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Fatigue Life Prediction and Strength Degradation of Wind Turbine Rotor Blade Composites

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ABSTRACT

Wind turbine rotor blades are subjected to a large number of highly variable loads, but life predictions are typically based on constant amplitude fatigue behaviour. Therefore, it is important to determine how service life under variable amplitude fatigue can be estimated from constant amplitude fatigue behaviour. A life prediction contains different elements: the counting method, formulations for describing S-N curves, constant life diagrams, and damage rules. For the description of damage, two models were investigated and compared, the Miner's sum method and strength-based life prediction. In the Miner's sum method, the results of a counting method and constant amplitude fatigue behaviour description are converted into a damage parameter, 'Miner's sum'. Potential effects of load order are not taken into account and the value of the damage parameter only indicates whether or not failure occurred: it does not relate to a physically quantifiable damage. In the strength-based method, life is predicted by calculating the effect of each load cycle on strength, until the load exceeds the remaining strength. An expected advantage of this cycle-by-cycle method is, that sequence effects can be implicitly included. Moreover, the damage parameter is at all times related to a physically quantifiable parameter (viz. strength). The successful application of the strength-based method requires a description of the post-fatigue strength, which entails considerable experimental effort. In addition, a strength-based life prediction is much more computationally intensive than Miner's sum and can not always utilise the same counting methods. The experimental research involved a considerable amount of material tests, which give a detailed image of static strength, constant and variable amplitude fatigue behaviour as well as strength degradation for different glass-fibre reinforced laminates. Block-test experiments confirm the existence of sequence effects on life. Residual strength tests show the strength degradation after fatigue for a range of fatigue load conditions. The significance of an adequate description of the constant amplitude behaviour is evident from the various life predictions. Commonly used simplifications, such as the Linear Goodman Diagram, result in highly non-conservative predictions. The residual strength model yields more conservative predictions than Miner's sum for the investigated tension-dominated load sequences. The experimental effort required for the determination of the strength degradation, and the computational effort do not justify this relatively small advantage. For future research, it is recommended to further improve the description of the constant life diagram.