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A framework for fracture assessments of dissimilar girth welds in offshore pipelines under bending

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A B S T R A C T

This work describes the development of a framework for structural integrity assessments of dissimilar girth welds in clad and lined pipes subjected to high levels of bending load for a wide range of pipe geometries, crack configurations, weld grooves and weld strength mismatch levels based upon an EPRI estimation scheme for crack driving forces coupled with a weld groove simplification procedure and the equivalent stress–strain relationship. Systematic validation of the method is provided and the crack driving force estimation accuracy is demonstrated through comparisons with numerical tools and 3-D finite element analyses for reeled pipelines.

1. Introduction

The reel-lay method is a very efficient technique employed for installation of subsea pipelines and risers [1,2]. In the reeling process, the welded flowline is coiled around a large diameter reel on a vessel and transported to the deployment location into the sea where the pipe is unreeled, straightened and finally layed to the sea floor as illustrated in Fig. 1. The main advantage of this method lies in onshore welding and inspection of the pipeline which allow very high quality welded joints in comparison to traditional laying techniques [2]. While fast and cost-effective, the reel-lay installation subjects the pipe to large plastic deformations up to 4% which causes significant issues related to the structural integrity assessment of the pipe girth weld.

New oil and gas exploration fields have moved to more hostile environments (such as very deep water offshore reservoirs) which demand the development of new technologies to assure safe and reliable operations. A case of considerable interest and strong concern in the oil and gas industry is the integrity assessment of submarine pipelines conducting corrosive hydrocarbons [3]. The utilization of clad and lined C-Mn steel pipelines, including X65 and X70 grade steels, with a thin internal layer of corrosion resistant alloy (CRA) is now often adopted to guarantee the required resistance against corrosion [3–5]. Despite being an economical viable option, clad and lined pipes introduce high level of material heterogeneity in the girth weld as the filler material employed in the fabrication has the same properties of the CRA material.

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Nomenclature

α	dimensionless parameter of the Ramberg–Osgood model
$\bar{\epsilon}$	logarithmic strain
$\bar{\sigma}$	uniaxial true stress
β	weld groove angle
β_1	angular parameter related to the circumferential surface crack geometry
δ	crack tip opening displacement
δ_e	elastic component of the crack tip opening displacement
δ_p	plastic component of the crack tip opening displacement
ϵ_{ys}	yield strain
ν	Poisson's ratio
ψ	slenderness parameter
$\sigma_{bm}(\varepsilon_p)$	stress-plastic strain relationship of the base material
σ_{bw}	yield stress of the base material
$\sigma_{eq}(\varepsilon_p)$	equivalent stress-plastic strain relationship
$\sigma_{wm}(\varepsilon_p)$	stress-plastic strain relationship of the weld material
σ_{ys}	yield stress
σ_{yw}	yield stress of the weld material
θ	surface crack length
ε_z	global applied strain
φ	angle of rotation imposed in the reference point
$\|OF\|$	total length of the straight line from point O to point F
ξ_k	coefficients for the polynomial fitting of factor h_2
a	crack depth
b	remaining crack ligament
c	circumferential crack half-length
D_e	pipe (cylinder) outer diameter
E', E	Young's modulus under plane stress (plane strain) conditions
f_1	functions of the weld joint geometry and mismatch ratio
f_2	functions of the weld joint geometry and mismatch ratio
h	square weld strip width
h_2	dimensionless proportionality parameter between δ_p and applied loading
h_c	width of the clad layer
h_{eq}	width of the equivalent square weld bevel
h_{eq}^{clad}	width of the equivalent square weld bevel for the clad pipe
h_r	root width
h_w	weld groove width
J	J-integral
K_I	(Mode I) elastic stress intensity factor
L	pipe model length
l_c	length of the slip-line inside the clad region
l_w	length of the slip-line inside the weld region
M	applied bending moment
m	dimensionless constant which relates J and CTOD under small scale yielding (SSY)
$M(s)$	mismatch ratio related to the length s
M_y	weld strength mismatch
M_0	limit load of the cracked pipe configuration
M_0^{bm}	limit bending load of the homogeneous structure
M_0^{mism}	limit bending load of the idealized bimaterial welded joint
$M_{cm}(\varepsilon_p)$	mismatch ratio of the clad material with respect to the base material as a function of the plastic strain
M_{eq}	equivalent mismatch ratio of the equivalent weld material including the clad layer
$M_{wm}(\varepsilon_p)$	mismatch ratio of the weld material with respect to the base material as a function of the plastic strain
n	Ramberg–Osgood strain hardening exponent
N_0^{bm}	limit tension load of the homogeneous structure
N_0^{mism}	limit tension load of the idealized bimaterial welded joint
P_0^{bm}	limit load for the homogeneous component made of the base material
P_0^{mism}	limit load of the idealized bimaterial welded joint
P_0^{wm}	limit load for the homogeneous component made of the weld material
R_b	reel drum radius
R_m	mean radius of pipe