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Interpretation of creep crack initiation and growth data for weldments

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Abstract

Creep crack growth testing of macroscopically homogeneous materials is well established and standardised test procedures are detailed in ASTM E1457. In ASTM E1457 the use of the compact tension C(T) specimen is specified and crack growth data are interpreted using the fracture mechanics parameter C^*. The resulting benchmark crack growth data are used in assessment procedures, together with estimates of the value of C^* in the component, to predict creep crack growth behaviour. In this work, the results of a series of creep crack growth tests performed on a Type 316 stainless steel weldment at a temperature of 550 °C are presented. The initial crack is located within the heat affected zone (HAZ) of the weldment. Since there are currently no agreed methods for determining C^* in inhomogeneous laboratory specimens, this paper examines the application of procedures in ASTM E1457 for the characterisation of crack growth in weldments. In addition, the creep toughness parameter K^{c}_{mat} is evaluated for the material. It is shown that the creep crack growth rates in the weldment may be described by the C^* values obtained following ASTM E1457 in conjunction with parent material properties. Comparison of the results with similar data for Type 316H stainless steel parent material shows that the crack growth rates for the crack located within the HAZ are higher and the initiation times lower than the parent values, for the range of test conditions examined. Simple analytical models based on ductility exhaustion arguments have been shown to bound the crack initiation and growth data for the weldment.

Keywords: Creep crack growth; C^*; 316 Stainless steel; Weldments; Heat affected zone (HAZ)

1. Introduction

The integrity and residual life assessment of high temperature components containing defects, that have been detected or are assumed to exist as a result of inspection limitations, is dependent on verifiable material properties such as the uniaxial creep (UC), creep crack initiation (CCI) and creep crack growth (CCG) properties. The information derived from experiments, therefore, needs to be validated and standardised so that the

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Nomenclature

a	crack length
a_0, a_f	initial crack length, final crack length
$\dot{a}$	crack growth rate
$\dot{a}_0$	initial crack growth rate
$\dot{a}^{NSWA}$	crack growth rate prediction from the approximate NSW model
$\dot{a}^{NSW\text{-}MOD}$	crack growth rate prediction from the modified NSW model
C_e	linear elastic compliance function
$\bar{h}_n$	material parameter used in NSW-MOD crack growth model
n	power-law creep stress exponent
r	radial distance from the crack tip
r_c	creep process zone size
t_i	initiation time
t_T	transition time
$t_{0.2}$, $t_{0.5}$	time to reach 0.2 mm, 0.5 mm of crack growth
t_f	test duration
A	coefficient in the power-law creep strain rate expression
A_p	plastic area under the load displacement curve
B, B_n	specimen thickness and (net) thickness between side-grooves
C^*	steady state creep fracture mechanics parameter
D, ϕ	material constants in $\dot{a}$ correlations with C^*
D', m	material constants in $\dot{a}$ correlations with K
E	elastic (Young's) modulus
E'	effective elastic modulus $= E/(1-v^2)$ for plane strain; E for plane stress
H, H'	factors to calculate J or C^* from load line displacement or displacement rate
I_n	dimensionless function of n in RR stress field distribution
J	elastic–plastic fracture mechanics parameter
K	stress intensity factor
K^c_{mat}	creep fracture toughness parameter
NSW	Nikbin Smith and Webster
P	applied load
RR	creep crack tip field (Riedel and Rice)
W	specimen width
B, ψ	constants in the relation describing the dependency of K^c_{mat} on time
Δ, $\dot{\Delta}$	load line displacement, load line displacement rate
Δ_e, Δ_p, Δ_c	magnitude of the load line displacement associated with elastic, plastic and creep strains, respectively
$\dot{\Delta}_c$	component of the load line displacement rate directly associated with the accumulation of creep strains
$\dot{\Delta}_i$	component of the load line displacement rate directly associated with instantaneous (elastic and plastic) strains
$\dot{\Delta}_{i,e}$	component of the load line displacement rate directly associated with instantaneous elastic strains
Δa	amount of crack growth
ε_f, ε_f^*	uniaxial and multiaxial creep ductility
$\dot{\varepsilon}^c$	creep strain rate
η	geometric factor to calculate C^* from load line displacement rate
v	Poisson's ratio
σ_{ij}, ε_{ij}	crack tip stress and strain fields; subscript ij indicate stress or strain component