

Ductile fracture of pipelines - effects of constraint correction and circumferential crack growth

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ABSTRACT

Surface cracks lead to major challenges for the structural integrity assessment of pipelines. A procedure to account for constraint correction of crack growth resistance curves is presented. The procedure is based on numerical FE-studies carried out using shell and line-spring finite elements. Crack tip opening displacement, T -stress and crack growth are accounted for. Crack growth in circumferential direction is important when analysing short crack lengths compared to diameter. This is also taken care of in addition to crack growth in thickness direction. The results are compared with detailed 3D-analyses and full scale testing of pipe segments.

NOMENCLATURE

α	Coefficient in Ainsworth's equation
a	Crack depth
Δa	Increment of crack depth extension
β	Biaxiality ratio
$2c$	Crack length
Δc	Increment of crack length extension
C'_{ij}	Compliance matrix of line-spring
$CTOD$	Crack tip opening displacement
δ_{ij}	Kronecker delta
ε^{pl}	Plastic strain
ε_0	Strain at onset of yielding
J	J -integral
K_I	Stress intensity factor Mode I
m	Exponent in Ainsworth's equation
n	Hardening exponent
ν	Poisson's ratio
O	pipe circumference
q_i	Displacements in line-spring
Q_i	Internal forces in line-spring
Q	Q -parameter
r	distance from crack tip
SEN	Single edge notched specimen
$SENB$	Single edge notched bending specimen
$SENT$	Single edge notched tension specimen
σ_0	Yield stress
σ_{ij}	Components of the stress tensor
τ	Shear yield stress
t	shell thickness
T	T -stress

INTRODUCTION

Surface cracks in girth-welds are common, and rise challenges to structural integrity assessments. Pipelines will experience severe load histories during their lifetime. The laying-phase is probably the most critical phase. Several methods for pipe-laying are used today, and reeling is one of them. When reeling a pipeline, the pipe will go through a load-history with large plastic deformation, hence it is both a local and global challenge. Global due to possible buckling, and local with respect to possible crack growth. The reeling-process consists of several stages. Pipe segments are welded together and wound to a spool on a laying-ship. When off-shore, the pipe-line is un-wound. This load-cycle can make the pipe be subjected to plastic strains of the order of 2-3%, in which the ductility and the crack growth resistance are important challenges to manage.

Traditional pipeline design criteria used today are mainly focusing on the buckling phenomenon. The maximum allowable strain limit on the compressive side of the pipe is about 3%, but on the tension side, the maximum strain is restricted, and fracture is mainly a problem on the tension side. For offshore pipelines, the installation phase is mostly displacement controlled and resulting in high plastic strains. British Standard (2000) for fracture assessments is mainly for load controlled situations, hence a strain based design approach is more realistic (see Linkens et al. (2000)).

The stresses in the pipe are mainly of membrane type, even for pipes subjected to global bending (see Chiesa et al. (2001)). This will reduce the constraint in the near crack-tip region, thus increasing the fracture toughness. This situation characterises many structural applications. Use of a high-constrained single edge notched bending (SENB) specimen could