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Simulation and experimental validation of mixed mode delamination in multidirectional CF/PEEK laminates under fatigue loading

P. Naghipour [a,b,*], M. Bartsch [a], H. Voggenreiter [a,b]

[a] Institute of Materials Research, German Aerospace Center (DLR), Linder Hoehe, 51147 Cologne, Germany
[b] Institute of Aircraft Design (IFB), University of Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany

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ABSTRACT

Cyclic mixed mode delamination in multidirectional composite laminates subjected to high cycle fatigue loading has been investigated by numerical simulations and cyclic mixed mode bending experiments. The numerical model includes lamina and interface elements. The description of the delamination crack growth rate is based on the cyclic degradation of bilinear interface elements linking the evolution of the damage variable with the delamination crack growth rate. The constitutive cyclic damage model is calibrated by means of mixed mode fatigue experiments and reproduces the experimental results successfully and with minor error. It is concluded that only with implementing a cyclic damage variable in the cohesive interface element the experimentally observed crack growth and stiffness degradation can be captured properly. Scanning electron microscopy of fracture surfaces after cyclic loading revealed that abrasion of crack bridging surface roughness is the main microscopical cause of weakening and degradation of the interface.

1. Introduction

The need for light weight structural materials with good resistance to fatigue has led designers of aircrafts to increasingly employ CFRP structures, when cyclic loading is of primary concern. The growth of the damage under subsequent fatigue loads may lead to final catastrophic failure of the component. Thus, predicting the extent of fatigue damage growth through development of an accurate fatigue damage model is essential to the continued employment of CFRP structures into even more demanding aerospace applications. One of the most common types of damage observed in CFRP composites subjected to cyclic loading is delamination. Typically, delamination failures initiate and propagate under mixed mode effect of normal and shear stresses. Therefore, in order to have a thorough understanding of the cyclic mixed mode delamination mechanism in CFRP structures, development of a reliable and predictive analysis tool has been one of the issues studied extensively by the aerospace industry.

There are diverse approaches to study the fatigue delamination phenomenon in composite materials. Among the most representative experimental approaches for description of the fatigue behaviour are fatigue life models, which predict the number of cycles corresponding to fatigue failure under fixed loading conditions (Ex. mixed mode delamination here) using an experimentally determined failure criterion (Andersons, 1994; Reifsnider, 1991; Suresh, 1991 or Talreja, 1999). The second approach can be classified as fatigue related fracture models, which basically study rate of crack growth under cyclic loading (Ex. mixed mode cyclic delamination). Fracture mechanics models relate the variation of the energy for formation of two new crack surfaces with the crack growth (Dowling and Begley, 1976; Ewalds, 1984; McDowell, 1997; Paris et al., 1961; Paris and Erdogan, 1963 or Rice, 1980). The fatigue crack propagation rate is denoted by dA/dN, where A is the crack area, or da/dN, where a is the characteristic crack length. The correlation of the fatigue crack growth rate with the amplitude of the energy release rate, ΔG (or stress intensity factor, ΔK) is commonly represented in a log–log diagram known as Paris plot (Paris et al., 1961; Paris and Erdogan, 1963). The Paris law, describing crack growth versus energy release rate is widely used and accepted among other empirical or semi-empirical crack growth laws. According to this law, the crack growth rate is related to the energy release rate range by a power law that can be expressed as

$$\frac{\partial A}{\partial N} = C\left(\frac{\Delta G}{G_c}\right)^m. \tag{1}$$

The parameters C and m (Paris plot parameters) must be determined experimentally. The energy release rate range, ΔG, depends on the loading conditions, and G_c is the critical energy release rate of the material. Finally, the third approach and meanwhile one of

* Corresponding author at: Institute of Materials Research, German Aerospace Center (DLR), Linder Hoehe, 51147 Cologne, Germany. Tel.: +49 2203 6013509; fax: +49 2203 696480.

E-mail address: parya.naghipour@dlr.de (P. Naghipour).

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