Abstract

Offshore wind is one of the most sustainable and efficient ways for generating renewable energy. However, operating and maintaining wind turbines in a demanding and costly offshore environment poses significant challenges. Eventually, offshore wind turbines will reach the end of their operational lifespan. The primary factor influencing the lifespan of offshore wind turbines is corrosion fatigue of their foundations, as they endure severe dynamic loads and corrosive seawater conditions. The key question is when failure will happen and how many years they can function effectively. To address this question, this thesis aims to develop novel computational models that encompass multiple scientific disciplines, enabling accurate predictions of the service lifespan of offshore wind turbines.

The proposed modelling framework builds upon recent advancements in the phase field fracture formulations for fatigue damage. It introduces a cyclic degradation of fracture energy, which effectively recovers Paris law behavior and stress-fatigue life (S-N curves). Furthermore, the framework incorporates the impact of a harsh environment using a mechanistic, implicitly multiscale approach that accounts for the degradation of fracture energy due to the hydrogen content. Our study demonstrates that the presented coupled deformation-diffusion-damage model allows accurate prediction of fatigue crack nucleation and growth across a wide range of loading scenarios and specimen geometries. Notably, the model successfully captures the concept of transition flaw size, a fundamental aspect of engineering standards and fracture mechanics-based design.

By comparing the numerical simulations with experimental data, it is evident that the model reliably predicts fatigue lives, endurance limits, and accounts for the influence of stress concentration factors and load ratios, without requiring fitting procedures. Furthermore, the model establishes a connection between S-N curves and Paris law behavior, facilitating the prediction of fatigue crack growth in brittle materials using stress-fatigue life data and vice versa. This versatile modelling framework also offers a valuable tool for assessing the influence of the environment on the Paris law and S-N curve parameters. This enables optimization of design and maintenance strategies through the utilization of *Virtual Testing* and *Digital Twins* concepts, as well as facilitates efficient planning of targeted experimental campaigns.