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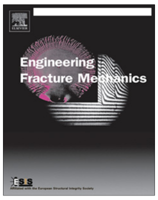

Crack path prediction in rolled aluminum plates with fracture toughness orthotropy and experimental validation

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ABSTRACT

The paper presents a numerical procedure for the accurate calculation of crack paths in plane structures. The *J*-integral is used to determine crack tip loading quantities such as stress intensity factors or the energy release rate. Crack paths are predicted applying a modified maximum energy release rate approach accounting for the fracture toughness orthotropy in rolled plates of aluminum alloy Al-7075-T651 where the anisotropy of elastic constants is negligible. Experiments with CT-specimens are carried out to determine the fracture toughnesses in and perpendicular to the rolling direction. The numerically predicted crack paths for differently shaped specimens are in good agreement with those obtained from experiments.

1. Introduction

Rolled sheets of aluminum are known to exhibit a texture inherently giving rise to anisotropic material behavior. Besides the elastic properties, only slightly depending on the orientation, the fracture toughnesses in and perpendicular to the rolling direction differ by approximately 10–15%. Neglecting this feature, numerically predicted and experimentally observed crack paths agree qualitatively, however not quantitatively.

Several papers [31,32,2,1] focus on the calculation of crack tip loading quantities in orthotropic structures with stationary cracks, however not regarding crack growth or crack paths. Established numerical techniques for crack path prediction as elastic or elastic–plastic boundary value problem are often based on the FE-method. Convenient tools for calculating crack paths are e.g. iterative procedures in connection with intelligent remeshing algorithms and integrated post processors. The accurateness of the predicted crack paths goes along with the precise calculation of crack tip loading quantities, e.g. the J_k-integral, or in the linear elastic fracture mechanics (LEFM) the energy release rate (ERR) G or stress intensity factors (SIF). These quantities, which are depending on the applied loads and the geometrical configuration, are provided numerically by post processing procedures such as the *J*-integral [15,43], the crack tip element (CTE) method [22,5], the interaction integral (I-integral) technique [51,55] or the modified crack closure integral (MCCI) method [44]. Here, path-independent integrals are beneficial as, in contrast to the CTE or MCCI method, no special requirements of the FE-meshes have to be considered and numerical input data may be taken far from the crack tip.

The *J*-integral is based on Eshelby's general theory on configurational forces acting at singularities and inclusions [18] and was introduced by Cherepanov [15] and Rice [43] who applied the formulation of this path-independent integral to strain concentration problems. The two-dimensional J_k-integral vector, introduced by Budiansky and Rice [9], is composed of the coordinate $J_1 = J$ and J_2 and provides an extended path-independent formulation of the classical *J*-integral for arbitrary

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Nomenclature

$\bar{a}$	mean crack length
a_0	initial crack length
Δa	increment of crack advance
$\mathrm{d}a/\mathrm{d}N$	crack growth rate
a_{ij}	compliance tensor
B	specimen thickness
C	crack growth rate coefficient
C_{ijkl}	elasticity tensor
E	Young's modulus
$\vec{e}_i$	local coordinates
$\vec{\bar{e}}_i$	global coordinates
e_0	geometric parameter
f_{ij}	complex angular function
G	energy release rate
G_c	crack growth resistance
G_R	ratio of energy release rate and crack resistance
G_{th}	threshold parameter for fatigue crack growth
g_i	complex angular function
H	energy quantity indicating crack deflection
J_k	J-integral vector
ΔK	stress intensity factor range
K_{I}	mode I stress intensity factor
K_{II}	mode II stress intensity factor
K_{Ic}	fracture toughness
$K_{\mathrm{I}}^{\max}$	maximum stress intensity factor of pulsation load
K_{Ith}	threshold value for fatigue crack growth
m	crack growth rate exponent
n_j	normal vector of the integration contour
P_Q	load value
Q_{kj}	energy momentum tensor
r	radius
s_k	complex constants
u	strain energy density
u_i	displacement vector
Δu_i	jump of the displacements across the crack faces
W	geometric parameter
ΔW^c	work required for crack closure
z_k	crack growth direction

Greek letters

α	global crack deflection angle
β	local crack deflection angle
δ_{ij}	identity tensor
ϵ	infinitesimal distance
ε_{ij}	strain tensor
φ	radial coordinate
Γ	integration contour
ν	Poisson's ratio
Π	total potential energy
ψ	mixed-mode ratio
σ_{ij}	stress tensor
χ	ratio of orthotropic fracture toughness

Special symbols

$\Re\{\}$	real part of complex quantity in brackets
$\Im\{\}$	imaginary part of complex quantity in brackets
I	normal crack opening mode
II	plane shear crack opening mode
A, B	specimen shapes