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.

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