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Effect of structural geometry and crack location on crack driving forces for cracks in welds

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Abstract

This paper quantifies the effect of geometry (planar or cylindrical) and crack location (internal or edge cracks; weld center or interface cracks) on crack driving force for welded joints, via systematic elastic–creep and elastic–plastic finite element (FE) analyses for welded joints. For engineering estimates of crack driving forces for mismatched welded joints, the equivalent material approach is employed. It is found that the equivalent material concept works very well only for a planar geometry with an internal crack, such as the middle cracked tension specimen. For a planar geometry with an edge crack, it works reasonably well, but tends to provide conservative results for under-matching and for interface cracks. For a cylindrical geometry with an edge crack, the results are similar to those for a planar geometry with an edge crack, but caution should be exercised for over-matching, as non-conservative estimates are possible due to gross-section yielding. For a cylindrical geometry with an internal crack, excessively conservative estimates for under-matching are found, and thus an improved estimation method is desired.

Keywords: C^*-integral; Weldment; Equivalent material; Mismatch limit load; Geometry effect

1. Introduction

Due to its significance in practice, defect assessment methods for heterogeneous structures such as strength mismatched welded joints have called for increasing attention (e.g., see Refs. [1,2]). To determine the crack driving forces for such mismatched welded joints, existing assessment methods for homogeneous structures (e.g, Refs. [3–5]) need to be modified to incorporate the mismatch effect, and accordingly, several methods have been tailored to the strength mismatch effect (e.g., see Refs. [6–9]). It has been shown that the most important modification for a defect assessment method specific to strength mismatched weldments is to

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Nomenclature

a	crack length, half length of a center crack
b	remaining ligament
B	material constant in a power law creeping material, Eq. (4)
c	characteristic length
$C(t)$	C-integral under transient creep conditions
C^*, C^*_{FE}	steady state value of $C(t)$ integral, and the FE C^* value for power law creep
E	Young's modulus
E'	$=E/(1-\nu^2)$ for plane strain; $=E$ for plane stress
h_1	plastic calibration function for the plastic J, J_p, in the GE/EPRI approach
J	J-integral
J_e	elastically calculated value of $J, = K^2/E'$
K	linear elastic stress intensity factor
M	mismatch factor; Eq. (8) for plastic problems, and Eq. (11) for creep problems
n	stress exponent for the R–O fit or for power law creep, Eq. (2) or Eq. (4)
P, M_b	applied load and bending moment
P_L, M_L	plastic limit load and moment of a cracked specimen (component)
P_0	normalizing load
r	mean radius of a cylinder
T	temperature
t	time
w	width of the edge-cracked specimen; half width for the $M(T)$ specimen; thickness of the cylinder
α	coefficient for the R–O fit, see Eq. (2)
θ	half crack angle for a through-wall crack, see Fig. 2
$\dot{\varepsilon}$	(creep) strain rate
ε	(creep) strain
ν	Poisson's ratio
σ	stress; equivalent Mises stress
ψ	slenderness of weld, Eq. (17) or Eq. (18)

Subscripts

b	properties related to base materials
e	properties related to equivalent materials
m	properties related to mismatch configurations
w	properties related to weld metals

Abbreviations

FCCP	fully circumferential cracked pipe
FE	finite element
GE/EPRI	General Electric/Electric Power Research Institute
$M(T)$	middle crack tension specimen
R–O	Ramberg–Osgood
SE(PB)	single-edge-cracked specimen in pure bending
SE(T)	single-edge-cracked specimen in pin-loaded tension
TWCP	through wall cracked pipe

incorporate the mismatch effect on the yield load (mismatch corrected yield load) [9,10]. A limited number of mismatch corrected yield load solutions have been compiled for plate configurations in Refs. [12,13] and for pipe configurations in Ref. [7]. It has been also found that the mismatch yield load solutions strongly depend