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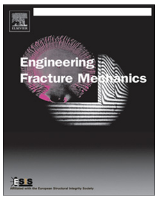

Prediction of creep crack growth behavior in Cr–Mo–V steel specimens with different constraints for a wide range of C^*

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ABSTRACT

The stress dependent creep ductility and strain rate model were implemented in a ductility exhaustion based damage model, and the creep crack growth rates in Cr–Mo–V steel specimens with different constraints over a wide range of C^*-integral have been predicted by finite element analyses. The predicted creep crack growth rates agree well with the existing experimental data. The creep crack growth rate increases with increasing specimen constraint, and the specimen constraint has effect on the C^*-integral values of the slope turning points on the crack growth rate curves. The mechanical mechanism of specimen constraint effects on creep crack growth behavior was analyzed and discussed. The results show that the constraint effects on the creep crack growth behavior for a wide range of C^*-integral mainly arise from interaction of crack-tip stress states and stress dependent creep ductility of the steel. The constraint dependent creep crack growth rate data in a wide range of C^*-integral should be obtained and used in creep life assessments of components.

1. Introduction

Some experimental and theoretical evidences have shown that the crack-tip constraint can affect creep crack growth (CCG) rates [1–13]. For a given C^* value, CCG rates in plane strain (PE) are significantly greater than those in plane stress [2–6]. The experimental results of Tabuchi et al. [7] and Tan et al. [8,9] have shown that there is an effect of specimen thickness on CCG rates, and the specimens with larger thickness exhibit higher CCG rates. It also has been found that the CCG rates measured in the middle tension (M(T)) specimens are lower than those obtained from deep crack compact tension (C(T)) specimens at the same C^* value for the austenitic stainless steels [10–12] and the ferritic steels [13].

In the standards for measuring CCG rate of materials, the C(T) specimen with deep crack ($a/W = 0.5$, where a is the crack length and W is the specimen width) in PE is usually recommended [14], in order to ensure that the crack tip has relatively high constraint to obtain conservative CCG rate data. However, the defects formed in manufacturing process and service are usually surface cracks for high temperature components. These cracks often have lower crack-tip constraint. Therefore, the uses of the fracture tests and calculations based on deep crack specimens with high constraint in design or life assessment for most practical situations are unduly conservative and overly pessimistic [1]. To reduce the excessive conservatism, the creep crack-tip constraint effect needs to be incorporated in the CCG life assessments. For this purpose, the C^*–Q two-parameter creep fracture mechanics was investigated and developed [15–17], and the Q is used to quantify the creep constraint. Bettinson et al. examined the effects of specimen type and load level on Q [17], and the constraint effects on CCG rate were

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Nomenclature

a_0	initial crack length
A	constant in Norton creep model
A_1, A_2	constants in 2RN creep model
B	specimen thickness
B_N	net specimen thickness
C^*	C^* integral analogous to the J integral
C^*_a	C^* value at turning point 1
C^*_b	C^* value at turning point 2
C^*_c	C^* value at turning point 3
c_1, c_2	constants in stress dependent creep ductility formula
da/dt	creep crack growth rate
E	Young's modulus
F	applied load
H	factor to estimate C^* in experiment using load line displacement
K_{in}	initial stress intensity factor
m	constant in stress dependent creep ductility formula
n	stress exponent in Norton creep model
n_1, n_2	stress exponents in 2RN creep model
Q	constraint parameter
R	creep constraint parameter
R^*	load-independent creep constraint parameter
$\dot{V}_c$	creep load line displacement rate
$\dot{V}_t$	total load line displacement rate
W	specimen width
$\dot{\varepsilon}_c$	creep strain rate
ε_f^*	multiaxial creep ductility
ε_f	uniaxial creep ductility
ε_{f1}	lower shelf creep ductility
ε_{f2}	upper shelf creep ductility
σ_y	yield stress
σ_e	equivalent stress
σ_m	mean normal stress
ω	damage parameter
$\dot{\omega}$	damage rate
η	factor to estimate C^* in experiment using load line displacement

Abbreviations

2RN	two-regime Norton creep model
3-D	three dimension
CCG	creep crack growth
C3D8R	eight-node linear 3-D element
CREEP	a user subroutine in ABAQUS
C(T)	compact tension
C(T)2	compact tension specimen with 2mm thickness
C(T)5	compact tension specimen with 5mm thickness
C(T)10	compact tension specimen with 10mm thickness
M(T)	middle tension
M(T)2	middle tension specimen with 2mm thickness
LS	lower shelf
US	upper shelf
FE	finite element
PE	plane strain
SEN(T)	single-edge notched tension
SEN(T)5	single-edge notched tension specimen with 5mm thickness

examined by Budden and Ainsworth [16]. Based on creep crack-tip stress field analysis, a creep constraint parameter R has been defined in the previous work of authors [18]. Based on the parameter R, the creep crack-tip constraints induced by the crack depths [18,19], specimen thicknesses [20] and loading configurations [21] have been investigated in detail. For the convenience of engineering application, a load-independent creep constraint parameter R^* [22] has been defined by modifying