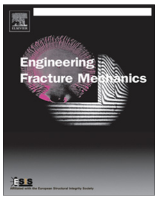
ARTICLE IN PRESS

Engineering Fracture Mechanics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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



A single edge notch specimen for fatigue, creep-fatigue and thermo-mechanical fatigue crack growth testing

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ARTICLE INFO

Article history:
Received 7 April 2017
Received in revised form 31 July 2017
Accepted 2 August 2017
Available online xxxx

Keywords:
Single-edge-notch
Crack growth
Stress intensity factor
Compliance
IN738

ABSTRACT

The importance of capturing crack growth behavior under creep-fatigue and thermo-mechanical-fatigue is well known. Such service load environments are often simulated by performing tests under load and displacement control conditions where the specimen may be subjected to both tensile and compressive loads. A single edge notch specimen was developed to accommodate tension and compression loading in fatigue, creep-fatigue and thermo-mechanical fatigue crack growth experiments. The stress intensity factor and compliance solutions were developed for the single edge notch specimen using a 3D fracture code (FRANC3D) and 2D boundary element code (FADD2D). Both codes agreed well with each other. It is shown in this work that using simple approximations in a 2D code such as FADD2D, accurate stress-intensity and compliance solutions can be obtained for specimen geometry with varying cross sections. An importance of using correct boundary condition is emphasized by displaying the difference in stress intensity solutions for rectangular edge-cracked plate under uniform-stress, and uniform-displacement cases. Also, it is shown that stress intensity solution for a threaded edge-cracked specimen considered in this paper is different from the solution for rectangular edge-cracked plate under displacement control. As a validation of the developed stress-intensity and compliance equations, fatigue crack growth tests were conducted using the single edge notch, compact type and a surface crack specimen. Tests were conducted under constant amplitude load control of 0.1 stress ratio, *R* for IN738 nickel base super alloy material. Agreement was found between the different specimen types in the intermediate crack growth rate range.

1. Introduction

Crack growth properties are often required to evaluate the structural integrity under the presence of detected or postulated flaws. Therefore, for sound design considerations, a good understanding and predictive capability for crack growth behavior under various conditions such as fatigue, creep-fatigue and thermo-mechanical fatigue are required. For example,

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http://dx.doi.org/10.1016/j.engfracmech.2017.08.011
0013-7944/© 2017 Published by Elsevier Ltd.

Please cite this article in press as: Narasimhachary SB et al. A single edge notch specimen for fatigue, creep-fatigue and thermo-mechanical fatigue crack growth testing. Engng Fract Mech (2017), http://dx.doi.org/10.1016/j.engfracmech.2017.08.011

Nomenclature

List of symbols

a	crack length
B	specimen thickness
C	compliance
da/dN	crack growth rate
E	Young's modulus of elasticity
F	boundary correction factor
h or H	half height of gage length
K	stress intensity parameter
N	number of fatigue cycles
$P, P_{\min}, P_{\max}$	applied, minimum and maximum load respectively
R	load ratio ($P_{\min}/P_{\max}$)
$R_{\varepsilon,mech}$	mechanical strain ratio ($\varepsilon_{\min}/\varepsilon_{\max}$)
W	specimen width
V	displacement
ΔK	stress intensity factor range under fatigue loading
ΔP	applied load range
$\varepsilon_{\min}, \varepsilon_{\max}$	minimum and maximum strain respectively
σ	applied stress

Abbreviations

ASTM	American Society for Testing and Materials
ANSYS	finite element software
BEA	boundary element analysis
C-FCG	creep-fatigue crack growth
CMOD	crack mouth opening displacement
C(T)	compact type
DEN(T-C)	double edge notch tension-compression specimen
FADD2D	2D code, fracture analysis by distributed dislocation
FEA	finite element analysis
FRANC3D	3D fracture code
LEFM	linear elastic fracture mechanics
PD	potential drop
SEN	single edge notch
SIF	stress intensity factors
TMF	thermo-mechanical fatigue
TMF-CG	thermo-mechanical fatigue crack growth
UTS	ultimate tensile strength
YS	yield strength

to predict residual lives of non-isothermal cracks in elevated temperature components, it is necessary to conduct fatigue crack growth test under thermo-mechanical fatigue, TMF, conditions [1–5]. These tests are typically performed in displacement-controlled mode with in-phase, IP and out-of-phase, OP, cycling conditions. Commonly utilized mechanical strain ratios are $R_{\varepsilon,mech} = -\infty$ (typically in combination with OP-Phasing) and $R_{\varepsilon,mech} = 0$ (typically in combination with IP-Phasing). Similarly, for isothermal cracks, crack growth data under fatigue and creep-fatigue conditions are needed [6–8]. During creep-fatigue crack growth tests, if the specimen displacement due to plastic and/or creep strains during loading can be reversed, ratcheting of the specimen can be avoided and more crack extension data can be extracted from each test by re-sharpening the crack tip stress fields [9]. Thus, during these tests, the specimen can be subjected to both tensile and compressive loads.

Compact type, C(T), specimens are commonly used for fatigue and creep-fatigue crack growth testing under constant-load-amplitude conditions. However, the use of the standard C(T) specimens [10–12] is only limited to positive load ratios. Also, C(T) specimens limits the amount of crack growth data that can be generated for the high stress intensity values, mainly due to accumulation of plastic and/or creep strains leading to ratcheting in the specimen. Recently [13], a double edge notch (DEN) specimen was modified to allow for tension-compression (T-C) loading during crack growth testing. Testing on DEN(T-C) specimen geometry revealed that it is prone to crack asymmetry issues [14]. So, it is highly desirable to have a specimen that does not have the issues associated with these standard specimens.

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