A Multiaxial Fatigue Damage Model for Fibre Reinforced Polymer Composites

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A MULTIAXIAL FATIGUE DAMAGE MODEL FOR FIBRE REINFORCED POLYMER COMPOSITES

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Abstract: A multiaxial fatigue damage model for fibre reinforced polymer composite materials is presented. The model combines (i) fatigue-induced fibre strength and modulus degradation, (ii) irrecoverable cyclic strain effects and (iii) inter-fibre fatigue. The inter-fibre fatigue aspect is based on a fatigue-modified version of the Puck multiaxial failure criterion for static failure. The model is implemented in a user material finite element subroutine and calibrated against fatigue test data for unidirectional glass fibre epoxy. A programme of uniaxial fatigue tests on quasi-isotropic glass fibre epoxy laminates is presented for validation of the novel fatigue damage methodology. The latter is successfully validated across a range of stress levels.

1 Introduction

Glass-fibre reinforced polymers (GFRP) are candidate low cost materials for use in ocean energy structures. Quasi-isotropic (QI) laminates are useful where (i) the loads are not very well understood, or (ii) the loads are complex and multi-directional in nature, both of which are relevant to the ocean energy (e.g. tidal turbine) application, which is a novel application. It is anticipated that long-term durability of materials will be a key factor in the success of candidate ocean energy devices. Hence, the fatigue of QI laminates is investigated as here part of a larger research programme investigating the fatigue behaviour of GFRP laminates while immersed in seawater.

Micromechanical approaches to fatigue modelling are preferred because they offer the possibility of being able to model any laminate configuration with any combination of applied loads. A convenient level for modelling is the single unidirectional (UD) ply level as these models can then be combined in a computer simulation of any laminate configuration.

Talreja described the fatigue damage mechanisms in a UD ply based on strain levels and subsequently when it is embedded in a laminate [1]. It was found that matrix and interfacial cracking occurred first parallel to the fibres, in the most off-axis ply, caused by a combination of transverse normal and shear loading on the ply. In epoxy/E-glass cracking started with localised transverse fibre debonding at approximately 0.12% strain in 90° plies and became full width (of test coupon) and of ply thickness by 0.42% strain [2] (termed inter fibre fracture (IFF) [3]). Fatigue cycling of an epoxy/E-glass laminate between 0 and 0.33% strain was found to initiate IFF in the 90° ply at the coupon edges around 3,500 cycles and these fractures propagated in both length and density at a steady rate [4]. Higher peak (cyclic) strains were found to increase the rate and maximum density of IFF in 90° plies.

Analysis of IFF initiation strain in plies at angles other than 90° is facilitated using composite laminate theory (CLT) to calculate the strains in the ply orientation. For example, Talreja

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