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Engineering Critical Assessment of Embedded Flaws in Undermatch Pipeline Girth Welds

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There is increasing demand for subsea transport of well-produced fluids that requires the use of bi-metallic pipelines. To optimize project costs, bi-metallic pipelines are often installed subsea by methods inducing cyclic plastic deformation. Engineering critical assessment (ECA) is typically required to derive acceptance criteria for weld flaws, most of which are embedded. As bi-metallic girth welds usually undermatch the parent metal, and ECA normally requires overmatch, this may be problematic. Although plastic deformation does not degrade the fracture toughness of overmatch welds, this may not hold for undermatch welds. Furthermore, in ECAs, the crack driving force (CDF) in embedded flaws is typically approximated by that in surface flaws, which may not always be appropriate. Therefore, this paper establishes a set of new CDF estimation schemes for embedded flaws in even- or overmatch welds and develops an ECA procedure for embedded flaws in undermatch bi-metallic girth welds.

INTRODUCTION

The demand for corrosion resistant subsea pipelines has steadily increased in recent years. This has promoted the use of corrosion-resistant pipes such as stainless steel or bi-metallic pipes. The latter are made of a carbon steel (CS) pipe and a thin (typically 3.0 mm thick) internal layer of a corrosion-resistant alloy (CRA) such as 316L, 625, 825, or 904L. Mechanically lined pipes (MLPs; refer to American Petroleum Institute, 2015; see also Det Norske Veritas, 2021), where the CRA and CS layers are adhered by a means of an interference fit and hot-roll metallurgically bonded (HRB) clad pipes, are often more readily available and use a variety of CRA grades, many of which are more corrosion resistant than are stainless steel pipes. Furthermore, MLP is much more economical than any other pipe with similar corrosion protection. Consequently, bi-metallic pipelines have been increasingly used at the expense of solid CRA pipelines. Significant additional cost savings are made by installing bi-metallic pipelines using the efficient reel-lay method. The susceptibility of a thin CRA liner to wrinkling when MLP is subjected to high-strain cyclic-plastic bending during reel-lay installation has been overcome by either increasing the liner thickness (Tkaczyk and Pépin, 2010; Tkaczyk, Pépin and Denniel, 2011, 2012a, 2012b; Pépin et al., 2015c, 2016, 2017, 2019) or flooding and pressurizing the pipeline (Endal et al., 2007; Tkaczyk et al., 2016).

Engineering critical assessment (ECA) is routinely performed to establish acceptance criteria for subsea rigid pipeline girth weld flaws, most of which are often located beneath the surface of the weld. The ECA typically involves fracture and fatigue assessments undertaken according to DNV-ST-F101 (Det Norske Veritas, 2021) and DNV-RP-F108 (Det Norske Veritas, 2019), which build on BS7910 (British Standards Institution, 2019) and generally require weld metal overmatch. This means that the yield strength of the weld metal must be higher than that of the parent metal to avoid strain concentrations in the weld. Fracture assessment, which is the main focus of this paper, involves estimating the crack driving force, most often in terms of the J-integral or the crack tip opening displacement (CTOD), and comparing it to the material's fracture toughness. The latter is usually obtained from low-constraint single- edge notch tensile (SENT) specimens tested following BS 8571 (British Standards Institution, 2018) or, less often, high-constraint single-edge notch bending specimens tested according to BS 7448-P4 (British Standards Institution, 1997).

The effect of prestrain on the fracture toughness of welded pipes was investigated experimentally by Pisarski et al. (1994). The fracture toughness of welds that had undergone straining to simulate reeling was similar to that of the as-received welds when the weld metal (WM) overmatched the parent metal (PM). However, the validity of this conclusion was questionable because pre-

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KEY WORDS: Bi-metallic pipe, reel-lay installation, cyclic prestrain, fracture toughness, fracture assessment.