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FATIGUE FAILURE PREDICTION IN GFRP COMPOSITE LAMINATES: COMPREHENSIVE FATIGUE DAMAGE MODEL, SOFTWARE IMPLEMENTATION IN SAMCEF AND BENCHMARK TESTS

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ABSTRACT

The estimation of the load carrying capabilities of glass fibre reinforced polymer (GFRP) laminated composite structures is challenged by the heterogeneity and intricate arrangement of the material components. The main reason that hinders the prediction of the mechanical response of laminated composite structures is the failure process that is driven by complex and interacting damage mechanisms. Moreover, fatigue failure prediction, despite of being crucial for a safe design remains far from mature. Simulation of fatigue-driven damage is almost limited to in-house research codes. The state-of-the-art intra-laminar fatigue damage simulation methods include semi-empirical residual stiffness models based on extensive experimental data that can be subsequently combined with residual strength models. Regarding the simulation methods for fatigue-driven delamination, most of the formulations are extensions of the quasi-static models accounting for an additional criterion for the development of the damage due to fatigue loading. A common strategy is incorporating a link between the damage rate and the fatigue crack growth rate described by a Paris' law-like expression. However, most of the formulations are limited to 2D applications or they have not been fully validated in 3D problems.

Usually, the intra- and inter-laminar regions are modelled independently. Thus, different models are used for each region without a direct coupling between them. However, the interchange of damage information between both regions becomes essential to model complex failure scenarios, such as matrix crack-induced delamination. This interaction has been considered in the literature, but very few contributions can be found concerning fatigue loading.

In this work, a comprehensive approach to the prediction of damage in a GFRP laminated composite structures is presented. The methodology was developed in the framework of the EU Horizon 2020 UPWARDS Project. UPWARDS was aimed at developing a high-performance computing (HPC) framework for integrated high fidelity dynamic simulations. The developed HPC simulation framework paves the way for extensive virtual prototyping of wind turbines, that will speed up wind turbine development and reduce the need for prototype testing.

First, a 3D progressive delamination method based on cohesive zone modelling that considers the effect of fatigue loading history on damage development was developed [1, 2]. The method was implemented in the Simcenter Samcef software as a new behaviour law and is currently available to users. The interface properties of an epoxy composite material commercially applied in the wind turbine industry, with a unidirectional architecture based on non-crimp fabrics with backing fibres in the ±45° directions, were fully characterized. The characterization campaign included testing under static and constant and variable amplitude fatigue loading. Then, the predictive capabilities of the simulation method were demonstrated on delamination demonstrator tests by comparing numerical results to testing data. More precisely, the delamination front shape and location as a function of the number of fatigue cycles were compared.

Second, an interaction criterion was developed aiming at linking the apparent stiffness of the interface elements to the damage at the surrounding ply elements. The damage at the intra-laminar regions was modelled by the fatigue damage model and the cycle-jump algorithm developed by van Paepegem et al. [3] and implemented in the Simcenter Samcef software.

Finally, a curved sub-structure specimen that resembles a wind turbine component was developed and tested under fatigue loading.

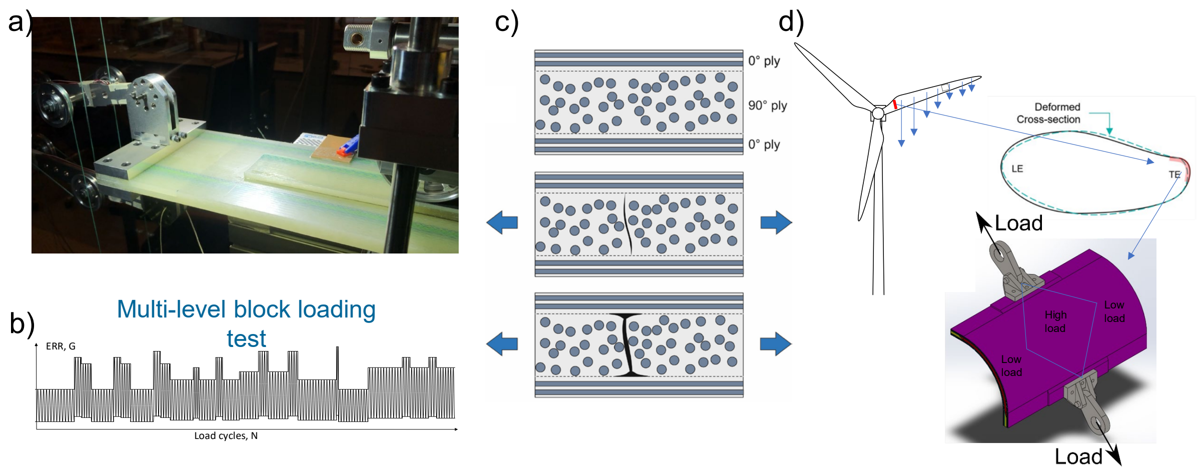

Figure 1: a) 3D inter-laminar damage model and benchmark test. b) Effect of fatigue loading history. c) Intra- and inter-laminar damage interaction. d) Curved wind turbine sub-structure specimen.

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REFERENCES

[1] Carreras, L., Bak, B.L.V., Jensen, S.M., Lequesne, C., Xiong, H., Lindgaard, E. *Benchmark test for mode I fatigue-driven delamination in GFRP composite laminates: Experimental results and simulation with the inter-laminar damage model implemented in SAMCEF*, Composites Part B: Engineering (*accepted for publication*).

[2] Jensen, S.M., Carreras, L., Bak, B.L.V., Lequesne, C., Lindgaard, E. *A crack growth rate model with load history effects for mode I fatigue-driven delamination under multi-level block loading*, International Journal of Fatigue (*accepted for publication*).

[3] Van Paepegem W, Degrieck J, De Baets P. *Finite element approach for modelling fatigue damage in fibre-reinforced composite materials*. Composites Part B: Engineering, **32**(7), 2001, 575-88.