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Materials and structures for wind turbine rotor blades - an overview

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SUMMARY

An overview is given of the use of composite materials in wind turbine blades, including common failure modes, strength-controlling material properties, test methods and modelling approaches at the materials scale, sub-component and component scale. Thoughts regarding future trends in the design, structural health monitoring and repair are given.

Keywords: failure modes, fracture mechanics, fatigue, repair, testing, modelling

BACKGROUND AND TRENDS

Wind turbine rotor blades are traditionally made of polymer matrix composite materials (laminates and sandwich structures). Rotor blades are the largest rotating components of a wind turbine. They should last for a minimum of 20 years. During this time they will be subjected to varying wind loads. Thus, they should be designed against different types of damage e.g. fatigue damage or damage due to extreme strong winds [1].

The major trends in the development of new wind turbines are (a) development of *larger size* wind turbines, and (b) *offshore* placement in large wind turbine parks. Combined, the two trends lead to several challenges with respect to rotor blades: First, the *weight* of wind turbine rotor blades increases dramatically with increasing blade length. For future blades, the gravitation loads will exceed the aerodynamics loads. Thus, weight savings become of great importance. In the design phase, this can be achieved by better design of structural details and by the use of stronger materials. More accurate design methods are needed and better material testing methods and material models are needed to give a better description of the materials properties. Second, since wind turbine blades traditionally are made of relative few parts being glued together, it becomes of great importance to ensure *high quality uniformity*. Blades that have manufacturing defects will be repaired, since large parts are costly and it is therefore very unattractive to discard them. Third, since offshore wind turbines are difficult and costly to access, it is desirable to *reduce the need for manual inspection* as much as possible. Sensors that can detect damage in the blades will be built-in, so that blade damage can be detected in proper time and inspection can be restricted to damaged blades. Fourth, there must be *reliable modelling tools* available for modelling of the damage evolution in wind turbine blades, such that it becomes possible to make accurate assessments of the detected damage and thus make knowledge-based decisions regarding whether the blade should be replaced, repaired, or kept in use without being repaired.

It is convenient to study wind turbine rotor blades at various length scales, from microscale (material), over macroscale (test specimen) to component scale (wind turbine rotor blade). The presentation will aim to present an overview of the current understanding of composite materials for wind turbine rotor blades.

MATERIALS TESTING AND MODELLING

Mechanical testing can be conducted at the microscale on specimens inside scanning electron microscopes using special loading devices. This enables in situ observations of details of the microscale damage evolution. In addition, single fibre tests or single fibre fragmentation test can be used for characterising the mechanical properties of the fibres and the fibre/matrix interface. The aim of such studies is to provide input to or compare behaviour with micromechanical models, e.g. made by the finite element method. Through parameter studies, micromechanical modelling is used for investigating the effect of microstructural parameters on the macroscopic properties.

At the macroscale, materials testing of composite materials for wind turbine rotor blades involves both static and cyclic loads, testing of the base materials (usually unidirectional layers), laminates, sandwich core materials, adhesives, gelcoats and interfaces between various layers. Strength and fatigue characterisation is made by traditional tension, compression and shear testing as well as fracture mechanics testing of interfaces. Recent developments include fracture mechanics approaches for determination of cohesive laws [2] for use in finite element simulations.

STRUCTURAL DESIGN AND TESTING

It is of great importance to investigate whether the material properties identified by testing of small laboratory specimens can be used for accurate predictions of large structural components. This is most conveniently done by studying simplified geometries. The sub-structures should be modelled using the appropriate strength, fracture toughness or fatigue properties, so that their load-carrying capability or the fatigue lifetime can be calculated. In parallel, the sub-structures are manufactured and tested. If a good agreement is found between model predictions and measurements, there is confidence in the design approach. Examples of sub-component problems studied are strength of sandwich structures, "medium size" adhesive joints, panels with artificial delaminations (buckling driven delamination) and rotor blade cross sections.

Although full scale testing of each new blade model is done as a part the certification process, blades are rarely tested to failure. In some cases, rotor blades have been tested to failure to identify the damage and failure modes. Modelling of the entire blade, accounting for possible damage evolution, is challenging; however work is in progress.

References

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