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Fracture assessments of clad pipe girth welds incorporating improved crack driving force solutions

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ABSTRACT

This work addresses an evaluation procedure for the *J*-integral in pipeline girth welds with circumferential surface cracks subjected to bending load for a wide range of crack geometries and weld mismatch levels based on the GE-EPRI and the reference stress framework. The study also addresses evaluation of critical flaw sizes for a subsea flowline clad pipe having an undermatched girth weld made of UNS N06625 Alloy 625. The 3-D numerical analyses provide a large set of *J*-solutions in cracked pipes with mismatched girth welds with implications of the potential applicability of ECA procedures in welded cracked structural components.

1. Introduction

The increasing demand for energy and natural resources has spurred a flurry of exploration and production activities of oil and natural gas in more hostile environments, including very deep water offshore hydrocarbon reservoirs. One of the key challenges facing the oil and gas industry is the assurance of more reliable and fail-safe operations of the infrastructure for production and transportation. Currently, structural integrity of submarine risers and flowlines conducting corrosive and aggressive hydrocarbons represents a key factor in operational safety of subsea pipelines. Advances in existing technologies favor the use of C–Mn steel pipelines, including API X65 and X70 grade steels, either clad or mechanically lined with corrosion resistant alloys (CRA), such as ASTM UNS N06625 Alloy 625 [1,2], for the transport of corrosive fluids.

A case of interest includes deep water steel catenary risers (SCRs) installed by the pipe reeling process which allows pipe welding and inspection to be conducted at onshore facilities. Here, the welded pipe is coiled around a large diameter reel on a vessel and then unreeled, straightened and finally deployed to the sea floor [3–6]. A key step in the reeled pipeline installation technique lies in the use of automatic ultrasound testing (AUT) during fabrication of girth welds, rather than radiography testing (RT), as the main inspection method thereby allowing a relatively straightforward application of standard fitness-for-service (FFS) procedures to determine tolerable flaw sizes [7]. However, a different picture emerges in the case of clad or lined pipe girth weld as fracture assessments and specification of critical flaw sizes for these components become more complex due to the dissimilar nature of the girth weld materials. Moreover, while faster and more practical,

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Nomenclature

α	Ramberg–Osgood dimensionless constant
α_{wm}	Ramberg–Osgood dimensionless constant for the weld metal
$\bar{\epsilon}$	true (logarithmic) strain
$\bar{\sigma}$	true stress
ϵ_p	plastic strain
ϵ_r	reeling strain
ϵ_{ref}	reference strain
ϵ_{ys}	yield strain
ϵ_{ys}^{wm}	weld metal yield strain
ϵ_z^b	longitudinal bending strain
$\widehat{K}_r$	applied toughness ratio
$\widehat{L}_r$	applied load ratio
ν	Poisson's ratio
σ^{bm}	true base metal stress
σ^{wm}	true weld metal stress
σ_0	yield (reference) stress
σ_b	bending stress
σ_{eq}	equivalent (effective) stress
σ_{ref}	reference stress
σ_{uts}	tensile strength
σ_{ys}	yield stress
σ_{ys}^{bm}	base metal yield stress
σ_{ys}^{wm}	weld metal yield stress
θ	crack length angle
$\tilde{\sigma}$	equivalent stress
ξ_n	coefficients of the polynomial fitting
a	crack depth
a_{cr}	critical crack depth size
b	remaining crack ligament
c	circumferential crack half-length
D_e	pipe outer diameter
E	Young's modulus
G_5	influence coefficient for a circumferential semi-elliptical surface crack
h	weld half width
h_1	nondimensional elastic–plastic parameter
J	J-integral
J_e	elastic component of the J-integral
J_{mat}	material's elastic–plastic toughness
J_{p-t}^{wm}	J_p-value corresponding to the limit bending moment using weld metal tensile stress
J_{p-y}^{wm}	J_p-value corresponding to the limit bending moment using weld metal yield stress
J_p	plastic component of the J-integral
K_r	normalized crack-tip loading
l	characteristic length
L_r	normalized load ratio
L_r^{max}	cut-off load ratio
M_b	bending moment
M_0^{wm}	limit bending moment for the all weld metal condition
M_y	mismatch ratio
n	Ramberg–Osgood strain hardening exponent
n_{wm}	Ramberg–Osgood strain hardening exponent for the weld metal
P	generalized load
P_0	generalized limit load
P_0^{bm}	limit load of the all base metal structure
P_0^{Mism}	limit load of the mismatched structure
P_0^{wm}	limit load of the all weld metal structure
Q_s	flaw shape parameter
R	reel radius
R_b	bending radius
R_e	pipe outer radius