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ScienceDirect

Procedia Structural Integrity 2 (2016) 205–212

Structural Integrity Procedia

www.elsevier.com/locate/procedia

21st European Conference on Fracture, ECF21, 20-24 June 2016, Catania, Italy

Delamination Propagation and Load Ratio Effects in DCB MD Woven Composite Specimens

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Abstract

Double cantilever beam (DCB) specimens fabricated from 15 plies of a plain woven prepreg (G0814/913) arranged in a multi-directional (MD) layup were tested by means of constant amplitude fatigue cycles under displacement control. Four different displacement cyclic ratios were used, namely 0.1, 0.33, 0.5 and 0.75. The delamination propagation rate da/dN was calculated from the experimental data and plotted with respect to different functions of the mode I energy release rate $\mathcal{G}_I$. When one of those functions, denoted here as $\overline{\Delta\mathcal{K}_I}$ was used, all of the data obtained for the different displacement ratios collapsed into one master curve.

Keywords: Carbon fibres; Laminate; Textile composites; Delamination; Fatigue;

1. Introduction

One of the most common failure modes in laminates is delamination or separation of plies (Raju , 2008; Bolotin , 1996). Thus, for design purposes, damage tolerance and total life predictions, it is important to investigate the delamination resistance of composites and their behavior under both quasi-static and cyclic fatigue loads. Several studies have been carried out recently regarding delamination propagation resulting from opening mode (mode I) fatigue deformation. Nevertheless, most of the studies examined unidirectional (UD) composite materials. Moreover, currently there is no standardized protocol for testing the propagation of a delamination under fatigue loads. The only existing standard test method considering mode I deformation under fatigue loads is ASTM D6115-97 (ASTM D6115 , 2011). This standard describes a test method for mode I fatigue delamination onset of UD fiber-reinforced polymer matrix composites which leads to a ”no growth” design law.

Recently, work has been carried out to specify a new standardized test method for measuring the delamination propagation rate under mode I fatigue deformation in UD composites (Brunner et al. , 2009; Stelzer et al. , 2014). The ability to reliably predict the delamination propagation rate may be used in order to design structures more efficiently according to a damage tolerance approach. However, the exponents of the power law used to relate the propagation rate

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10.1016/j.prostr.2016.06.027

da/dN and the energy release rate $\mathcal{G}_I$ have been shown to be high. Thus, small uncertainties in the applied loads will lead to large uncertainties in the predicted delamination growth rate (Martin and Murri , 1990). Jones et al. (2014a,b) have shown that when a new formulation of the power law relation between the delamination propagation rate da/dN and the energy release rate $\mathcal{G}_I$ is used, the exponents of the power law may be lowered significantly. While the current authors have found that the lowered exponents seem not to affect the sensitivity of the delamination propagation rate to small changes in the loads, this formulation may have other interesting aspects. The main one is that this new formulation seems to be unaffected by changes in the load ratio

$$R_P = \frac{P_{min}}{P_{max}}. \tag{1}$$

In eq. (1), P_{min} and P_{max} are the minimum and maximum loads, respectively, in a fatigue cycle.

The material considered in the current investigation is a plain weave, multi-directional (MD) carbon fiber reinforced polymer (CFRP) laminate fabricated from a prepreg containing carbon fibers in an epoxy matrix (G0814/913). The aim of this study is to develop a methodology for predicting the mode I delamination failure of woven MD laminate composites under different load or displacement ratios using linear elastic fracture mechanics (LEFM). Specifically, the propagation of a delamination between two different plies will be considered.

Banks-Sills et al. (2013) and Ishbir et al. (2014) investigated the material and interface being studied here and their findings and methodology were used as a basis for this investigation. In Banks-Sills et al. (2013), fracture toughness tests were conducted and constant amplitude fatigue tests at a fixed displacement ratio

$$R_d = \frac{d_{min}}{d_{max}}, \tag{2}$$

more precisely, $R_d = 0.1$, were conducted in Ishbir et al. (2014). In eq. (2), d_{min} and d_{max} are the minimum and maximum actuator displacements, respectively, in a fatigue cycle.

In Section 2, the test method will be described. The results will be presented in Section 3. Conclusions will be discussed in Section 4.

2. Methods

As mentioned previously, this study deals with the propagation of a delamination in an MD composite laminate resulting from opening fatigue deformation. More precisely, the layup of the laminate composite investigated here consists of 15 plies. Each ply is made of a plain weave of T300 carbon fibers pre-impregnated in a 913 epoxy matrix resulting in a G0814/913 prepreg. The fiber volume fraction was taken to be 51%. The plies are stacked in a multi-directional arrangement in which each ply is rotated by 45° in the ply plane with respect to its adjacent ply (see Fig. 1). The mechanical properties of the resulting composite laminate are given in Banks-Sills et al. (2013).

In order to obtain the delamination propagation rate under cyclic fatigue deformation of the material layup mentioned here, double cantilever beam (DCB) specimens (see Fig. 2), which were manufactured by Israel Aerospace Industries according to ASTM D6115 (2011), were tested. A Teflon insert, nominally 25.4 μm thick, was placed between the seventh and eighth plies of the laminate. Thus, the interface is between a $0°/90°$ and a $+45°/-45°$ weave. Each of these plies is taken to be effectively homogeneous and anisotropic.

Constant amplitude fatigue tests using the DCB specimen were carried out on four specimens. The geometric properties (see Fig. 2) of the tested DCB specimens are presented in Table 1, where h and b are, respectively, the specimen height and width; a_0 and a_{0f} are, respectivliy, the initial delamination lengths mesured from the load line and the edge of the specimen on its front side. The overall length L of the specimens was about 250 mm. Note in Table 1, the specimens are numbered as FTG (fatigue); 4, which represent the fourth batch of specimens; and a series number to represent the specimen. All tests were performed under displacement control and each test was conducted at