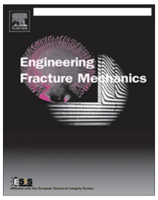
Engineering Fracture Mechanics 143 (2015) 121–137

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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



Two-parameter characterization of constraint effect induced by specimen size on creep crack growth

Lei Zhao *, Lianyong Xu *, Yongdian Han, Hongyang Jing

School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China
Tianjin Key Laboratory of Advanced Joining Technology, Tianjin 300072, China

ARTICLE INFO

Article history:
Received 18 January 2015
Received in revised form 12 June 2015
Accepted 15 June 2015
Available online 19 June 2015

Keywords:
Constraint effect
Specimen size
Creep crack growth
Predication approach

ABSTRACT

Experimental and numerical investigations on the effect of constraint induced by different specimen sizes on creep crack growth had been conducted using compact tension specimen with P92 steel. The experimental results revealed that at the same C^* values, creep crack growth rates increased as specimen size increased and the difference enlarged with increasing C^* values. In addition, the variations of constraint level Q during creep were obtained and a modified C^*–Q approach incorporating constraint effect was proposed to predict creep crack growth. In comparison with conventional single C^* parameter approach, two parameter approach could provide more accurate crack growth rates.

1. Introduction

Environmental and commercial demands on energy production have led to the development of power plants operable at super critical conditions. Increasing the operating temperature and pressure, the efficiency of conventional steam and gas turbine power plants could be significantly improved and then the fuel consumption and harmful emission of power plants could be remarkably reduced [1,2]. Creep crack propagation is among the most prevalent life inhibitors in high temperature structural components with flaws during manufacturing and servicing. Thus, creep crack growth assessment for structural components serving in elevated-temperature environment is one of the most important tasks to ensure the structure integrity.

To characterize and quantify creep crack propagation behavior, continuum fracture mechanics concepts have to be utilized. Specifically, an appropriate fracture mechanics parameter C^*, the time dependent analogue of the J contour integral used in elastic–plastic fracture mechanics, has been employed to correlate the creep crack growth rates, and defined as:

$$C^* = \int_{\Gamma} \left(W^* dy - T \frac{\partial \dot{u}}{\partial x} ds \right) \tag{1}$$

where W^* is the instantaneous stress-power or energy rate per unit volume; Γ is the path of the integral that encloses the crack tip contour; ds is the increment in the contour path; T is outward traction vector on ds; $\dot{u}$ is the displacement rate vector at ds; x, y, z is the rectangular coordinate system and $T\frac{\partial \dot{u}}{\partial x} ds$ is the rate of stress-power input into the area enclosed by across the elemental length ds.

---

* Corresponding authors at: School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China. Tel./fax: +86 022 27402439.
E-mail addresses: zhaolei85@tju.edu.cn (L. Zhao), xulianyong@tju.edu.cn (L. Xu).

http://dx.doi.org/10.1016/j.engfracmech.2015.06.032
0013-7944/

Nomenclature

a	current crack length
b	uncracked ligament length
a_0	initial crack length
r	radial distance from the crack tip
I_n	integration constant in the HRR stress field distribution
K	stress intensity factor
F	applied load in tests
B	specimen thickness
B_n	net specimen thickness between the bottoms of side grooves
W	specimen width
E	Young' s modulus
α	the strain hardening coefficient
m	exponent in a Ramberg–Osgood fit to the tensile data
Q	dimensionless constraint parameter
Y_0	half the distance between the output terminals
W	the width of the specimen
V_0	the initial voltage
V	the actual value of the potential.
A	coefficient in the power-law creep strain rate expression
n	power-law creep stress exponent
C^*	steady state creep fracture mechanics parameter
D, ϕ	material constants in a correlation with C^*
K	stress intensity factor
r_c	creep process zone size
J_p	plastic component of the J-integral
t_r	time to rupture in a uniaxial creep test
t_i	creep initiation time of crack growth at 0.2 mm
t_T	transition creep time
MSF	appropriate multiaxial stress factor
θ	crack tip angle
υ	Poisson ratio
σ_0	yield stress
σ_b	bending stress effect
ε_0	creep strain at stress σ_0
ε^t, ε^e, ε^p, ε^c	total, elastic, plastic and creep strain components
ω, $\dot{\omega}$	creep damage parameter and creep damage rate
ε_f	uniaxial creep failure strain
ε_f^*	multiaxial creep failure strain
σ_m, σ_e	hydrostatic stress and equivalent stress
δ_{ij}	Kronecker delta
$\tilde{\sigma}_{ij}(\theta, n)$, $\tilde{\varepsilon}_{ij}(\theta, n)$	dimensionless stress and strain functions of n and θ
$\dot{V}_c$	creep load line displacement rate
$\dot{\varepsilon}^c$	equivalent creep strain rate
$\dot{\varepsilon}_A^c$	average creep strain
$\dot{\varepsilon}_{ij}$	strain rate tensor
$\dot{a}$	creep crack growth rate
$\sigma_{\theta\theta}^{HRR}(r, 0)$	analytical crack-opening stress from the HRR field
$\sigma_{\theta\theta}(r, 0)$	numerical crack-opening stress from FEM

In general, the relation between creep fracture parameter and creep crack growth rates could be considered as a material property, which means that it should be independent of size and geometry [3]. Most of the current integrity analyses are based on this property, such as R5, BS7910 standards. However, some experimental and theoretical evidences have shown that crack tip constraints induced by specimen size, crack depth, geometry, and loading condition have great influence on the creep crack behavior. Therefore, many efforts have been made on modeling the constraint effect on the creep crack growth of metals at elevated temperatures [4].