Effect of Accumulated Plastic Strain induced during Reel-Lay Installation on Fracture and Fatigue Behavior of Welded Subsea Pipelines in a Hydrogen Charged Acidizing Environment

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ABSTRACT

The reel-lay method is widely used for installation of subsea pipelines. Reeled pipelines are typically subjected to two reverse plastic bending cycles. However, they may occasionally see up to five bending cycles during a contingency re-reeling operation. Concerns have been expressed that increased accumulated strain during re-reeling may reduce the fracture toughness (FT) and/or increase the fatigue crack growth rate (FCGR) of pipeline girth welds.

A test program was conducted in an acidizing environment to quantify the impact of accumulated plastic strain on the FCGR and FT of girth welds in the X65 pipeline, installed using the reeling methodology. Furthermore, an engineering critical assessment (ECA) analysis was performed, using the measured FCGR, to establish the minimum required FT for the girth welds of the subsea pipeline, operating in the acidizing environment.

Paris law FCGR testing as per ASTM E647 was performed in the environment on the material subjected to 5 plastic straining cycles and subsequently aged. The FCGR, measured in the acidizing environment, was accelerated by a factor of 22 relative to the BS 7910 in-air mean FCGR curves.

Slow-rising displacement FT testing as per ASTM E1820 was performed in the acidizing environment on the material subjected to 2 and 5 plastic bending cycles and subsequently aged. Three samples with a notch in both the heat affected zone (HAZ) and the weld centerline (WCL) were tested for the material subjected to 2 bending cycles. For this material condition, average threshold stress intensity values for cracking initiation, associated with 0.05 mm crack extension, were 2707 N/mm³/2 and 2510 N/mm³/2 for the WCL and the HAZ, respectively. The average threshold stress intensity value, associated with cracking initiation measured on three HAZ samples subjected to 5 bending cycles, was 2603 N/mm³/2.

An ECA analysis as per BS 7910 (2015) was performed using the measured FCGR and the specified non-destructive examination (NDE) flaw acceptance criteria to derive the minimum required FT for the pipeline to operate safely in the acidizing environment. The ECA analysis showed that the minimum required FT in the acidizing environment at the inner diameter location was 1819 N/mm³/2 for welds subjected to 2 bending cycles, and 1842 N/mm³/2 for welds subjected to 5 bending cycles due to increased cumulative tearing of up to 0.07 mm during re-reeling.

Therefore, additional bending cycles, associated with re-reeling, were shown to have an insignificant impact on the FT in the acidizing environment. Furthermore, the increased number of reeling cycles did not command any reduction in flaw acceptance criteria for the project specific application.

KEY WORDS: ECA, acidizing, hydrogen embrittlement, fracture mechanics, mechanical testing, fracture toughness, fatigue crack growth, girth welds

INTRODUCTION

The reel lay method is a cost-efficient subsea pipelay alternative to S-Lay and J-Lay, and is commonly used for the installation of small diameter pipelines (diameter < 0.5 m). Unlike other installation methods, where the pipeline remains in the elastic regime, reeling operations are associated with several cyclic plastic deformations of the pipe. Typical reeling installation operations involve two plastic bending cycles, whereas in certain instances, such as the insertion of in-line structures or abandonment and recovery of the pipeline, certain sections of the pipeline may be subjected to up to five bending cycles. Accumulated plastic strain, defined as the sum of strain increments, may contribute to a modification of the mechanical properties of the material.

The effect of reeling on the mechanical properties of pipelines has been extensively discussed in the literature (Sivaprasad et al., 2000; Cosham, 2001; Fukuda et al., 2005; Enami, 2005; Qiu et al., 2005). It has been demonstrated that in-air tearing resistance properties are unchanged.