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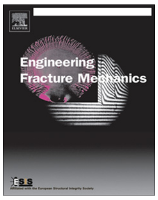

Fatigue crack growth experiments on specimens subjected to monotonic large scale yielding

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ABSTRACT

Fatigue crack growth behavior was investigated for through thickness long cracks in two different geometries at monotonic large scale yielding in a stainless steel 316L. Finite element computations on the coupling between the applied load, the crack length and the crack tip opening displacement, δ, were conducted. These coupling equations were used to control $\Delta\delta$ *in situ* in the experiments based on the potential drop measured crack length. The $\Delta\delta$ was able to characterize and correlate the fatigue crack growth load state for the present geometries and loads. Also the stress-intensity factor range, ΔK_{I}, could predict the growth rates due to large isotropic hardening at cyclic conditions and absence of crack closure.

1. Introduction

Fatigue damage and failure still remains among the most important concerns for the mechanical integrity of structures and components. High loads causing plastic deformation, in structures and components, are in general avoided due to both the theoretical and experimental difficulties (and uncertainties) connected with such designs. However, certain applications require the full use of the mechanical properties of the material and plastic deformation must be allowed, at least in local regions. One such application is the mixing of hot and cold water, for instance in nuclear power plants, where the thermal fluctuations can give raise to large plastic deformations at fatigue cracks that are positioned on the inside surface of the pipe. In such cases, most of the fatigue life consists of crack growth and only a minor part is consumed at crack initiation. Hence, the present study focused on the fatigue crack growth at large plastic strains.

The perhaps most commonly used crack tip characterizing quantity for large scale yielding (LSY) fatigue crack growth situations is the ΔJ-integral. Dowling and Begley [1] and Dowling [2] are the first, in the mid 1970s, to propose the ΔJ-integral as a correlation parameter for LSY fatigue crack growth. They estimate ΔJ from the load deflection curves for a standard compact tension (CT)-specimen and a center crack panel. The parameter succeeds in correlating fatigue growth rates for the two geometries at different load levels. A few years later Mowbray [3] presents LSY fatigue growth data and concludes that the overall results support the Dowling and Begley hypothesis that the crack growth rate is controlled by the operational definition of ΔJ. The LSY fatigue growth rates are also in line with small scale yielding (SSY) fatigue growth rates.

In the mid and second half of the 1980s computers found their way into the laboratories and in 1985 Joyce and Sutton [4] are among the first to use numerical simulations to compute ΔJ *in situ* from the load deflection curve, enabling direct control of the local parameter. The crack length is measured by the compliance and corrections for the crack closure level is done automatically. The LSY fatigue growth rates are again in line with SSY fatigue crack growth rates. A few years later Lambert

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Nomenclature

a	crack length
a_{PD}	a, based on potential drop measurements
a_{Visual}	a, visually measured on the specimen side
a_{ASTM}	a, measured according to ASTM E1820
b	rate of hardening process
B	specimen thickness
C	material parameter
d_{n}	dimensionless parameter
E	Young's modulus
J, K	energy release rate and stress-intensity factor
m, n	degree of polynomial and hardening parameter
N_{elements}	number of elements in the cyclic plastic zone
P, P_{L}	load and limit load
Q_∞	the maximum increase of the yield surface
$R_{\mathrm{G}}, R_{\mathrm{L}}$	global and local load ratio
$r_{\mathrm{p,cyc}}$	estimated cyclic plastic zone size
V_1	potential drop over the fatigue crack
$V_{1,corr}$	temperature corrected V_1
V_2	potential drop over the reference specimen
V_{ref}	reference potential
W	the sum of the crack length and uncracked ligament
$\bullet^{\mathrm{dev}}$	deviatoric part of $\bullet$
$\bar{\bullet}$, $\bullet_0$	average and initial/reference value
$\bullet_{\mathrm{max}}$, $\bullet_{\mathrm{min}}$	maximum and minimum value
$\bullet_i$, $\bullet_{\mathrm{I}}$	index and mode I load
$\bullet_{\mathrm{trans}}$, $\bullet_{\mathrm{rot}}$	translation and rotation
$\dot{\bullet}$	rate of $\bullet$

Greek characters

α	the degree of plane stress/plane deformation
α_{ij}	back stress tensor
β, γ	exponent in Paris law and curve fit parameter
δ	crack tip opening displacement
$\Delta\bullet$	range of $\bullet$
ϵ	true strain
$\bar{\epsilon}^{\mathrm{pl}}$	effective plastic strain
$\epsilon_{\mathrm{Y,cyc}}$	defined by $\sigma_{\mathrm{Y,cyc}}$ through Young's modulus
θ	temperature
κ	material parameter
σ_{ij}	stress tensor
σ_{FS}, σ_{UTS}	flow strength and ultimate tensile strength
σ_{Y}, $\sigma_{\mathrm{Y,cyc}}$	monotonic and cyclic yield strength
σ_0	strip yield strength
$\sigma\|_0$	initial size of the yield surface
σ^0	size of the yield surface
ν	crack mouth opening displacement

Acronyms

CMOD	crack mouth opening displacement
CT	compact tension
CTOD	crack tip opening displacement
ECT	edge crack tension
FE	finite element
LEFM	linear elastic fracture mechanics
LSY, SSY	large scale yielding and small scale yielding
PD	potential drop