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An integrated approach based on acoustic emission and mechanical information to evaluate the delamination fracture toughness at mode I in composite laminate

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ABSTRACT

This paper addresses a new method based on the combination of mechanical behavior and acoustic emission (AE) information of composite materials during mode I delamination. The method is based on a special purpose function, called sentry function, which is defined as the logarithm of the ratio between mechanical energy and acoustic energy ($f = \mathrm{Ln}(E_s/E_a)$). The sentry function is used to study the delamination process and to evaluate the delamination fracture toughness in mode I. The relationship between cumulative fracture toughness energy release rate (G_I) and the integral of the sentry function during crack propagation showed a transition point with two sensitive regions below and above it. This behavior can be followed to obtain the critical strain energy release rate value (G_{Ic}). Results obtained by means of the sentry function are compared with results obtained by a methodology proposed by other authors.

1. Introduction

Delamination is a critical damage mode in composite structures, not necessarily because it will cause the structure split into two or more pieces at the end of the damaging process, but because it can degrade the laminate strength to such a degree that it becomes useless in service. The design of composite structures to account for delamination and other forms of damage involves two fundamental considerations, namely damage resistance and damage tolerance. Knowledge of a laminated composite material's resistance to inter-laminar fracture is useful for product development and material selection.

Damage resistance is the measure of the capability of a material or structure to resist the initial occurrence of damage. This aspect must be considered for designing and maintaining the integrity of load carrying structures [1]. In this regard, we should also note that polymer matrix composites are given primary attention because of their importance and dominance in practical structural applications as well as the composite literature itself.

Mode I inter-laminar fracture has received the greatest attention from researchers. This is due to the fact that the delamination initiation energy is low compared to that of the shearing mode. Several studies were already conducted on the mode I fracture to determine the surface energies of composite materials by creating a crack propagation effect [2]. Researchers were thus able to consider the effect of ambient conditions and manufacturing variables on the strain energy release rate (G_I) [3]. The effect of fiber direction on delamination fracture toughness is a problem that was studied by Kim and Mayer [4], and Solaimurugan and Velmurugan [5]. Literature results show that adjacent ply delamination fracture toughness decreased as the mismatch angle of fiber between the same plies increased [6]. The reason for fracture energy dependence on fiber mismatch angle is considered to be the stiffness of the plies thus fibers have the highest contribution to the stiffness of each ply. The effects of temperature on delamination growth in a carbon/epoxy composite under fatigue loading also shows that at elevated temperatures the strain energy release rate threshold values for delamination growth under fatigue loading are significantly lower than the critical energy release rates in static tests [7,8]. The effect of loading rate on fracture toughness of laminated composites was studied by Kusaka et al. [9] and Hug et al. [10]. The results show a slight effect of loading rate on fracture toughness at rates up to 1.6 m/s, but beyond this rate threshold the fracture energy decreases [11]. So far, many researchers have tried to improve delamination fracture toughness through different techniques. In some investigations, improvements in delamination fracture toughness were performed through 3D fiber architecture (stitching, knitting and braiding). It was observed that through thickness stitching is a promising reinforcing technique for improving inter-laminar strength [12].

Some analytical and theoretical models simulated via finite element method (FEM) are also used for predicting inter-laminar delamination in composite structures [13]. The computed results

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