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 two-parameter criterion for predicting the fracture location along a surface crack

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ARTICLE INFO

Article history:
Received 13 September 2016
Received in revised form 12 July 2017
Accepted 14 July 2017
Available online xxxx

Keywords:
Surface crack
Fracture criterion
Two-parameter approach
J-integral
Constraint

ABSTRACT

The fracture prediction for materials containing surface cracks is not well established. In this paper, a new two-parameter fracture criterion which can predict the location of maximum crack extension along a surface crack front was presented. The surface-cracked specimens with different crack sizes and loads were selected, and the finite element method (FEM) was used to model the *J*-integral and the equivalent plastic strain (ε_p) distributions along the crack front for different specimens. And then, in succession, the areas A_{PEEQ} surrounded by the ε_p isoline ahead of crack tips under different *J*-integrals and the unified constraint parameter A_p were calculated. Based on the parameter A_p, *J*-integral and the fracture toughness J_{ref} measured in a standard test, the $J/(J_{ref}\sqrt{A_p})$, which considered the combined effects of crack driving force and material resistance force, was determined. The critical fracture location is the location for which the $J/(J_{ref}\sqrt{A_p})$ is a maximum. The results show that for all the specimens, the prediction results obtained by two-parameter criterion are consistent with the measured results obtained by experiments. The $J/(J_{ref}\sqrt{A_p})$ is a suitable prediction criterion to model the location of the maximum crack extension of surface crack. For comparison, similar predictions were also made using a single-parameter *J*-integral and $\sqrt{A_p}$.

1. Introduction

Surface cracks are among the most prevalent lifetime inhibitors in structures. These cracks commonly begin forming at material and manufacturing discontinuities [1]. A surface crack will grow until the crack reaches a critical size, at which time it loses stability and fractures, sometimes catastrophically. Thus, establishing accurate fracture criterion to predict the location of the maximum crack extension along a surface crack front is essential and significant for predicting the lifetime of structures, scheduling repairs, and avoiding catastrophic material failures.

Nevertheless, fracture prediction method is not well established for surface cracks in materials. In the traditional approach, the stress intensity factor *K* [2] and *J*-integral [3] were defined and K_{Ic} and J_{Ic} were used as the fracture criterion for brittle and ductile materials, respectively. However, the effect of constraint is not considered in the single-parameter fracture criterion, and inaccurate failure load may be produced.

Constraint is the resistance of a structure against plastic deformation, and the loss of constraint will increase the fracture resistance of a material [4]. In reference to the crack plane, constraint can be divided into two conditions of in-plane and out-of-plane. Some constraint parameters have been defined to characterize the constraint effect, such as *T* [5], *Q* [6,7] A_2 [8] and α_h [1] for in-plane constraint and T_Z [9–11] for out-of-plane constraint, and a few two-parameter fracture criterion have been

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http://dx.doi.org/10.1016/j.engfracmech.2017.07.022
0013-7944/

Please cite this article in press as: Yang J. A two-parameter criterion for predicting the fracture location along a surface crack. Engng Fract Mech (2017), http://dx.doi.org/10.1016/j.engfracmech.2017.07.022

Nomenclature

a	crack length
A_2	parameter quantifying next term in elastic stress-field expansion
A_p	parameter quantifying both in-plane and out-of-plane constraints
A_{PEEQ}	area surrounded by equivalent plastic strain isoline
A_{ref}	area surrounded by an equivalent plastic-strain value
c	crack half-width
E	Young's modulus
J	J-integral
J_{Ic}	fracture toughness characterized by J-integral
J_{ref}	fracture toughness measured in a standard test
K	stress intensity factor
K_{Ic}	fracture toughness characterized by stress intensity factor
M	applied maximum bending moment
Q	a constraint parameter under elastic-plastic condition
S	applied axial stress
T	T-stress constraint parameter under elastic condition
T_Z	factor of the stress-state in 3D cracked body
t	specimen thickness
w	specimen half-width
α	stain hardening coefficient in Ramberg-Osgood relation
α_h	hyper-local constraint factor
ε	strain
ε_0	corresponding extensional strain at yield
ε_p	equivalent plastic strain
n	stain hardening exponent in Ramberg-Osgood relation
ν	Poisson's ratio
σ	stress
σ_0	yield stress
φ	crack parametric angle
Φ	normalized location on surface-crack front
$\Phi_{\max}$	location on surface-crack front for maximum value of certain parameters
$\Phi_{\min}$	location on surface-crack front for minimum value of certain parameters

Abbreviations

FEM	finite element method

proposed based on these parameters. These criterion have successfully improved the accuracy of fracture prediction. However, the parameters mentioned previously can quantify the in-plane or out-of-plane constraint separately, but not are equally sensitive to both constraints, which exist in the engineering structures. This will limit its application and affect its prediction accuracy.

Fortunately, some unified constraint parameters [12–15] and approach [16,17] that can character both in-plane and out-of-plane constraints have been proposed. And based on these parameters and approach, a new unified constraint parameter A_p [18,19] has been defined by the author. It provides the possibility to build a valid fracture prediction criterion which is suitable for different in-plane and out-of-plane constraint conditions.

In addition, based on the constraint parameter α_h, Leach et al. [1] presented a two-parameter approach $J\alpha_h$ to predict the location of maximum crack extension along a surface crack front and made excellent work to investigate the maximum crack extension location in experimentations, which provides a valuable reference for the verifying of the fracture prediction criterion.

In this paper, the J-integral and A_p around the surface crack front were calculated for specimens with different loads and crack sizes by the finite element method (FEM), and based on the J-integral and A_p, a two-parameter fracture prediction criterion for the surface crack is presented herein. The prediction results were then compared with experiment results in the literature [1]. For comparison, similar predictions were also made using a single-parameter J-integral and $\sqrt{A_p}$

2. The fracture prediction criterion

In general, the value of J-integral is an expression of the crack driving force, and the location of J-integral with the maximum value has the maximum crack driving force. While constraint is the resistance of a structure against plastic deforma-