Improving Materials Qualification and Design against HISC of Duplex and Superduplex Stainless Steel

PUBLISHABLE SUMMARY

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Background

Failures of duplex and superduplex stainless steel due to hydrogen induced stress cracking (HISC) have raised unresolved concerns regarding subsea system integrity. DNV Recommended Practice RP-F112 'Design of duplex stainless steel subsea equipment exposed to cathodic protection' (2008) has been issued. However, as a result of lack of data in several areas, some concerns remain for industry:

- RP-F112 provides two routes of assessment, and these can provide significantly different allowable service loads depending on the severity of the geometrical stress raisers;
- RP-F112 may be overly conservative for some product forms;
- RP-F112 recommends X-ray and UT inspection for welds in new designs, areas of uncertainty and 'critical' items, to ensure absence of flaws.

This project addressed these issues, firstly by means of large scale testing to explore the limitations of DNV-RP-F112 and secondly by attempting to develop a simple and practical test to complement austenite spacing measurements when assessing the HISC resistance of duplex stainless steels. TWI Core Research Project 19346 (TWI, 2009-2011) was run in parallel with this project, and results from the CRP were included in project reports where applicable.

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Objectives

- Review and summarise TWI experience in the following areas: critical strain for HISC, quantitative data on low temperature creep, the effects of pre-strain, pressure and temperature on HISC and fracture toughness values appropriate to subsurface flaws in duplex and superduplex stainless steel (DSS/SDSS) under cathodic protection.
- Compare actual failure conditions from full-scale tests on welded DSS pipe, and large-scale tensile tests on bulk materials with different austenite spacings, with the DNV RP-F112 allowable loads and strains;
- Quantify the behaviour of buried flaws under representative hydrogen charging conditions;
- Identify aspects of DNV-RP-F112 that might benefit from review during future revisions;
- Investigate the correlation of austenite spacing and other microstructural parameters with the HISC resistance of DSS under hydrogen charging conditions;
- Develop a practical HISC qualification test method that can complement the use of austenite spacing as a determinant of a material's relative HISC resistance;
- Identify areas for improvement in the current austenite spacing measurement procedure and develop open source software to automate the austenite spacing measurement as far as is possible

Project Outcome

- A summary of the available TWI data on HISC.
- A comparison of actual failure conditions from full-scale tests on welded DSS pipe, and large-scale tensile tests on bulk materials with different austenite spacings, with the DNV RP-F112 allowable loads and strains;
- An understanding of the behaviour of buried flaws under representative hydrogen charging conditions;
- A proposal regarding aspects of DNV-RP-F112 that might benefit from review during future revisions;
- New data regarding the correlation of austenite spacing and other microstructural parameters with the HISC resistance of DSS under hydrogen charging conditions;
- A practical HISC qualification test method that can complement the use of austenite spacing as a determinant of a material's relative HISC resistance;
- Open source software (but made available to the sponsors only) to automate the austenite spacing measurement as far as is possible.

Benefits

- Ability to design thinner DSS components for subsea use, saving weight, complexity and cost.
- Ability to avoid unnecessary NDT.

Participants

The Sponsor Group comprised:

- ExxonMobil Development Company;
- FMC Technologies Inc;
- Petrobras;
- Sandvik AS;
- Shell (UK) Ltd;
- Technip UK Ltd;
- BP.

Scope of Work

A summary of the available TWI data on HISC has been completed.

Four materials received from the Sponsors and two materials from TWI, representing a range of austenite spacings, microstructures and manufacturing methods, are being used for the project.

Task 1:

A finite element modelling re-analysis of existing full-scale girth welded pipe bend test data, and a comparison of the failure load and strain with the allowable loading and strain from DNV-RP-F112 has been completed.

Large scale tensile testing is in progress on bulk materials with three (3) different austenite spacings, in order to compare actual failure conditions with the DNV RP-F112 allowable loads and strains.

Task 2:

A short term HISC qualification test method is being developed. The target is to demonstrate that a short test, at a suitable fraction of the material proof stress, would be equivalent to a 30 day test at a lower stress. After completing an initial series of tests using two materials and a wide range of stresses and durations, the preferred test method is now being evaluated with a wider range of austenite spacings and/or microstructures is required, using all six materials.

A semi-automated method for measuring austenite spacing is being developed in accordance with the method described in DNV-RP-F112, and suitable alternative microstructural quantifications are also being explored. The HISC resistance of each of the six materials, as measured in the short term HISC tests as described above, will be plotted as a function of the various microstructural parameters.

Task 3:

The final task aims to mimic the cold creep that a pipe material undergoes around a buried flaw before the flaw is exposed to hydrogen by exposing a notched specimen to cold creep (in air) under constant displacement conditions, before introducing a 3.5%NaCl solution and applying a potential of -1100mV to promote hydrogen ingress. Comparative tests will be performed where the specimens are exposed to cathodic polarisation from the start of the test. The performances of the specimens will be compared and conclusions will be drawn upon the influence of cold creep on the crack initiation from a pre-existing flaw in duplex stainless steel exposed to hydrogen ingress.

Project Budget

The project had a duration of 3.5 years and a budget of £420,000. It was funded by seven Sponsors each making a contribution of £60,000. The fee for additional companies buying-back into the project results is £60,000.

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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