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Technical Report

Post-buckling failure in multi-delaminated composite wind turbine blade materials

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ABSTRACT

This study models the inter-laminar damage due to low velocity impacts on hybrid composite materials typical of those used in wind turbine blade structures. The effect of z-pinning using natural flax yarn on the critical buckling load and post-buckling behaviour of multi-delaminated composite beams was investigated. Laminated composite beams were pinned through their thickness using natural flax yarns to control delamination failure during the post-buckling process. A multiple delamination with a triangular shape was inserted into each of the beams to simulate the damage caused by a low velocity impact e.g. ice, on composite wind turbine blades. For a laminate design of $[C_{90}/G_{90}]_4$, global collapse caused no delamination failure during the post-buckling test while delamination failure occurred for a laminate design of $[C_0/G_0]_4$. In this case, z-pinning can significantly increase the failure resistance within a composite structure and it can then postpone the failure process. The buckling process of a multi-delaminated composite beam was also simulated by finite element software ANSYS and the results were substantially verified by relevant experimental results.

1. Introduction

Fibre-reinforced polymer (FRP) composite materials are widely used because of their high strength-to-weight and stiffness-to-weight ratios compared with many traditional materials [1,2]. One of the most serious failure modes in laminated composite materials is delamination, which can occur in several situations, during the manufacturing process, during maintenance and due to the impact of a foreign body [3]. The area of the delaminations increases through the thickness away from the impact surface as the shock expands away from the point of impact [4], so delaminations due to low velocity impact often appear at several interfaces of the laminated composite material (multiple delamination).

Laminated composite materials containing one or more delamination can buckle at a lower level of compressive load than laminated composites without delamination, and this level depends on the size, position and shape of the delamination [5,6]. Wind turbine blades are typically manufactured from FRP composites and delamination failure can be an important issue in these structures. In extreme conditions, like ice impacting, multiple delamination with a triangular shape is found in different parts of a blade, introducing local damage, which can cause catastrophic failure under various loading conditions including buckling.

Buckling and post-buckling are two loading conditions that can occur in large wind turbine blades due to gravitational, aerodynamic and centrifugal forces.

Bucking and post-buckling behaviour in delaminated composite structures have been studied to determine buckling resistance loads. Parlapalli et al. [7] proposed an analytical model to predict lower and upper bounds of the buckling load of a composite beam with two enveloped delaminations. In their model the characteristic equation governing delamination buckling was derived using Euler–Bernoulli beam and theory and classical lamination theory, performing proper linearization and imposing the appropriate continuity and boundary conditions. Gaudenzi et al. [8] analysed the non-linear behaviour of delaminated composites panels under compression. They presented the theoretical formulation of this modification in conjunction with a general formulation of the continuation method and the modified virtual crack closure technique (MVCCT) for the evaluation of delamination growth.

Cappello and Tumino [9] studied the buckling and post-buckling behaviour of unidirectional and cross-ply composite laminated plates with multiple delaminations. According to their results, both delamination length and position and stacking sequence of the plies influence the critical load of the plate; furthermore, linear and non-linear buckling models are not always in good agreement.

Many researchers have studied the delamination buckling of composite structures with stitching using various techniques. Parlapalli et al. [10] studied how the buckling loads of delaminated glass/epoxy composite laminates are affected by through-the-thickness stitching using two different types of aramid threads, Kevlar and Twaron. Buckling loads can be predicted from experimental data using the Southwell, Vertical Displacement and Membrane Strain Plot methods.

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