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Acoustic emission monitoring of interlaminar delamination onset in carbon fibre composites

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Abstract

This article presents the development of an experimental methodology based on acoustic emission wave detection for determining delamination onset and propagation in carbon fibre composite materials under quasi-static and fatigue loading. Delamination was investigated in quasi-static interlaminar fracture testing over a wide range of mixed-mode ratios (G_{II}/G_T = 0, 0.3, 0.5 and 1) for unidirectional and woven samples. An acoustic emission wave detection method was developed to detect delamination onset, and the corresponding fracture toughness was computed. Interlaminar fracture toughness was also calculated by beam theory and from finite element analysis with the virtual crack closure technique. The mechanical testing results, acoustic emission monitoring and numerical model's interlaminar fracture toughness were used to define delamination initiation criteria by drawing two-dimensional envelopes corresponding to $G_C = f(G_{II}/G_T)$. The acoustic emission wave detection method showed damage accumulation before observable crack propagation, and its failure envelope corresponded to lower fracture energies than the standard test and modelling methods. Mode I fatigue testing with acoustic emission monitoring was performed on the woven samples for different energy release rate ratios (G_{IMAX}/G_{IC} = 0.3–0.8). A first series of samples were tested to construct an onset delamination fatigue curve $\Delta G = f(N)$. A second series of samples were used to study the cumulative acoustic emission energy distribution during delamination growth. An unsupervised pattern recognition methodology is presented for crack opening and closing testing, in order to discriminate between fatigue signal noise and acoustic emission signals emitted from crack initiation and crack growth. Correlations were observed between the acoustic emission energy distribution, the load range, the delamination length and the crack growth rate.

Keywords

Acoustic emission, delamination onset, composite, mixed modes I and II, virtual crack closure technique, fatigue crack growth, cluster analysis, noisy acoustic emission signal discrimination

Introduction

The mechanical behaviour of composite materials is more complex than that of homogenous and isotropic materials. In fact, the inhomogeneity and anisotropy of composite material microstructure lead to complex damage mechanisms under static and fatigue loading. Damage onset and accumulation are serious concerns for designers using composites in critical structural elements because the cracks affect the reliability of life prediction and can compromise structural integrity. Damage can include fibre breakage, matrix cracking, fibre–matrix debonding and delamination, with the latter being considered the most prevalent life reduction factor in composite structures.[1,2] Delamination may originate from several sources such as residual stresses from curing,[3] geometric discontinuities, edges, impact damage and so on. After initiation, an internal or near-surface delamination can propagate under static and fatigue loads, causing a redistribution of the stresses in the plies of a laminate that may reduce the strength and fatigue life of the structure.

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