Measuring the Effect of Cathodic Protection on the Performance of Thermally Sprayed Aluminium Coatings at Elevated Temperature

GROUP SPONSORED PROJECT OUTLINE

PR21481

January 2013

Summary

Thermally sprayed aluminium (TSA) coatings are increasingly used to mitigate the corrosion on subsea pipelines and structures. Other than the results of work published in the early 1990s relating to the effect of various levels of cathodic protection (CP) at ambient North Atlantic seawater temperatures, there are limited published data covering the interaction of TSA and CP when applied to hot and thermally-cycled risers and hydrocarbon transportation pipelines. To address the issues highlighted above, this project will use quantitative methods to measure coating current demand under selected CP values and to measure potential and corrosion rate at E_{corr} during long-term testing at elevated temperature. The scope of work will include evaluation of two TSA-based coating compositions, the use of sealant and the effect of thermal cycling. The implication of project results for cathodic protection design codes and standards will be reported.

With many new fields involving the installation of increasingly difficult-to-maintain and remote deep-water facilities and extraction of hotter hydrocarbons, generation of such data will provide oil producers and installation companies with increased confidence in the long-term reliability of TSA coatings in subsea service.

TWI Ltd, Granta Park, Great Abington, Cambridge CB21 6AL, UK. Tel: +44 (0)1223 899000

Project Concept

Thermally sprayed aluminium (TSA) coatings are increasingly used to mitigate the corrosion on subsea pipelines and structures[1-2]. Other than the results of works published in the early 1990s relating to the effect of various levels of cathodic protection (CP) at ambient North Atlantic seawater temperatures[3-4], there are no published data covering the interaction of TSA and CP when applied to thermally-cycled risers and hydrocarbon transportation pipelines. In addition, little consideration is given to the interaction of TSA and anode-based or impressed current cathodic protection systems in international codes and standards[5-7], with the exception of ISO 15589-2 which advises that TSA should not be subject to over-protection potential more negative than -1150mV Ag/AgCl.

The ability of TSA to protect steel in offshore and coastal environments has been consistently demonstrated in long-term laboratory and on-site studies[4, 8-10] including performance superior to the best marine paint systems[10]. Its use has increased significantly in the last 25 years with many offshore (topside, splash zone and subsea structures, risers and heat exchangers) and onshore applications (process pipe work, fittings and vessels under insulation) being adopted. Subsea TSA corrosion rates consistently less than 10 microns per annum and its ability to provide a significant level of cathodic protection (CP) to steel even when the coating is damaged, have been confirmed in several studies conducted at ambient (10-30°C) and elevated temperatures (80°C) [3-4,10-11]. Furthermore, the ability of TSA to mitigate other corrosion-related mechanisms such as (external) chloride stress corrosion cracking of stainless steels at elevated temperature (110-130°C) has been demonstrated both in rigorous laboratory testing and in offshore application[11-12].

Most long term tests reported in the literature have been concerned only with the free corrosion properties of the coatings. However, when immersed in seawater, TSA is generally applied in combination with cathodic protection but only limited data were published in the early 1990s[3-4]. They indicated that TSA reduced conventional anode work load to around 20% of normal values although showed increasing TSA consumption rate at less negative potentials. Limited data pertaining to the interaction of TSA with CP level at elevated temperature (70-100°C) exist[4] but TSA is being increasingly used on hot risers and hot hydrocarbon pipelines. Such applications are also subject to thermal cycling due for example to planned or unexpected interruptions in production. Subsea pipelines are also subject to variation in external surface temperature due to seabed burial and hydrocarbon fluid cooling with transmission distance.

There is also evidence that, when applied correctly, sealants can significantly extend the life of TSA coatings, but the occasional reported failure of sealed coatings and detailed laboratory-based studies indicate that further optimisation of this aspect is required[2,5,10]. To add to this concern, there are limited published data on the interaction of current TSA sealant specifications and CP[4]. Furthermore, although Zn-rich formulations are considered unreliable in subsea applications, the performance ranking of pure Al, Al-Mg, Al-Zn-In and other formulations still remains the subject of some debate[3,9-10].

To address the issues highlighted above, this project will use quantitative methods to measure coating current demand under selected CP values and to measure potential and corrosion rate at E_{corr} during long-term testing at elevated temperature. The scope of work will include evaluation of two TSA-based coating compositions, the use of sealant and the effect of thermal cycling.

A major output of the project will be quantitative data from which TSA-coating corrosion rate at various levels of cathodic potential can be calculated. The test duration period will be sufficiently long that stable TSA-coating behaviour will be well-established, thus increasing significantly the reliability of the data generated and its value when applied to design of cathodic protection systems. The implication of project results for cathodic protection design codes and standards will be reported.

In addition to long-standing expertise in materials engineering (metallurgy, corrosion, structural integrity and inspection) in the context of welded offshore facilities, TWI has increasingly supported the oil and gas sector in the evaluation, testing and specification of TSA coatings through four Joint Industry Projects[10-11,15-16], which have included work of relevance to this proposal comprising:

- Design, build and operation of apparatus to measure the performance of TSA-coated steel coupons mounted in a tower containing oil at 130°C exposed to water at 5-10°C (including coupons buried in sand).
- Calculation of TSA corrosion rate (μm/year) at elevated temperature (80°C) using linear polarisation resistance (LPR) methods.

- Extensive use of LPR methods to derive the corrosion rate of sealed and unsealed Al alloys (Al, Al-Mg, Al-Zn-In) in simulated splash and tidal zone conditions.

In delivering this project, TWI will use its state-of-the-art thermal spraying facilities and associated characterisation capability including (but not limited to):

- Thermal spraying booths with 6-axis robots.
- TSA coating systems: twin wire arc spraying and wire flame spraying.
- Equipment for adhesion testing, metallography, SEM analysis, substrate surface profile and cleanliness measurement.

These facilities, and specifically the robot-mounted twin wire arc spraying (TWAS) system, will be used to produce test coupons for this project.

Objectives

The main objective of this project is to generate data demonstrating the compatibility of TSA with cathodic protection applied across a range of representative potentials. This will include measurement of the effects of selected environmental conditions and variation in coating specification comprising:

- TSA coating and anode behaviour at elevated temperature.
- TSA coating performance when subject to thermal cycling.
- TSA coating composition and use of sealants.

Benefits

With many near-to-medium term fields under development involving the installation of increasingly remote, deep-water facilities and the extraction of higher temperature hydrocarbons, the main benefits of this project are:

- Generation of environment-specific cathodic protection design data, which will provide oil producers and installation companies with increased confidence in the long-term reliability of TSA coatings in inaccessible, deep-water service.
- Extended operating life of facilities in remote locations with reduced maintenance costs.
- The opportunity to reduce anode mass on subsea structures by up to 80% (thus reducing structural mass and cost).

Approach

The project will commence with a preliminary evaluation in Work Package 1 of the effect of temperature on the behaviour of TSA coating and anode material using simple laboratory tests. These baseline data and input from Sponsors regarding typical service conditions (elevated temperature and thermal cycling) will be combined to define test conditions for Work Packages 2 and 3, which will evaluate respectively the effects of elevated temperature and thermal cycling on the interaction of TSA with cathodic protection. Work Package 4 will provide a detailed interpretation of the implication of test results for CP design.

WP1 Preliminary Evaluation of the Effect of Temperature on the Behaviour of Uncoupled and Coupled TSA Coating and Anode Material

Preliminary work will be undertaken to confirm the detail of the test conditions proposed for WP1 (Elevated Temperature) and WP2 (Thermal Cycling) based on representative environmental service conditions provided by Sponsors and laboratory testing comprising:

- Uncoupled response (free corrosion potential / E_{corr}) of two unsealed TSA alloy compositions (on an inert substrate) up to 90ºC.
- Uncoupled response (free corrosion potential / E_{corr}) of AlZnIn anode material up to 90ºC.

- Coupled response of unsealed TSA (on an inert substrate) and anode up to 90ºC.
- TSA-coated steel with holiday areas up to 20%.

These preliminary tests will be conducted in synthetic seawater conforming to ASTM D1141[17] at atmospheric pressure with potential and current recorded throughout a minimum test period of three months (required so that system conditions have had time to stabilise).

WP2 Interaction of TSA with Cathodic Protection at Constant Elevated Temperature

A detailed study will be undertaken to simulate the interaction of TSA with cathodic protection under a range of representative service environments. Test apparatus will be assembled to undertake the following (or similar) work scope:

- TSA-coated test coupons mounted in wall of tower containing hot oil at 130°C, immersed in chilled artificial seawater at 10°C.
- TSA coating skin temperatures of unburied and buried test coupons.
- Cathodic protection levels: E_{corr} and under-protection at 2 levels.
- Impressed potential by Pt electrodes and selected tests including AlZnIn anodes.
- Potential and current recorded.
- TSA coating composition down-selected from WP1.
- Sealed and unsealed TSA.
- Coatings with holidays.
- Test conducted at atmospheric pressure.
- Test duration of 12 months.

Test coupons (coatings and anodes) characterised as follows:

- Test coupon surface examined post-exposure.
- SEM examination of coating microstructure and EDX element analysis of corrosion products following exposure.

WP3 Interaction of TSA with Cathodic Protection Subject to Thermal Cycling

A detailed study will be undertaken to simulate the interaction of TSA with cathodic protection subject to representative thermal cycling service conditions. Test apparatus will be assembled to undertake the following (or similar) work scope:

- Half buried, vertical TSA-coated pipes containing oil cycled from 130°C to 10°C, immersed in chilled artificial seawater at 10°C.
- Cathodic protection level to be determined from WP1 and WP2.
- Impressed potential by Pt electrodes and selected tests including AlZnIn anodes.
- Potential and current recorded.
- TSA coating composition down-selected from WP1.
- Sealed and unsealed TSA.
- Coatings with multiple holidays.
- Test conducted at atmospheric pressure.
- Test duration of 12 months.

Performance of coatings and anodes characterised as follows:

- Test coupon surface examined post-exposure.
- SEM examination of coating microstructure and EDX element analysis of corrosion products following exposure.

WP4 Implication of Test Results for Cathodic Protection Design

Detailed interpretation of WP1-3 test results will be undertaken with regard to their implication for cathodic protection design codes and standards including:

- Effect of increasing temperature on TSA corrosion rate and electrochemical potential.
- Current density requirements and potential to achieve adequate CP design under typical service conditions compared with design values recommended in international CP design codes.
- Effect of cathodic polarisation levels on TSA coating corrosion.
- Effect of sealants on TSA corrosion rate and electrochemical potential.
- Behaviour of sacrificial anodes in the presence of TSA.
- Effect of increasing temperature on anode corrosion rate and electrochemical potential.
- TSA corrosion mechanism based on corrosion products and calcareous deposits on coatings and holidays.

Deliverables

The main deliverables of this project are:

- Individual Work Package reports detailing the effect of elevated temperature and thermal cycling on TSA coating performance and cathodic protection.
- Detailed interpretation of WP1-3 test results and their implications for offshore structure CP design.
- Quarterly e-mail progress statements and progress meetings at six month intervals.

Price and Duration

The estimated price of the proposed work is £350,000, excluding VAT and it is estimated that the project will be completed in two years. TWI is seeking five or more participants, each contributing £70,000, excluding VAT. The project can commence once three participants have been recruited, and a modified programme will be proposed.

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Further Information

For further information on how a Group Sponsored Project (GSP) runs please visit:

http://www.twi.co.uk/services/research-and-consultancy/group-sponsored-projects/

GSP Co-ordinator: Kirsty Jones

Email: gsp@twi.co.uk

Project Leader: Shiladitya Paul

Email: shiladitya.paul@twi.co.uk