Research outputs:

**Fatigue damage evolution in unidirectional glass/epoxy composites under a cyclic load**
The initiation and progression of fiber damage in on-axis UD glass/epoxy materials under fatigue loading conditions were studied. Uniaxial tension–tension fatigue tests at different load levels were carried out to monitor the fiber damage evolution through the fatigue lifetime. The damage evolution was quantified by initial fiber breaks, the evolution of fiber breaks, fragmentation and clustering progression. Through qualitative and quantitative analyses, it is shown how the fiber damage evolution depends on the number of cycles, the applied load level and the number of broken fibers during the first cycle.

**General information**

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Assessment and propagation of mechanical property uncertainties in fatigue life prediction of composite laminates

A probabilistic model for estimating the fatigue life of laminated composite materials considering the uncertainty in their mechanical properties is developed. The uncertainty in the material properties is determined from fatigue coupon tests. Based on this uncertainty, probabilistic constant life diagrams are developed which can efficiently estimate probabilistic $\Delta$-$N$ curves at any load level and stress ratio. The probabilistic $\Delta$-$N$ curve information is used in a reliability analysis for fatigue limit state proposed for estimating the probability of failure of composite laminates under variable amplitude loading cycles. Fatigue life predictions of unidirectional and multi-directional glass/epoxy laminates are carried out to validate the proposed model against experimental data. The probabilistic fatigue behavior of laminates is analyzed under constant amplitude loading conditions as well as under both repeated block tests and spectral fatigue using the WISPER, WISPERX, and NEW WISPER load sequences for wind turbine blades.

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Fatigue strength of composite wind turbine blade structures

Wind turbines are normally designed to withstand 20-30 years of life. During this period, the blades, which are the main rotating structures of a wind turbine, are subjected to high fluctuating load conditions as a result of a combination of gravity, inertia, and aeroelastic forces. For this reason, fatigue is one of the foremost concerns during the design of these structures. However, current standard fatigue methods used for designing wind turbine blades seem not to be completely appropriate for these structures because they are still based on methods developed for metals and not for composite materials from which the blades are made. In this sense, the aim of this work is to develop more accurate and reliable fatigue-life prediction models for composite wind turbine blades. In this project, two types of fatigue models are implemented: fatigue-life models and damage mechanics models. In the first part of the project, a probabilistic multiaxial fatigue-life model for composite materials, which takes the variability in the material properties into account, is proposed. In this model, novel probabilistic constant life diagrams are developed, which can efficiently estimate probabilistic $-N$ curves at any load level and stress ratio. However, due to the low accuracy level of current multiaxial macroscopic fatigue failure criteria and damage accumulation theories for predicting the fatigue-life of composite materials under multiaxial and variable cycle load conditions, the proposed probabilistic fatigue-life model seems unsuitable for wind turbine blades. Based on this limitation, in the second part of the project, a damage mechanics-based multiscale approach using a 2D finite-element-based cross-section model for analyzing wind turbine blades under fatigue is proposed. By using this approach, reliable predictions about the effect of off-axis matrix cracks on the structural response of the blades are obtained. These results establish a basis for the development of an extended model that allows predicting the off-axis crack evolution in the blades and includes other types of damage, such as delaminations, fiber-related damage, etc. Furthermore, and following the framework of the proposed multiscale approach, a microscale fiber-related damage evolution study for on-axis UD glass/epoxy laminates under fatigue loading conditions is also presented. This study provides significant information for developing future fatigue models that allow predicting the catastrophic failure of multidirectional composite laminates and, therefore, possible failures in wind turbine blades.
Structural Damage Prediction of Full-Scale Wind Turbine Blades Under Fatigue Loading
Anchondo, R. I. E., PhD Student, Department of Wind Energy
Branner, K., Main Supervisor, Department of Wind Energy
Castro Ardila, O. G., Supervisor, Department of Wind Energy
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Fatigue strength of composite wind turbine blade structures
Castro Ardila, O. G., PhD Student, Department of Wind Energy
Branner, K., Main Supervisor, Department of Wind Energy
Brøndsted, P., Supervisor, Department of Wind Energy
Mikkelsen, L. P., Examiner, Department of Wind Energy
Burchardt, C., Examiner
Varna, J., Examiner
Burchardt, C., Examiner
Varna, J., Examiner
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