature failure at the specimen boundaries, overlamination and ply wood clamp were applied as local reinforcements and boundary constrains. Randomly distributed speckles were painted on the specimen for Digital Image Correlation (DIC) measurements. The actuator force and the crosshead displacement were recorded during the test, which was performed quasi-statically until collapse of the specimen. Post-failure observation was conducted to identify failure modes and their characteristics.

Numerically, a nonlinear finite element (FE) model is developed using three-dimensional solid elements incorporated with progressive failure analysis techniques. Nonlinear buckling response of the trailing edge subcomponent is captured and multiple failure modes, i.e., adhesive joint debonding, sandwich core failure and composite fracture are predicted. Using the FE model, the failure process of the trailing edge subcomponent is reproduced and it is compared with experimental measurements and post-failure observation. The effect of different material properties and loading conditions are examined further to better understand the failure mechanisms of the trailing edge in question.

It is found that the ultimate strength of the trailing edge is buckling-driven. The failure process after the peak load-carry capacity is of the chain-of-events nature. Different failure modes interact with each other and lead to the post-failure characteristics. Numerical results of failure analyses of trailing edge subcomponents showed a reasonably good agreement with experimental observation. Based on a parametric study, better structural designs of trailing edges are proposed in order to improve the structural integrity of wind turbine blades.