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Development of Girth Weld Flaw Assessment Procedures for Pipelines Subjected to Plastic Straining

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Numerical finite element analyses (FE) have been undertaken of circumferential flaws in the girth weld of a pipeline subjected to plastic straining simulating installation by reeling, and the J driving force curves derived. These were then compared with J driving force curves derived using the guidelines described in DNV-RP-F108 intended for installation methods involving repeated plastic straining. The assessment procedure is based on BS 7910 FAD methods. Strains up to 2% were considered. Analyses were undertaken for surface breaking weld root flaws located at the weld fusion boundary. The pipe was nominally to API 5L Grade X65 strength, with a 323.9-mm diameter ($12\frac{3}{4}$-in) and 20.6-mm wall thickness. Conclusions are drawn concerning the conservatism in flaw assessment procedures conducted to DNV-RP-F108 and the treatment of welding residual stress.

INTRODUCTION

The definition of rational flaw acceptance criteria for girth welds in pipelines subjected to axial straining within the context of existing codified fracture mechanics-based assessment procedures is problematic since these are essentially stress-based. Although there is no fundamental problem in using such procedures, the solutions provided are not always the most suitable for strain-based assessments. Nevertheless, with appropriate modifications, assessments based on BS 7910 (BS, 2005) procedures have been used successfully for a number of years to set acceptance criteria for pipeline installation methods involving plastic straining such as by pipe reeling. The flaw acceptance criteria provided by these methods have, in many cases, enabled larger flaws to be accepted than those based on workmanship standards, such as BS 4515 and API 1104. The benefits to the industry have included reduced repair rates without loss of integrity and increased lay rates. The demonstration of integrity by means of an existing and well-established assessment procedure is considered important since it enables independent third-party verification to be undertaken.

Another benefit to industry in using fracture mechanics-based assessment methods is that information provided by automated ultrasonic testing on flaw size (height and length) can be assessed properly, since codes such as API 1104 and BS 4515 provide workmanship acceptance criteria based on flaw length, not height. Nevertheless, for certain situations involving plastic straining, flaw sizes predicted by fracture mechanics procedures can be smaller than those based on workmanship standards. Although it could be argued there is nothing inherently wrong with such a conclusion because the workmanship criteria are intended for installation methods not involving plastic straining, industry experience indicates that flaw tolerance is better than predicted by fracture mechanics analyses.

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In order to address these concerns, a joint industry programme was conducted by DNV-TWI-SINTEF to provide guidelines for fracture control of subsea pipelines' installation methods involving cyclic plastic straining. The guideline was issued to sponsors in 2003, and this document (Wästberg et al., 2004) provided the basis for a DNV Recommended Practice published in 2006. The flaw assessment procedure, referred to hereafter as the reeling procedure, is based on BS 7910 but with adjustments to make it suitable for plastic straining conditions. Novel features of the procedure include the use of single edge notched tension specimens to define fracture toughness, and use of sub-scale segment specimens to validate, by experiment, the procedure used to generate acceptable flaw sizes. The procedure has been used successfully in many pipeline installation projects and also applied to in-service assessment of pipelines subjected to plastic straining, e.g. due to lateral buckling and ground movement.

The purpose of this paper is to establish margins against possible failure when using the procedure as currently formulated in DNV-RP-F108. This is done by comparing the J driving force curves predicted by the current procedure, for a given pipe size and range of flaw sizes, with those obtained by numerical finite element analyses (FE).

PIPE CASE MODELLED

Analyses conducted are representative of pipe that would typically be installed by reeling. Although this would involve a series of repeated plastic strains during the installation phase, the case considered here is the application of a single monotonic strain when the pipe is first wound onto the reel. The pipe has a 323.9-mm ($12\frac{3}{4}$-in) outside diameter and 20.6-mm wall thickness, and is nominally to API 5L Grade X65 strength. The 0.2% offset yield strength of the parent pipe in the longitudinal direction considered in these analyses is 485 MPa and the tensile strength is 594 MPa. The pipe contains a girth weld with a 0.2% offset yield and tensile strengths, which overmatch the corresponding parent pipe properties by approximately 20%. For the purposes of these analyses, the work hardening rates of both materials are assumed to be the same. Fig. 1 shows the engineering stress-strain curves.

The pre-existing flaws considered were internal surface flaws located at the weld root region of the weld fusion boundary. The nominal weld width chosen for this location was 8 mm and is