11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

PREDICTION OF THE ELASTIC PROPERTIES AND FATIGUE DAMAGE EVOLUTION IN BUNDLE-BASED COMPOSITES FOR WIND TURBINES

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Keywords: Fatigue, Analytical modelling, Wind turbine, NCFs

ABSTRACT

Wind turbines represent a highly sustainable mean for the energy production. In the last years, the length of rotor blades has increased to produce more power without making taller towers. In fact, for a rotor blade of twice the length, the power output is quadrupled. Structural light-weight materials with high specific stiffness and capable of withstanding cyclic loadings are required.
Composite materials play an important role in the rotor blade assembly. Multidirectional laminates made from non-crimp fabrics (NCFs) are commonly used in areas like shear webs, leading edge and trailing edge. In these materials, unidirectional bundles are held together by other fibre bundles, characterized by a lower areal weight and different orientations. Figure 1 shows a schematic representation of a NCF layer considered in this work (DEVOLD AMT, U-E-640 g/m^2-1260 mm), with 0° load carrying bundles, 90° and ±45° backing bundles [1].

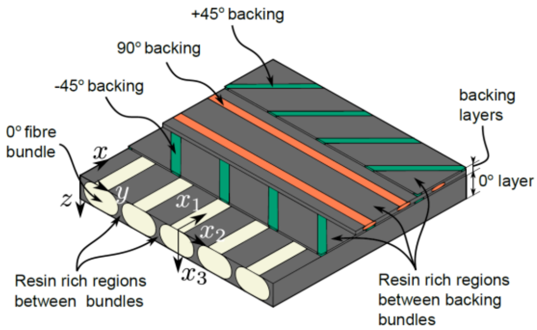

Figure 1: Representation of a NCF layer [2].

The current work aims at modelling the elastic properties and the fatigue behaviour of NCFs used in rotor blades, with particular focus on the crack formation. For the validation, experimental data regarding the static and the fatigue behaviour of multidirectional NCF laminates were taken from Ref. [2]. The considered layup is [$_b$0/$_b$50/$_b$0/$_b$-50]$_s$, where the subscript "b" indicates the position of the backing bundle. The laminate was infused after placing the dry NCF layers of Figure 1 at 0° and ±50°. A glass/epoxy system was used, allowing to monitor the damage evolution during the fatigue tests by taking frontal pictures of the samples, highlighting the initiation and propagation of off-axis cracks. The crack density evolution in the 50° layer was obtained from the frontal images using the same procedure explained in [3].
First, the analytical model proposed in [4] for the estimation of the elastic properties and the stresses distribution in textile composites was extended to NCFs, allowing to consider the bundle-based nature of the material. The input parameters required are: the thickness of the laminate, the areal weight of the bundles, the material elastic properties and the dimensions of the cross sections of the bundles. If

the geometry of the mesostructure is not known, the fibre volume fraction inside the bundles is required.
The elastic properties of each layer were calculated with a modified Mori-Tanaka approach, representing the bundles as ellipsoids with an infinite length and orthotropic elastic properties. In this way, an exact solution for the Eshelby's tensor can be used. An iso-strain condition is then applied between overlapped layers, considering their orientations, resulting in an accurate prediction of the laminate Young modulus, as showed in Figure 2.

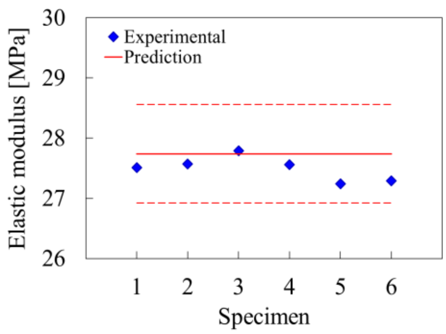

Figure 2: Young modulus of the laminates: experimental data and prediction.

The crack density evolution was then predicted extending the analytical model proposed by Carraro et al. [5], together with the novel definition of *bundle-crack density* introduced in [6] for bundle-based composites. Crack initiation and crack propagation were treated separately. A Weibull distribution was assumed to describe the variability in the crack formation, while a Paris-like law was used to describe the relationship between the crack growth rate and the energy release rate. Figure 3 shows the prediction of the *bundle-crack density* in the non-interactive regime [5] (valid for the initial part of the trend only) for one load level.

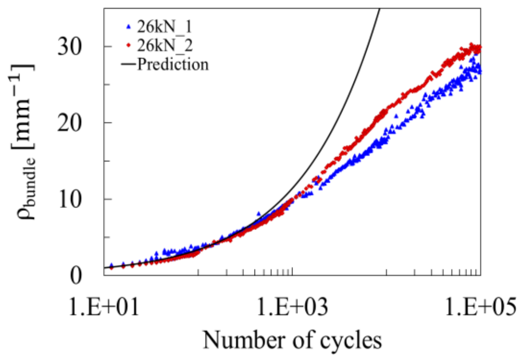

Figure 3. Prediction of the *bundle-crack density* in the non-interactive regime for a single load level.

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