Increasing the Fatigue Life of Offshore Structures using Thermally Sprayed Aluminium Coatings

JOINT INDUSTRY PROJECT OUTLINE

PROP302829

Summary

Fixed and floating offshore structures have been widely adopted for offshore installations in the oil and gas industry. Fixed offshore structures are also increasingly being proposed for wind turbine structures. Cathodic protection (CP) in the form of anodes is usually specified for the submerged parts to reduce the rate of material loss over the design life. Industrial experience and applied research have shown that thermally sprayed aluminium (TSA) behaves in the manner of a distributed anode and can similarly mitigate corrosion of submerged structure, whilst its use can significantly reduce the cost of implementing corrosion protection.

In addition to corrosion, such structures also see twenty or more years' of cyclic loading imposed by winds, waves and tidal action. Current design codes provide fatigue guidance for the principal joint geometries in structural grade steels, including the effect of free corrosion and CP in seawater. Although the effect of TSA coating on material loss due to corrosion has been widely studied, there are no useful data for its corrosion fatigue performance on welded joints. The current project will address this by conducting fatigue endurance tests and fatigue crack growth rate in seawater on appropriate joints details with TSA coating.

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Background

Fixed and floating offshore structures have been widely adopted for offshore installations in the oil and gas industry. Fixed offshore structures are also increasingly being proposed for wind turbine structures. Cathodic protection (CP) in the form of anodes is usually specified for the submerged parts to reduce the rate of material loss over the design life. Industrial experience and applied research have shown that thermally sprayed aluminium (TSA) behaves in the manner of a distributed anode and can similarly mitigate corrosion of submerged structure (Thomason 1985; Gartland 1993; Wolfson 1996; Kuroda 2006; Paul 2012). A recent report indicates that the cost of implementing corrosion protection on two monopiles in the Baltic Sea was reduced by 30% with the replacement of a conventional anode and paint system with a TSA coating (Rocha 2017).

In addition to corrosion, such structures also see twenty or more years' of cyclic loading imposed by winds, waves and tidal action, and are therefore designed for good fatigue resistance. Current design codes (such as BS EN ISO 19902, BS 7608, BS 7910 and DNVGL RP-C203) provide fatigue guidance in terms of SN curve and fracture mechanics methods for the principal joint geometries in structural grade steels, including the effect of free corrosion and CP in seawater. Under free corrosion conditions the environmental reduction factor (ERF) of 3 is applied to the SN curve for air, i.e. the fatigue life is reduced by a factor of 3; in addition there is no fatigue limit at low stress ranges. For typical wave loading, where much of the fatigue damage occurs at low stress ranges, this has a very significant effect on the predicted life. Under CP the ERF is 2.5 at high stress ranges and the SN curve and is coincident with the air curve at low stress ranges, giving much longer lives than under free corrosion.

Although the effect of TSA on material loss due to corrosion has been widely studied, there are no useful data for its corrosion fatigue performance on welded joints. A recent publication indicates that TSA can significantly extended the crack initiation stage when fatigue testing X80 steel in 3.5wt% NaCl solution although, once initiated, the crack growth was slightly higher than that of bare X80 steel (Zhao 2016). However, this study is not representative of the behaviour in seawater, since it does not take into account the known protective behaviour associated with the calcareous minerals deposited by the application of CP or use of TSA. Furthermore, this study did not take into the effect of welds. The current project will address this by conducting fatigue endurance tests and fatigue crack growth rate tests in seawater on appropriate joints details with TSA coating in order to establish the suitability of this coating process.

Objectives

The main objectives of the proposed project are:

- Conduct a thorough review of published information on the effect of TSA on welded steels, with emphasis on fatigue performance.
- To determine the fatigue strength in air and seawater of representative welded joint details with TSA coating.
- To study the effect on fatigue strength of damage to the TSA coating adjacent to the welds in joints tested in seawater.
- To measure fatigue crack propagation rates in seawater for the parent steel and weld metal with and without TSA coating in seawater.

Benefits

The study will provide data of benefit to designers and code drafting bodies considering adoption of TSA as an alternative to coating conventional anode system in the submerged zone.

Successful qualification of the use of TSA as an alternative to conventional anode and paint based corrosion protection provides the opportunity to reduce significantly the installation and maintenance costs of offshore corrosion protection systems, such as the 30% installation savings cited in the Arkona case study.

Approach

Manufacture of test samples

Welded panels including typical butt welds and fillet welds used in both fixed and floating offshore structures will be produced from a representative grade of offshore structural steel, such as EN 10025-2 grade S355J2. Joint geometries, steel grade, welding process, consumables and procedures will be selected by the project Sponsors.

It is anticipated that the plate thickness will be 20 or 25mm. Panels will be cut to produce test pieces of dimensions to be agreed and TSA coated to an agreed specification. Separate welded panels will be used for extraction of plate and weld samples for fatigue crack growth rate (FCGR) and exposure tests.

Fatigue endurance tests

Tests will be conducted under axial loading at a positive mean stress to simulate the effect of the high tensile residual stresses expected in the structure. The test environment will be air at ambient temperature for a number of control samples, and synthetic seawater (ASTM D1411) for the main test programme. The seawater temperature will be controlled by circulation through a cooled header tank. The loading frequency in seawater will be close to the characteristic wave frequency of 0.2Hz; a higher frequency will be used for tests in air, in the range 5 to 10 Hz. Applied load ranges will be set to achieve lives in the range 100,000 to 1 million cycles (the latter gives a test duration of 8 weeks at 0.2Hz). Tests will be continued until extensive cracking is present or to 1 million cycles if failure does not occur. Periodic visual inspection will allow signs of early cracking to be detected.

Specimens with and without TSA coating will be tested in air to produce a baseline S-N curve and also to determine if the TSA coating has any effect on the fatigue performance.

Specimens with TSA coating (TSA intact) will be also tested in seawater. A number of samples will have a controlled area of coating removed adjacent to the weld toe (TSA damage) to simulate the effect of local damage in service on the fatigue performance in seawater.

The un-coated specimens will be also tested in seawater with CP to compare the fatigue performance with the TSA coated specimens.

All specimens to be tested in seawater will be pre-soaked to ensure that the specimens will be saturated with hydrogen or in the worst case, that the near surface material would be saturated. Tested samples will be examined and sectioned to establish the point of crack initiation relative to the weld and the integrity of the TSA coating on the remainder of the plate. Results will be analysed to obtain a mean SN curve for each joint type and each environment for comparison with those in the design codes.

Fatigue crack growth rate tests

FCGR tests will be carried out in accordance with BS ISO 12108 to obtain growth rates in air and seawater using edge notched samples tested in 3 point bending. The specimens extracted from the parent material, weld metal and HAZ will be tested both in air (no coating) and seawater (TSA coated). Specimen surfaces will be TSA coated for tests in seawater, with the notch introduced after coating and therefore bare steel. The tests will be aimed at covering a range of ΔK values representative of that expected for a crack growing from the toe in the welded samples.

Deliverables

The main deliverables of the project will be design guidance relating to the effective use of TSA on submerged structures based on data pertaining to:

- The fatigue strength in air and seawater of representative welded joint details with TSA coating.
- The effect on fatigue strength of damage to the TSA coating adjacent to the welds in joints tested in seawater.
- The fatigue crack propagation rates in seawater for the parent steel and weld metal with and without TSA coating in seawater.

Price and Duration

The overall estimated price for the work is £396,000 (excluding VAT), which requires £33,000 per annum for 2 years (£66,000 total) from each of the six Sponsors. It is anticipated that the project will commence with an agreed scope of work with a minimum of four Sponsors.

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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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