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Fracture behavior of clad pipeline containing a canoe shape surface crack subjected to large bending moment

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ABSTRACT

This paper concerns the fracture assessment of a clad pipeline subjected to large bending moment, and identifies different parameters influencing the fracture behaviors. The evolution of Crack Tip Opening Displacement (CTOD) of a pipeline containing a canoe shape crack on the external surface of the girth weld is studied under pure bending and combined pure bending and internal pressure through 3D elastic-plastic Finite Element (FE) simulations. Various parameters affecting the evolution of CTOD like crack depth, crack length to perimeter diameter ratio, internal pressure and the weld geometrical configurations have been investigated. It is observed that only the average width of the weld has a significant influence on the fracture response under pure bending, while the weld reinforcement height and fusion line slope have a moderate influence on the fracture behavior under biaxial loading. The crack at the interface between the weld and back steel has a similar fracture response to that of a crack located in the weld with equivalent effective crack depth. Finally, a strain based Failure Assessment Diagram (FAD) is proposed and compared with the fracture assessments produced by BS7910:2013, and 3D elastic-plastic FE simulations suggest that the British Standard is more conservative especially for deep cracks.

1. Introduction

As energy consumption around the world increases, the demand for long distance offshore pipelines also increases rapidly. These clad pipelines are linked through girth welding, therefore, potential embedded and surface cracks are always found to initiate from this region. The pipelines suffer frequently large plastic strains up to 3% [1,2]; furthermore, they can be subjected to high internal pressure accompanied with large bending. Hence, the weld materials should have adequate resistance against crack propagation and final failure.

Current codes of practice used for fracture assessment of cracked structures mostly focus on load controlled conditions and they are not suitable to apply to clad pipelines subjected to large plastic deformation during both installation and operation. Therefore, some practical codes developed by Det Norske Veritas (DNV) [1,2] based on the same procedure provided in BS 7910:2013 [3] on the reference stress method [4], are not adequate to provide guidelines for fracture assessment of cracked clad pipeline. For load based procedures, it is hard to validate the utilization of non-linear strain-stress constitutive materials relationship and non-linear elastic-plastic fracture mechanics theory. Therefore, a strain based approach is proposed [5,6]; but it is still based on small plastic strain assumption, and it is doubtful whether it can be applied to clad pipelines having large plastic strains.

The *J*-integral is frequently used for fracture assessment of cracked structures, and a lot of research has been published on

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estimation of J-integral with various crack geometries and loading conditions [7–9]. Linkens et al. [7] developed an explicit expression of J-integral for small cracks. However, Budden [8] validated that the proposed J-integral expression was over-estimated for semi-elliptical cracks in plate. Sandvik et al. [9] simplified the formulas of strain-based fracture responses for girth welded pipelines with a canoe shape crack, and it was validated by 3D FE simulations which showed the accuracy of the equations to be significantly higher than the reference stress method. In addition, they included the tangency criterion to determine the global failure strain: the Crack Driving Force (CDF) and the resistance of crack growth are identical, and the derivatives of the CDF and the crack growth resistance are identical as well.

CTOD is another fracture parameter frequently used in practice because J-integral and CTOD are equivalent to some extent [10]. Østby et al. [11] investigated the fracture behaviors of a pipeline containing a long crack on the external surface of the girth weld when the pipeline had large plastic strain. Nourpanah and Taheri [12] studied the crack tip constraint of pipelines having large plastic strains. Recently, the evolution studies of CTOD on girth welded pipelines have been conducted in Refs [13–15], where different crack configurations of elliptical cracks were constructed and analyzed using FE models. In this study, the objective is to analyze nonlinear elastic-plastic fracture behaviors of clad pipelines containing a canoe shape surface crack subjected to pure bending and biaxial loading including bending and internal pressure. The crack depth, crack length to perimeter diameter ratio, internal pressure and weld geometry are investigated to find out how these parameters influence the fracture response.

Besides introduction reviewed in this section, Section 2 describes the generation of FE models and material properties; Section 3 shows the FE results and discusses the influences of various parameters; and finally, Section 4 compares the fracture assessment of BS7910:2013 [3] and the results obtained from 3D elastic-plastic FE simulations.

2. Numerical simulations

2.1. Geometrical configurations

A typical segment of clad pipeline is shown in Fig. 1, which is the same as that described in Refs. [13–15]. The external diameter is 362.8 mm and the overall thickness is 20.9 mm. The internal wall consists of a layer of 3 mm thick Corrosion Resistance Alloy (CRA),

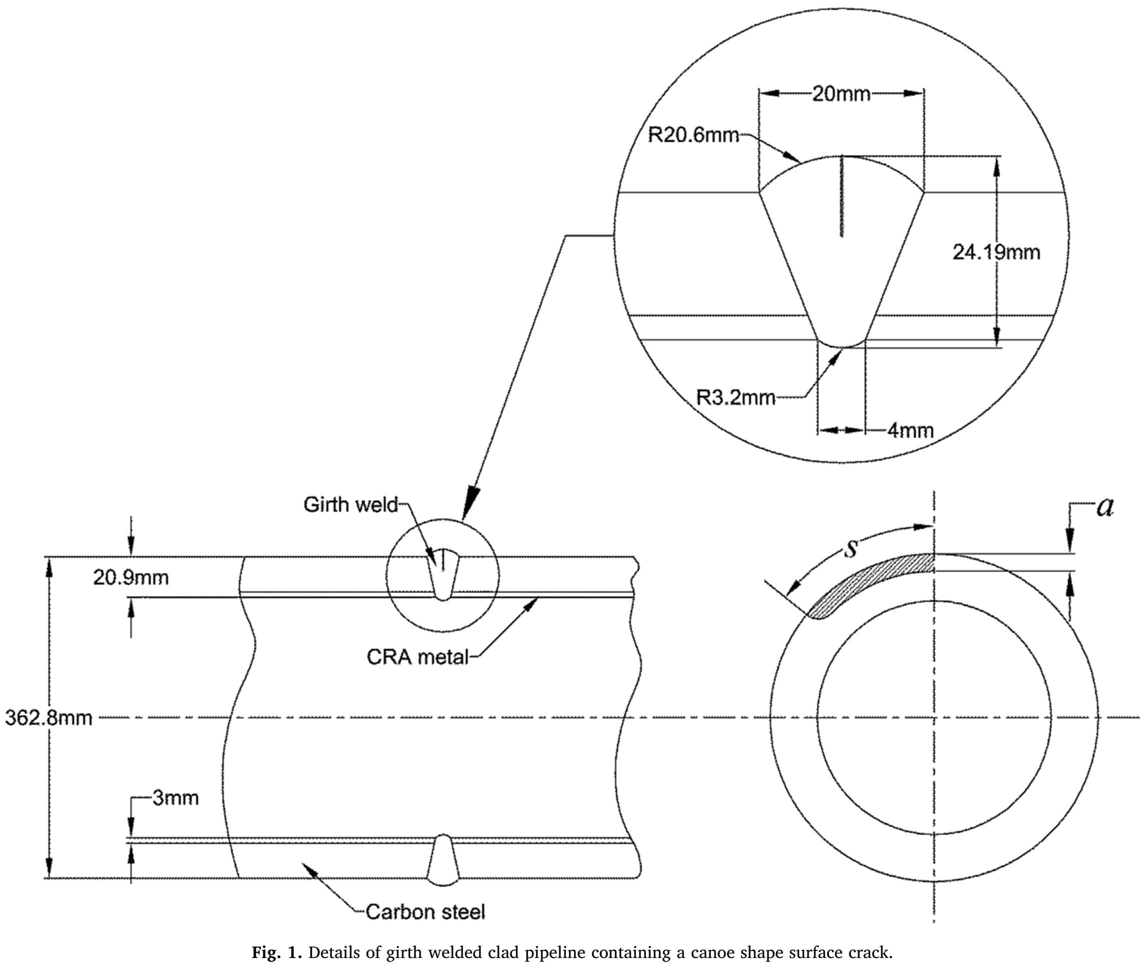

Fig. 1. Details of girth welded clad pipeline containing a canoe shape surface crack.