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A computationally-efficient micromechanical model for the fatigue life of unidirectional composites under tension-tension loading

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Abstract

Failure of fibre-reinforced composites is affected by fatigue, which increases the challenge in designing safe and reliable composite structures. This paper presents an analytical model to predict the fatigue life of unidirectional composites under longitudinal tension-tension. The matrix and fibre-matrix interface are represented through a cohesive constitutive law, and a Paris law is used to model fatigue due to interfacial cracks propagating from fibre-breaks. The strength of single-fibres is modelled by a Weibull distribution, which is scaled hierarchically though a stochastic failure analysis of composite fibre-bundles, computing stochastic S-N curves of lab-scaled specimens in less than one minute. Model predictions are successfully validated against experiments from the literature. This model can be used to reduce the need for fatigue testing, and also to evaluate the impact of constituent properties on the fatigue life of composites.

Keywords: Micro-mechanics, Analytical modelling, Cohesive interface modelling, Fibre reinforced material, Fatigue

1. Introduction

Many studies have shown that composite materials are sensitive to cyclic degradation, as experimental results show a significant reduction in the stiffness and strength of composites with the increasing number of fatigue cycles applied, both under simple and more complex loading cases [1–11]. Due to limited capabilities to predict the behaviour of composites across their entire life-time, large safety factors are often employed, leading to inefficient and over-designed components. It is therefore critical to be able to predict the life span of composites under cyclic loading, since fatigue is one of the main failure mechanisms in engineering structures (such as pressure vessels and aircraft components) [12].

Fibre-reinforced composites are inhomogeneous by nature and have a more complex behaviour than that of homogeneous materials, since different types of damage can occur in the different constituents; this fact makes the life-time prediction of composite materials a challenging task. Carbon fibres have an elastic behaviour and are generally considered to be insensitive to fatigue effects [13]; however, even a UniDirectional (UD) Carbon-Fibre Reinforced Polymer (CFRP) is vulnerable to degradation under tension-tension cyclic loading, due to the formation of damage in the matrix and in the fibre-matrix interface [14, 15].

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