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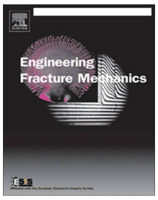

Prediction of creep crack initiation behavior considering constraint effects for cracked pipes

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ABSTRACT

The creep crack initiation (CCI) location and time of axial surface cracks with different sizes in cracked pipes have been comparatively predicted by finite element calculations based on creep ductility exhaustion model and creep fracture mechanics considering constraint effects by using two new creep constraint parameters (R^* and A_c). The effects of calculation methods of the parameters C^*, R^* and A_c along the crack fronts on the prediction accuracy of CCI time have been analyzed. It has been found that with decreasing crack length, the CCI location changes from the deepest part to near surface part along the crack front, and the composite parameters composed of C^* and constraint parameters can predict the CCI location. The CCI time of pipe cracks increases with decreasing crack depth and length due to the decrease of crack-tip constraint level. The excessive conservatism in conventional CCI life assessments using single parameter C^* can be significantly reduced by using the two-parameter concept (C^*-R^* and C^*-A_c) considering constraint effects. When the average values of C^*, R^* and A_c along the crack fronts (instead of the values at the deepest locations of crack fronts) are calculated and used in CCI life predictions of cracked pipes, the prediction accuracy with respect to the finite element calculations based on creep ductility exhaustion model can be significantly improved. The C^* values calculated by reference stress method can lead to extra conservatism in CCI life predictions.

1. Introduction

Creep crack initiation (CCI) and growth (CCG) are the principle mechanisms of failure in high- temperature components [1]. The CCI time is generally defined as the time required for a small crack extension (it is typically 0.2 mm or 0.5 mm) from a defect. Because CCI time can take a large fraction (80%) of total service lifetime of a component [2–4], it is important to assess the CCI life of high-temperature components.

Many experimental [5–7] and numerical investigations [8–11] have shown that creep crack-tip constraint induced by specimen geometries and dimensions, crack sizes, testing duration, loading conditions and material properties can influence CCI time. The CCI time decreases with increasing creep crack-tip constraint [8–10]. For a given C^* value, the CCI time in low constraint M(T) specimens is significantly longer than that obtained in high constraint C(T) specimens for 316H stainless steel [10] and Cr-Mo-V steel [8,9]. It has also been shown that long term CCI time is shorter than the CCI time of prediction line from short term test for a specific C^* value [6]. Different approaches for CCI time assessments have been developed, such as time-dependent failure assessment diagram (TDFAD) [12,13], two-criteria diagram (2CD) [14–16] and

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Nomenclature

a	crack depth
A_1, A_2	constants in 2RN creep model
A_c	unified characterization parameter of in-plane and out-of-plane creep constraint
A_{CEEQ}	area surrounded by equivalent creep strain isoline
A_{ref}	area surrounded by equivalent creep strain isoline in a standard specimen
$2c$	crack length
C^*	C^* integral analogous to the J integral
$C_1{}^*$	C^* value in cracked specimen or component
$C_2{}^*$	C^* value in standard reference C(T) specimen in plane strain
D	inner diameter of pipes
f_1, f_2	conservative factor
K	stress intensity factor
K_{cr}	creep stress intensity factor
L	characteristic length
n_1, n_2	stress exponents in 2RN creep model
Q	constraint parameter
p	internal pressure
r	distance from a crack tip
R_i	inner radius of pipes
R_o	outer radius of pipes
R^*	load-independent creep constraint parameter
T_z	out-of-plane constraint parameter
t	creep time; pipe wall thickness
t_i	creep crack initiation time
$t_{0.2}$	creep crack initiation time for a crack extension of 0.2 mm
$t_{0.5}$	creep crack initiation time for a crack extension of 0.5 mm
t_{red}	creep redistribution time
W	specimen width
$\dot{\varepsilon}_c$	creep strain rate
$\dot{\varepsilon}_{ref}$	creep strain rate at reference stress
ε_f^*	multiaxial creep ductility
ε_f	uniaxial creep ductility
ε_c	equivalent creep strain
σ_{22}	opening stress
$\sigma_{22,\mathrm{CT}}$	opening stress of C(T) specimen under plane strain
σ_e	von Mises effective stress
σ_m	hydrostatic stress
σ_{ref}	reference stress
σ_φ	axial tension stress
ω	damage parameter
$\dot{\omega}$	damage rate
Φ	angular parameter characterizing crack front position

Abbreviations

3-D	three-dimensional
2RN	2- regime Norton
C3D8R	eight node brick elements
CCI	creep crack initiation
CCG	creep crack growth
CEEQ	equivalent creep strain in ABAQUS code
C(T)	compact tension
FEM	finite element method
M(T)	middle cracked tension
PE	plane strain

Nikbin-Smith-Webster model (NSW model) [16]. In these approaches, the constraint effects have not been considered, and the conservative CCI life prediction may be produced. To reduce the excessive conservatism, it is necessary to establish engineering approaches of CCI life prediction incorporating creep constraint effects.

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