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قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات

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AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

DESIGN AND PRODUCTION ENGINEERING

Investigation of Honeycomb Composite Structure for Wind Turbine Blades with Acoustics Emissions Damage Assessment

A Thesis submitted in partial fulfilment of the requirements of the

PhD in Mechanical Engineering

By

Ahmed Hesham Abdulaziz Mohamed Albadr Hashim

M.Sc., Mechanical Engineering, Design and Production Engineering

Ain Shams University, 2016

Supervised by

Prof. Adel M. Elsabbagh

Prof. Karen M. Holford

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Cairo –2021

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Statement

This thesis is submitted as a partial fulfillment of Doctor of Philosophy in Mechanical Engineering Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Dedications

I dedicate this work to

My parents and Family

Prof Ahmed M. Hussein (May Allah be pleased with him)

I believe this work never could be done without the sacrifices made by my wife Sama to keep me moving forward with the work.

Thesis Summary

For optimum aerodynamics in wind turbines, blade materials must have a low weight to bending stiffness ratio. Due to the cost savings compared to using carbon fibre composites alone, aluminium honeycomb will play a critical role in producing longer wind turbine blades with fibre glass as the outer skin in the future.

The thesis includes a study on the glass fibre aluminium honeycomb sandwich structures to be implemented in a wind turbine blade. The study takes staged approach starting by conducting a structural optimisation on the honeycomb sandwich structure to minimise the weight to bending stiffness ratio then studying acoustic emission wave propagation on such complex structure then testing the specimens under bending tests and finally building the whole wind turbine blade with the optimised honeycomb sandwich structure. The acoustic emission wave study is conducted on glass fibre plate then on sandwich specimens of limited honeycomb cells to find out the effects of the cell on the wave propagation from plate to plate and finally on full-scale sandwich panel. It is found that Lamb waves are developed in the glass fibre and the top plate of the honeycomb sandwich structure. In the bottom plate of the honeycomb sandwich structure, it is found that the honeycomb cells act as conduits of AE waves transmission from top to bottom plate. The waveform in the bottom plate is biased to the flexural mode of the Lamb wave with extremely diminished extensional mode.

The A_o mode and S_o mode wave velocities have been studied in directions from 0^o to 90^o with 15^o interval. It is found that A_o velocity does not change with the direction as it depends mainly on the out-of-plane stiffness. On the other hand, the S_o velocities change with direction with respect to the fibre direction. Moreover, the dispersion curves for the wave propagation have been analysed numerically and experimentally

and the insertion loss concept has been proposed in order to quantify the effects of the honeycomb cells on the wave propagation in the skin plates.

The AE source location studies on the sandwich panels are conducted using two famous techniques, the time of arrival method and the Delta-T mapping. The acoustic emission sources are generated on both plates of the sandwich panel while the sensors are solely bonded to one of them.

It is found that Delta-T mapping gives half average error of that of the time of arrival. Further, it is demonstrated the capability of the Delta-T mapping for source location on 2D and 3D.

Thereafter, the bending testing has been conducted on the sandwich specimen coupled with Delta-T Mapping to assess the damage in the specimen and the location. It is found that the acoustic emission testing is not only able to locate the damage on the specimen but also can describe the damage mechanism. The damage progression in the specimen under bending is characterised using both the scanning electron microscope then correlated to the acoustic emission signal frequencies and energy.

Finally, the honeycomb sandwich panel is then used in manufacturing of vertical axis wind turbine blade with aerofoil NACA8412 and the manufacturing considerations are demonstrated.

Keywords: Acoustic emission; Wave propagation; Attenuation Rates; Sequential quadratic Programming; Damage Analysis; Finite element modelling

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