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The jump-like crack growth model, the estimation of fracture energy and J_R curve

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Abstract

In this paper the jump-like crack growth model for monotonic loading is applied to re-examine both the onset of crack growth and process of stable crack growth. In the former case the fracture energy associated with a new surface creation is estimated and the in-plane constraint influence on this quantity is examined using the J–A_2 approach. In the later case the formula to compute the J-resistance curve is re-examined and compared with the one known from the standards. In the analysis the plane strain model of a structural element made of elastic–plastic material is assumed.
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Keywords: Fracture energy; In-plane constraint; J_R-curve; Jump-like crack growth

1. Introduction

In the most analyses of stable crack growth under monotonic loading it is assumed that the crack extension is a continuous process. It is a natural consequence of the fundamental assumptions of mechanics of continuum. However, the microscopic observations of the fracture surfaces reveal that in the most real cases the crack growth process is not a continuous one. It concerns both cleavage and ductile fracture mechanisms which are a result of microcrack or void nucleation-growth-coalescence processes taking place at a small distance from the front of a macro-crack. There are many observations and theories (often controversial) concerning these processes that are summarized e.g. in the recent book [1] or paper [2]. The complexity of the crack growth process can be observed in the three-dimensions (3D) during the in situ observations using a high resolution synchrotron X-ray tomography. Qian et al. [3] are among the first who presented such results for ductile materials. This paper [3], is the best example that the real fracture process, in the most cases, is not a continuous propagation of the straight crack front.

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Nomenclature

a, a_i	crack length, crack length after ith jump
b	unbroken ligament of the specimen
n	Ramberg–Osgood power exponent
u	load–point displacement
u_e, u_p	elastic, plastic part of the load–point displacement
u_i	displacement vector
x	coordinate, measuring distance from the crack tip along the crack faces
A_1, A_2	coefficients in the YCS formulae
ΔA	finite crack surface increment
A'	new crack surface
A_c, A_u, A_F	surfaces of crack, displacement and external loading application areas (Fig. 2)
B	specimen thickness
C_i	specimen compliance after ith crack jump
E'	$E' = E$, E-Young modulus, for plane stress, $E' = E/(1 - \nu^2)$ for plane strain
F_i	external force
G	energy release rate
J	J-integral
J_c, J_{IC}	critical value of the J-integral and critical plane strain standard value of J-integral respectively
K	stress intensity factor
L	characteristic length in the YCS formulae
N	$N = 1/n$
P_i	external force
R	work of external forces
S	surface of the specimen
T_i	stress vector along the plane of the crack location
U	strain energy
U_e, U_p	elastic and plastic strain energy
V	volume of the specimen
W	specimen width
α	constant in the Ramberg–Osgood relation
ε_{ij}	strain tensor
ε_0	σ_0/E
η	coefficient relating J-integral to the deformation energy
ν	Poisson ratio
σ_{ij}	stress tensor
$\tilde{\sigma}^k_{ij}$	$k = 1, 2, \ldots$ functions in the YCS formula
Γ	fracture energy per unit surface
HRR	Hutchinson–Rice–Rosengren
OC	O'Dowd–Shih
SIF	SIF
ssy	small scale yielding
YCS	Yang–Chao–Sutton

Discontinuous crack growth is even more pronounced during fatigue, stress corrosion, hydrogen assisted cracking or fracture at high temperatures. Many jump-like crack growth models were presented in the literature (e.g. [4–10]) in order to explain a complex nature of these processes.

In this paper the analysis is limited to fracture process under monotonically increasing external loading or load–point displacement only. Both the onset of crack growth and stable crack growth will be discussed.

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