Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 213 (2018) 173–182

Procedia Engineering

www.elsevier.com/locate/procedia

7th International Conference on Fatigue Design, Fatigue Design 2017, 29-30 November 2017, Senlis, France

Toward composite wind turbine blade fatigue life assessment using ply scale damage model

Damien CAOUS[a,b,]*, Christophe BOIS[c], Jean-Christophe WAHL[c], Thierry PALIN-LUC[b], Julien VALETTE[a,c]

[a]TENSYL, 48 rue Jacques de Vaucanson, Pôle Arts&Métiers, 17180 Périgny, France
[b]Arts et Métiers ParisTech, I2M, CNRS, Esplanade des Arts et Métiers, 33405 Talence, France
[c]Université de Bordeaux, I2M CNRS, 15 rue de Naudet, 33170 Gradignan, France

Abstract

Fatigue design optimization of composite material structures is limited by the classical approaches used, derived from knowledge based on metal fatigue. Other approaches exist to describe damage mechanisms of composites but they cannot always be applied at the structure scale because of their complexity. However, assumptions can be made in the case of beam structures to reduce the structural investigation at the section scale. With these assumptions this paper proposes to compare a progressive fatigue damage model written at the ply scale to the normative approach for the assessment of wind turbine blade section design. It is shown that the normative approach is very conservative and the progressive fatigue damage model provides very useful information to understand damage propagation at the structure scale.

Peer-review under responsibility of the scientific committee of the 7th International Conference on Fatigue Design.

Keywords: Damage model, Fatigue, Wind turbine blade

1. Introduction

At the present time, the wind power industry is facing the double challenge of further increasing the size of turbines for off-shore production and making them lighter for land-based production, so that they can be adapted for

---

* Corresponding author. Tel.: +33 (0)5 46 28 22 83
E-mail address: damien.caous@tensyl.com

Peer-review under responsibility of the scientific committee of the 7th International Conference on Fatigue Design.
10.1016/j.proeng.2018.02.019

use in less windy areas. The main stumbling block has been identified in the hope that the design of the blades can be optimised to meet these challenges, and it concerns the precision of their design under fatigue.

A wind turbine blade is generally designed to be in rotational operation for 20 years in wind fields that by their very nature are variable. This creates structures that are highly subject to fatigue. We are talking about 10^8 cycles approximately, which makes fatigue over a long lifetime the main design criterion [1]. In addition to high resistance to fatigue, the material used for the blades should have a low mass, which has a direct impact on stress, sufficient stiffness so that it does not impair the aerodynamic properties of the turbine, and a cost that makes wind energy competitive. With all these elements combined, it soon became clear that glass fibre non-crimp fabrics (NCF), with possibly carbon fibres locally with polyester or epoxy matrices, were required for medium and large sized blades. Although long fibre composites have high resistance to fatigue, there is as yet no commonly accepted design method devoted specifically to these materials and the normative approach currently used in the context of blade certification is based on a transposition of existing knowledge of the fatigue behaviour of metals [2]. In this study, the normative approach is compared with a progressive fatigue damage model written at the ply scale.

2. Calculation methods

2.1. Calculating stresses at the section scale

Stresses in the blade are traditionally calculated section by section based on assumptions of the behaviour of beam structures. First, it is assumed that the blade sections remain flat and perpendicular to the neutral fibre (Euler Bernoulli beam theory). From this, we formulate a relation between longitudinal strain ε_x on the laminates in the section, under tensile loading and bending, and strain in the section expressed in the form of axial strain a (in mm/mm) and bending strains (b, c) (in mm^{-1}):

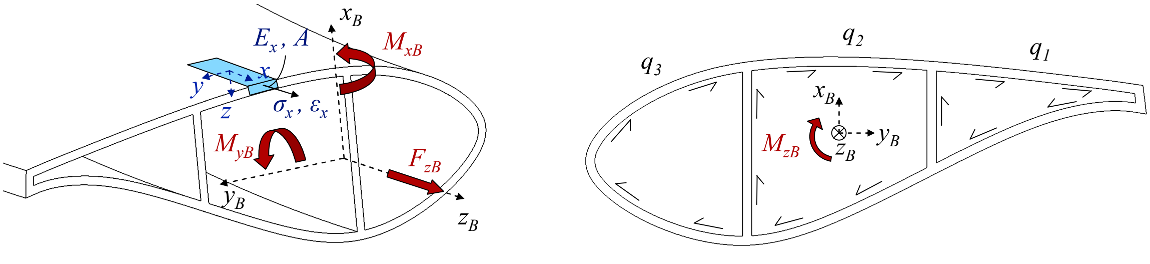
$$\varepsilon_x = a + b.x_B + c.y_B \tag{1}$$

where x is the longitudinal axis of the laminate which coincides with the longitudinal axis of the blade z_B. x_B and y_B are the coordinates of the laminated element of the section within the blade coordinate system (x_B, y_B, z_B) (Fig. 1.a).

Assuming that the laminates are subjected to in-plane stress state ($\sigma_z = 0$), membranous (constant strain in the thicknesses of the laminates), and where $\sigma_y = 0$, it can be shown that for a section formed of balanced laminates its bending-traction behaviour can be expressed in the form:

$$\begin{Bmatrix} F_{zB} \\ M_{yB} \\ M_{xB} \end{Bmatrix} = \begin{bmatrix} <EA> & <Em_X> & <Em_Y> \\ -<Em_X> & -<EI_{YY}> & -<EI_{XY}> \\ <Em_Y> & <EI_{XY}> & <EI_{XX}> \end{bmatrix} \begin{Bmatrix} a \\ b \\ c \end{Bmatrix} \tag{2}$$

where $<EA>$, $<Em_X>$, $<Em_Y>$, $<EI_{XX}>$, $<EI_{YY}>$ and $<EI_{XY}>$ are the terms for the stiffness matrix of the section [3].



(a) (b)

Fig. 1. (a) Markers and notations to describe a blade section under bending and traction
(b) Shear flow in a section of wind turbine blade made up of 3 closed cells