Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 2 (2016) 221–226

Structural Integrity
Procedia

www.elsevier.com/locate/procedia

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

Modelling and predicting fatigue crack growth in structural adhesive joints

A.J. Kinloch[a]*, R. Jones[b] and W. Hu[b]

[a]Department of Mechanical Engineering, Imperial College London, London, SW7 2AZ, UK
[b] Centre of Expertise for Structural Mechanics, Department of Mechanical and Aerospace Engineering, Monash University, Clayton, Victoria, 3800, Australia

---

Abstract

The present paper examines crack growth in a range of structural adhesive joints under cyclic-fatigue loadings. It is shown that cyclic-fatigue crack-growth in such materials can be modelled by a form of the Hartman and Schijve crack-growth equation which aims to give a unique and linear 'master' representation for the fatigue data points that have been experimentally obtained. This relationship is shown to capture the experimental data representing the effects of test conditions, such as the *R*-ratio ($=\sigma_{min}/\sigma_{max}$) present in the fatigue cycle and test temperature. It also captures the typical scatter often seen in such tests, especially at low values of the fatigue crack-growth rate. Furthermore, the methodology is shown to be applicable to, and to unify, the results from Mode I (opening tensile), Mode II (in-plane shear) and Mixed-Mode I/II fatigue tests. Finally, it is used to predict successfully the rate of fatigue crack-growth in two bonded-repair type joints where naturally-occurring disbonds have initiated and grown.

Peer-review under responsibility of the Scientific Committee of ECF21.

Keywords: Bonded repairs; Fatigue; Hartman and Schijve; Life prediction; Modelling fatigue.

---

* Corresponding author. Tel.: +44-207-594-7081
E-mail address: a.kinloch@imperial.ac.uk

Peer-review under responsibility of the Scientific Committee of ECF21.
10.1016/j.prostr.2016.06.029

Nomenclature

a	crack length
A	constant in the Hartman-Schijve crack-growth equation
da/dN	rate of crack growth per cycle
D	constant in the Hartman-Schijve crack-growth equation
G	strain-energy release-rate (SERR)
G_{max}	maximum value of the applied strain-energy release-rate in the fatigue cycle
G_{min}	minimum value of the applied strain-energy release-rate in the fatigue cycle
ΔG	range of the applied strain-energy release-rate in the fatigue cycle, as defined below
ΔG	$= G_{max} - G_{min}$
$\Delta\sqrt{G}$	range of the applied strain-energy release-rate in the fatigue cycle, as defined below
$\Delta\sqrt{G}$	$= \sqrt{G_{max}} - \sqrt{G_{min}}$
$\Delta\sqrt{G_{th}}$	value of $\Delta\sqrt{G_I}$ at a value of da/dN of 10^{-10} m/cycle
$\Delta\sqrt{G_{thr}}$	range of the fatigue threshold value of $\Delta\sqrt{G_I}$, as defined below
$\Delta\sqrt{G_{thr}}$	$= \sqrt{G_{thr.max}} - \sqrt{G_{thr.min}}$
m	exponent
n	exponent in the Hartman-Schijve crack-growth equation
N	number of fatigue cycles
R	displacement ratio ($=\delta_{min}/\delta_{max}$)
δ_{max}	maximum displacement applied during the fatigue test
δ_{min}	minimum displacement applied during the fatigue test

1.Introduction

Adhesively-bonded components and bonded repairs are widely used throughout the aerospace industry. However, given the central role that damage-tolerance assessment and analysis plays in the design and certification of modern aerospace structures and bonded repairs (Miedlar et al. 2003), it is imperative to understand their cyclic-fatigue behaviour. Further, it is important to have a sound, and validated, means for accounting for the effects of test conditions, such as the R-ratio, test temperature and type of loading, and the inherent variability, and hence scatter, seen in the fatigue performance of structural adhesives. The measurement and predictive methods developed so far (e.g. Ripling et al. 1963, Jethwa and Kinloch 1997, Curley et al. 2000, Pascoe et al. 2013, Azari et al. 2014) have been largely based upon the principles of linear-elastic fracture-mechanics (LEFM). Nevertheless, the use of fracture-mechanics methods for design and life-prediction studies for structural adhesives still represent relatively new areas of research and have yet to be adopted by design engineers. Current fracture-mechanics approaches to crack growth in structural adhesive joints are based on variants of the Paris crack-growth equation, where the rate of crack growth per cycle, da/dN, is assumed to be linearly related to either $(G_{max})^m$ or $(\Delta G)^m$. Here G_{max} is the maximum value of the applied strain-energy release-rate in the fatigue cycle and ΔG is the range of the applied strain-energy release-rate in the fatigue cycle ($=(G_{max} - G_{min})$). However, several major problems have been found to arise with this approach of using either ΔG or G_{max} as the 'crack driving force (CDF)'.

Firstly, unfortunately, the value of the exponent, m, in this relationship tends to be relatively large for structural adhesives (and fibre-composite materials). Secondly, fatigue crack growth may be initiated from relatively small naturally-occurring material discontinuities, and be more rapid than predicted from experimental data obtained from relatively 'long-crack' tests. Thirdly, how to account for typical scatter that is observed in the experimental fatigue tests is a challenge. Fourthly, how to account for, and model, the effects of the particular test conditions, such as the R-ratio employed, the test temperature and the mode of loading, has yet to be resolved. The present paper presents a study of the use of the Hartman-Schijve approach to model and predict fatigue crack-growth in structural adhesives in order to overcome the aforementioned problems.