Composite Structures 225 (2019) 111114

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

A modified cohesive zone model for fatigue delamination in adhesive joints: Numerical and experimental investigations

Ahmad S.M. Al-Azzawi[a,c,*], L.F. Kawashita[b], C.A. Featherston[a]

[a] School of Engineering, Cardiff University, The Parade, Cardiff CF24 3AA, UK
[b] Bristol Composites Institute, University of Bristol, University Walk, Bristol BS8 1TR, UK
[c] College of Engineering, University of Babylon, Babylon, Iraq

ARTICLE INFO

Keywords:
Fibre metal laminates (FMLs)
Glare®
Fatigue
Delamination
Cohesive zone model (CZM)
Digital image correlation (DIC)
Acoustic emission (AE)

ABSTRACT

A modified cohesive zone model (CZM) has been developed to simulate damage initiation and evolution in Fibre-Metal Laminates (FMLs) manufactured in-house but based on the Glare® material specifications. Specimens containing both splice and doubler features were analysed under high cycle fatigue loading. The model uses a novel trapezoidal traction-separation law to describe the elastic-plastic behaviour of this material under monotonic and high-cycle fatigue loading. The model is implemented in the software Abaqus/Explicit via an user-defined cohesive material subroutine. Several models of increasing complexity were investigated to validate the proposed approach. A two-stage experimental testing programme was then conducted to validate the numerical analyses. Firstly, quasi-static tests were used to determine the ultimate tensile strength (UTS) of a series of specimens with and without internal features. Secondly, high-cycle fatigue tests were conducted on both laminate types with variable load amplitude so that S-N curves could be built. Tests were monitored using digital image correlation (DIC) for full-field strain mapping and acoustic emission (AE) sensing to detect the initiation and propagation of damage during quasi-static and fatigue tests. Good correlation was observed between predicted onset and growth of delaminations and the history of cumulative AE energy during the tests, which supports the validity of the cohesive modelling approach for FMLs.

1. Introduction

Fibre-metal laminates (FMLs) like Glare® are manufactured from metal sheets bonded with glass fibre reinforced composites using high toughness thermoset matrix materials. Where large panels are required, joints including splices (staggered overlapping layers) and doublers (additional external or internal layers) are used. One of the most common failure modes for FML structures is delamination in these joints [1]. Delamination in fibre composites has been modelled by researchers using a number of different approaches. These include the cohesive zone model (CZM) which incorporates both continuum damage and fracture mechanics concepts [2] and which has been used to model delamination initiation and propagation under high cycle fatigue [3–7]. This paper describes work done to extend the CZM approach to model elastic-plastic behaviour such as that exhibited in FMLs.

Fatigue has been shown to account for at least 90% of all service failures due to mechanical faults across a range of industries [8]. With the increased use of hybrid materials such as Glare® in aircraft and other critical structures it is important to be able to predict fatigue damage behaviour in these more complex materials and particularly in associated manufacturing features such as splices and doublers. This can be achieved by both experimental and analytical methods. Experimental studies usually focus on mechanical characterisation through tension-tension cyclic loading tests, yielding either S-N curves for fatigue life estimation or Paris-type curves for crack growth rate estimation. Analytical techniques provide efficient design and analysis methods which are particularly important for industrial applications. A number of studies have been conducted into modelling damage in the adhesive joints of composite laminates under fatigue loads. Models are generally based on either stress or strain analysis. Adhesive damage models reported in the literature use a number approaches including fracture mechanics and continuum damage mechanics [9–12]. In such approaches a damage parameter (D) is defined which modifies the constitutive response of the adhesive, with damage accumulation expressed in terms of the number of cycles to failure. However, although continuum damage approaches provide a valuable predictive framework, they do not give a clear definition of the fatigue initiation and propagation phases.

* Corresponding author at: College of Engineering/Al-Musayab, University of Babylon, Babylon, Iraq.
E-mail address: ahmadsaddy@yahoo.com (A.S.M. Al-Azzawi).

https://doi.org/10.1016/j.compstruct.2019.111114
Received 17 December 2018; Received in revised form 20 May 2019; Accepted 4 June 2019
Available online 05 June 2019
0263-8223/