ARTICLE IN PRESS

Engineering Fracture Mechanics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

A new method for fatigue life prediction based on the Thick Level Set approach

L.O. Voormeeren [a,b,*], F.P. van der Meer [b], J. Maljaars [a,c], L.J. Sluys [b]

[a] TNO, Department of Structural Dynamics, PO Box 6012, 2600 JA Delft, The Netherlands
[b] Delft University of Technology, Faculty of Civil Engineering and Geosciences, PO Box 5048, 2600 GA Delft, The Netherlands
[c] Eindhoven University of Technology, Faculty of Built Environment, PO Box 513, 5600 MB Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form 22 April 2017
Accepted 7 May 2017
Available online xxxx

Keywords:
Fatigue
Thick Level Set
Fracture mechanics
Damage mechanics
Interface elements

ABSTRACT

The last decade has seen a growing interest in cohesive zone models for fatigue applications. These cohesive zone models often suffer from a lack of generality and applying them typically requires calibrating a large number of model-specific parameters. To improve on these issues a new method has been proposed in this paper based on the Thick Level Set approach. In this concept, material degradation due to cyclic loading is the result of interaction between damage evolution and fracture mechanics. The Thick Level Set formulation has been extended to interface elements, in order to allow for separation of strain energy in the bulk and energy required for surface creation. Global fracture parameters, derived from a free energy description governing the interface elements, are used as input for the empirical crack growth rate relation (Paris' equation). It must be emphasized that in contrast to existing fatigue models, the Thick Level Set approach does not require the definition of a damage evolution law. Instead, damage is updated automatically by a continuously moving damage front. It is shown that applicability is not limited to fatigue behavior of linear elastic materials; elastic-plastic materials such as steels can be analysed as well. The sensitivity of model parameters is investigated and discussed and the practical relevance is explored for standard test configurations.

1. Introduction

The presence of fatigue cracks is a major concern in many structures such as bridges, offshore wind turbines and airplanes. Regular inspections are required to monitor fatigue crack growth during the lifetime, with an interval that has to account for the uncertainty in predictive models. The costs associated with these inspections are typically high due to instrumentation and accessibility issues. Consequently, improving the predictive capabilities of fatigue models could significantly reduce costs.

Over the years, many numerical models have been developed to improve the physical understanding of the mechanisms involved in fatigue crack growth, with mixed success. Promising techniques such as the eXtended Finite Element Method have been used for fatigue life prediction [1]. Other models use node-release techniques to investigate fatigue phenomena such as plasticity-induced crack closure [2,3]. The last decade, however, there has been a growing interest in cohesive zone models (CZM) for fatigue life prediction. In a cohesive framework, fracture is considered a degradation process in which

* Corresponding author at: TNO, Department of Structural Dynamics, PO Box 6012, 2600 JA Delft, The Netherlands.
E-mail address: l.o.voormeeren@tudelft.nl (L.O. Voormeeren).

http://dx.doi.org/10.1016/j.engfracmech.2017.05.007
0013-7944/

Nomenclature

a, a_0	crack length, initial crack length
$\Delta a, \Delta\bar{a}$	crack increment, crack increment for cycle jumping
b	isotropic hardening parameter
A	crack surface
B	specimen thickness
$\mathbf{B}$	matrix containing derivatives of shape functions
C	Paris' equation constant
C_{eff}	Paris' equation constant accounting for crack closure
C_{kin}	initial kinematic hardening modulus
c_1	damage function parameter
d	damage scalar
Δd_{max}	damage increment for cycle jumping
$\mathbf{D}$	cohesive stiffness tensor
D_0	initial cohesive stiffness
E	Young's modulus
$\mathbf{f}_{\text{ext}}$	external force vector
$\mathbf{f}_{\text{int}}$	internal force vector
F	applied force
g	constraint equation
G	global energy release rate
$\mathbf{jac}$	partial derivatives in consistent tangent matrix
K, K_I	mode-I stress intensity factor
ΔK	stress intensity factor range
ΔK_{eff}	effective stress intensity factor range
$\mathbf{K}$	stiffness matrix
l_c	size of damage transition zone
l_{el}	element length
L_i, L_o	distance inner and outer supports
m	Paris' equation constant
N	number of cycles
ΔN	number of cycles to be jumped
$\mathbf{N}$	matrix containing shape functions
p	equivalent plastic strain
Q_∞	isotropic hardening parameter
$\mathbf{r}$	residual force vector
R	stress ratio
$\mathbf{R}$	rotation matrix
$\mathbf{t}$	external traction vector
$\mathbf{u}$	displacement vector
U	effective stress intensity ratio
$\mathbf{w}$	matrix containing integration point weights
V	bulk domain
W	specimen width
x	Cartesian coordinate
Y	local energy release rate
$\boldsymbol{\alpha}$	back stress tensor
$\boldsymbol{\delta}$	cohesive displacement jump vector
$\boldsymbol{\epsilon_p}$	plastic strain tensor
$\boldsymbol{\epsilon_e}$	elastic strain vector
ϕ	level set field
ψ	free energy of interface
Π	potential energy
σ_0	size yield surface
$\sigma\|_0$	initial yield stress
$\boldsymbol{\sigma}$	stress vector
γ	kinematic hardening parameter
Γ_{coh}	interface domain
Γ_{t}	boundary domain on which external tractions are applied
$\boldsymbol{\tau}$	cohesive traction vector
ν	Poisson's ratio
Ω	volume domain