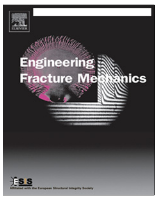
Engineering Fracture Mechanics 154 (2016) 92–110

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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



Creep crack growth prediction and assessment incorporating constraint effect for pressurized pipes with axial surface cracks

S. Liu, G.Z. Wang [*], S.T. Tu, F.Z. Xuan

Key Laboratory of Pressure Systems and Safety, Ministry of Education, East China University of Science and Technology, Shanghai 200237, China

ARTICLE INFO

Article history:
Received 8 August 2015
Received in revised form 10 January 2016
Accepted 11 January 2016
Available online 14 January 2016

Keywords:
Constraint effect
Creep crack growth
Two-parameter
Single-parameter
Pressurized pipes

ABSTRACT

Creep crack growth life is firstly predicted and assessed by two-parameter concept to incorporate constraint effect for pressurized pipes with inner axial surface cracks. The prediction and assessment results are compared with those based on conventional single-parameter C^* and finite element calculations. For shallower and shorter cracks, the life assessments based on single-parameter C^* are excessively conservative. To reduce excess conservativity, it is strongly recommended to incorporate constraint effect. With decreasing initial crack sizes, the benefits gained from two-parameter assessments increase. The crack growth profile may also be correctly predicted by two-parameter calculations. The C^* calculation of reference stress method leads to extra conservativity.

1. Introduction

It has been well known that crack-tip constraint state has significant influence on fracture behavior of materials, and the loss of constraint causes the increases in fracture toughness. The constraint effect is usually caused by specimen or structure geometry, crack size, loading configuration, etc. To improve accuracy in structural integrity assessments, the crack-tip constraint effect requires to be incorporated by suitable constraint parameter. The quantification of constraint has been widely investigated within the elastic–plastic fracture mechanics frame, and some methodologies incorporating constraint effect have been established. However, the studies on creep crack-tip constraint effect is still limited, and the methodology incorporating creep constraint effect for creep life assessments has not been established. In the present codes of high-temperature creep defect assessments, the constraint effect still has not been incorporated.

Many experimental and theoretical evidences have shown that constraint can affect creep crack growth (CCG) rate [1–18]. For a given C^* value (creep fracture mechanics parameter), the CCG rates in plane strain state are significantly greater than those in plane stress state [2–6]. The CCG rates also increase with increasing crack depth [7] and specimen thickness [8–12]. In terms of constraint effect caused by loading configuration, the CCG rate of the middle tension (M(T)) specimen is significantly lower than that of the compact tension (C(T)) specimen for different steels [13–16]. Some experiments also showed that the creep crack growth rates in the single edge-notched tensile (SEN(T)), single edge-notched bend (SEN(B)), double edge notch tension (DEN(T)) and M(T) specimens are generally lower than those in C(T) specimens [18]. Yokobori et al. proposed a parameter Q^* for correlating creep crack growth rate [19–22], and their work showed that the creep crack growth rate for a thick specimen is higher than that of a thin specimen [20]. The creep ductility and constraint effect can be estimated by using the parameter Q^* [21], which were defined as "structural brittleness" [22]. In recent work of Shlyannikov

---

[*] Corresponding author. Tel./fax: +86 21 64252681.
E-mail address: gzwang@ecust.edu.cn (G.Z. Wang).

http://dx.doi.org/10.1016/j.engfracmech.2016.01.009
0013-7944/

Nomenclature

a	crack depth
a_0	initial crack depth
$\dot{a}$	creep crack growth rate
$\dot{a}_0$	creep crack growth rate of the standard specimen
Δa	crack depth increment
A	coefficient in power-law creep strain rate expression
$2c$	crack length
$2c_0$	initial crack length
Δc	crack length increment
C^*	creep fracture mechanics parameter
C_d^*	C^* value at the deepest point along crack front
C_s^*	C^* value at the surface point along crack front
$C(t)$	$C(t)$ integral
D	inner diameter of pipes
E	Young's modulus
f_1, f_2	conservativity factor
G_i	influence coefficients
K	stress intensity factor
J	J-integral
Kcr	creep stress intensity factor
L	characteristic length
n	power-law creep stress exponent or power-law strain hardening exponent in Ramberg-Osgood relation
p	internal pressure
Q	constraint parameter under elastic-plastic condition or an elliptical integral of the second kind defining the shape of the ellipse
Q^*	parameter for correlating creep crack growth rate
r	distance from a crack tip
R	creep constraint parameter
R_i	inner radius
R_o	outer radius
R^*	load-independent creep constraint parameter
R_d^*	R^* value at the deepest point along crack front
R_s^*	R^* value at the surface point along crack front
t	creep time or pipe thickness
t_{f,C^*-R^*}	creep crack growth life from two-parameter C^*–R^* assessment
t_{f,C^*}	creep crack growth life from single-parameter C^* assessment
$t_{f,E}$	creep crack growth life predicted by empirical equations
$t_{f,\mathrm{FEM}}$	creep crack growth life predicted by finite element method
t_{red}	stress redistribution time
Δt	time increment
W	specimen width
α	strain hardening coefficient in Ramberg-Osgood relation
$\dot{\varepsilon}$	creep strain rate
ε_e	elastic strain
ε_c	accumulated creep strain at the reference stress σ_{ref} for time Δt from uniaxial creep data
$\dot{\varepsilon}_0$	creep strain rate at normalized stress
$\dot{\varepsilon}_{\mathrm{ref}}$	creep strain rate at the reference stress
θ	polar coordinate at the crack tip
σ_0	normalized stress
σ_{ref}	reference stress
σ_ϕ	axial tension stress
σ_{22}	opening stress
$\sigma_{22,\mathrm{CT}}$	opening stress of C(T) specimen under plane strain
$\Delta\sigma$	opening stress difference
υ	Poisson's ratio

Abbreviations

3-D	three-dimensional
CCI	creep crack initiation