Demonstration of the Resistance to Hydrogen Embrittlement of Dissimilar Joints for Subsea Applications

PUBLISHABLE SUMMARY

20601

Background

Subsea dissimilar joints typically comprise a heat treated buttering weld deposit on a steel forging and an as-welded austenitic closure weld to a pipeline steel. In service, such equipment is subject to cathodic protection (CP) and the dissimilar interfaces can be susceptible to embrittlement by hydrogen generated by CP. A small number of subsea dissimilar interface failures has occurred.

Numerous potential solutions to the problem have been proposed, many involving forgings with a lower carbon content than the commonly used 8630, but consensus has not been reached on how to ensure that a chosen configuration is fit-for-purpose and on the most appropriate material combinations for future applications, many of which will include high strength pipe.

This project will provide a comprehensive ranking of the various material options and a reliable material qualification test method. In addition, given that the issue is complex, a practical guidance document will be prepared to assist industry in identifying and qualifying preferred materials and joining procedures.

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Objectives

- Determine residual stresses and their distributions across a selection of dissimilar joints.
- Rank the resistance to hydrogen assisted crack initiation of a range of material combinations for subsea dissimilar joints.
- Define a test procedure for qualifying future dissimilar joints for subsea service, validated against full-scale test data.
- Prepare a practical guidance document to assist industry in implementing the results of this and previous Joint Investigative Projects on dissimilar joints.

Project Outcome

Regular e-mail progress statements and progress reports are being issued during the project. Six-monthly meetings are being held to present the work in progress and a final meeting will be held to present the overall project findings.

The main deliverable of this project will be a final report, detailing:

- Examples of qualified materials and procedures for subsea dissimilar joints, for the avoidance of hydrogen embrittlement.
- A validated qualification method for subsea dissimilar joints, giving confidence in materials selection and welding procedure.

Benefits

- Validated recommendations for materials and for subsea dissimilar joints, which are resistant to hydrogen embrittlement.
- A validated acceptance criterion and method for ranking subsea dissimilar joint performance, giving confidence in materials selection for through life performance.
- Insight into the avoidance of further costly and environmentally damaging dissimilar joint failures.

Participants

The Sponsor Group currently comprises:

- BHP Billiton Petroleum Inc;
- BP Exploration Operating Company Ltd;
- Cameron International Corporation;
- ExxonMobil Development Company;
- FMC Kongsberg Subsea AS;
- Petrobras;
- Statoil Petroleum AS.

Scope of Work

The project can be broadly categorised into five separate work activities:

1. Fabrication of test materials

The dissimilar pipe joints chosen by the Sponsor Group for investigation during this project were:

- P-F22\B-625\C-625;
- P-F22\B-LAS\C-625;
- P-8630M\B-625\C-625;
- P-8630M\B-LAS\C-625;
- P-F65\C-625.

Where: P-parent, B-buttering, LAS-low alloy steel and C-closure weld

These pipe joints were manufactured in a symmetrical configuration, such that the mechanical properties of each joint component were mirrored, either side of the closure weld centre line. Two examples of each joint geometry were produced, such that intermediate and full scale testing could be developed. The full-scale testing programme encompasses testing of the P-8630M\B-625\C-625, the P-F65\C-625 and the P-F22\B-625\C-625 dissimilar joints.

2. Characterisation of joints

All joints will be characterised metallographically, with light and scanning electron microscopy, and by Vickers hardness testing (5kg load). The incidence of weld flaws will be characterised by ultrasonic inspection, using techniques previously shown to be applicable to detection of lack-of-fusion flaws in dissimilar joints (Nageswaran and Bird, 2008), and additional sections taken through any flaws identified.

The environmental cracking resistance will be measured at each type of dissimilar interface using single edge notch bend (SENB) testing. Testing will be performed on pre-hydrogen-charged specimens at 4°C under -1100mV cathodic polarisation conditions in 3.5% NaCl solution. J-R curves will be constructed by testing 6 SENB specimens for each interface with differing total crack extensions.

Fractographic examination will be conducted in a scanning electron microscope with energy dispersive x-ray (EDX) spectroscopy, to verify crack path characteristics in relation to the dissimilar fusion boundary.

The residual strain profiles across dissimilar joints have been calculated following neutron diffraction measurements in the axial, radial and hoop directions for three of these joints containing multi-run girth welds. Profiles of residual stresses were constructed from these measurements. Three dissimilar metal interface combinations were investigated: (1) ASTM A182 F22 steel to ERNiCrMo-3 (alloy 625) weld metal (PWHT'd joint), (2) AISI 8630M steel to ERNiCrMo-3 (alloy 625) weld metal (PWHT'd joint) and (3) ASTM A964-F65 low alloy steel to ERNiCrMo-3 (alloy 625) weld metal without PWHT.

3. Intermediate scale testing

Intermediate scale testing is being carried out as an alternative means of assessing the susceptibility of the dissimilar interface to hydrogen cracking. Testing will be performed in tension on test specimens taken in the transverse direction. Hydrogen pre-charged test samples will be tested in 3.5% NaCl solution maintained at 4°C under -1100mV$_{SCE}$ to replicate cathodic polarisation.

Comparative tensile tests will also be performed in air and in NaCl solution at 4°C without CP, in order to evaluate the general susceptibility of each joint type to hydrogen embrittlement. The fracture surfaces generated during intermediate testing will be thoroughly analysed in order to assess the mechanisms of fracture resulting from each interface and test type. The fracture surfaces will be compared to those generated through small scale environmental J-R curve testing.

4. Full scale testing

Two jigs have been designed and developed for testing full size pipes under conditions which closely replicate the worst-case in-service conditions. Crack initiation in the full scale pipe will be identified via acoustic emission/repeated ultrasonic testing and visual inspections. The following joints will be subjected to full-scale testing:

- P-F22\B-625\C-625;
- P-8630M\B-625\C-625;
- P-F65\C-625.

5. Qualification test protocol

The overall aim of this project is to develop a validated qualification test protocol, in order to assess the suitability of a dissimilar weld type to subsea service under cathodic protection.

Intermediate scale testing, validated using full scale testing, will allow a qualification test protocol to be developed. Every effort will be taken to minimise the complexity of testing, in order to achieve a qualification test protocol that is versatile, robust and reproducible with clear pass/fail criteria.

Price and Duration

The project has a duration of three years (dependent on full-scale testing duration) and a budget of £560,000. Currently, there are seven Sponsors, each making a contribution of £80,000.

Further Information

For further information on how a Joint Industry Project (JIP) runs please visit:

http://www.twi-global.com/services/research-and-consultancy/joint-industry-projects/

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