Tribology International 68 (2013) 17–25

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

The influence of high shear and sand impingement on preferential weld corrosion of carbon steel pipework in CO_2-saturated environments

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ARTICLE INFO

Article history:
Received 29 May 2012
Received in revised form
11 November 2012
Accepted 12 November 2012
Available online 29 November 2012

Keywords:
Galvanic current
Preferential weld corrosion
Sand
Submerged impinging jet

ABSTRACT

Preferential weld corrosion (PWC) has proved problematic for the oil and gas industry for a number of years. Although the effect of high flow rates on PWC in inhibited CO_2-saturated solutions has been studied by authors, the consideration of a higher, localised turbulence over the weld material and the implications this has on PWC appears minimal. This work considers this very effect, along with developing an understanding of the threats posed to weld integrity by sand particle presence in the process fluid using a submerged impinging jet (SIJ) apparatus.

Experiments were conducted using a commercially available film-forming oilfield corrosion inhibitor which was evaluated in both flow-induced corrosion and erosion–corrosion environments in its ability to control PWC. The SIJ setup allowed control over the individual flow velocities at each nozzle, meaning shear stress could be intensified over the 1% Ni–0.25% Mo weld material to simulate localised turbulence at the sample surface. Galvanic current and mixed potential measurements were performed to ascertain changes in galvanic interactions between the two materials. The work demonstrates that localised turbulence over internal weld beads and the presence of sand within oil and gas systems can influence PWC in certain environments.

1. Introduction

1.1. Factors influencing PWC

PWC is thought to occur mainly from galvanic effects due to local compositional and micro-structural differences between the weld, heat affected zone (HAZ) and parent metal which create local anodes and cathodes [1]. The cycle of heating and cooling that occurs during the welding process alters the microstructure and surface composition of the weld and adjacent parent metal. This creates a complex mix of metal phases in the weldment, which can possess no fewer than 9 different zones [2]. In practice, only minor changes to the weld material composition are made and the microstructure is controlled to ensure the weld material matches that of the parent metal as closely as possible.

The location and morphology of PWC attack can be influenced by many parameters including the environment (water to crude oil ratio, temperature, pressure, pH etc.) and physical flow conditions [3]. If the weld material and HAZ are anodic relative to the parent metal, this can increase the rate of material loss of the welded region. The severity of the attack is exacerbated by the fact that the weld and HAZ have such a small area in comparison to the parent metal. However, the addition of elements such as nickel, chromium, molybdenum, copper, aluminium and vanadium can help to provide a more noble potential [1]. By keeping the weld material cathodic to the parent metal, preferential attack can be avoided and the corrosion can be distributed over the large parent metal surface.

It is difficult to determine the mechanisms and cause of PWC, even with vast amounts of information and industrial experience. All of the factors which affect CO_2 corrosion (pH, partial pressure, flow velocity, temperature etc.) will also have an influence on the location and severity of the attack [1]. Many of these parameters are interrelated and therefore difficult to assess individually. For example, the temperature will directly influence pH, the scaling behaviour, rate of reactions and the protective capability of the corrosion product films. The influence of flow is believed to have one of the greatest effects on weld corrosion [1].

Based on a review of PWC literature [1–10], the general consensus is that environmental effects take precedence over the weld chemical composition and microstructure. Therefore, the primary approach to prevent PWC is to ensure the correct corrosion inhibitor selection and application. Operators need to be careful as there is strong evidence to suggest that certain corrosion inhibitors may increase PWC (particularly at low concentrations) in certain CO_2 environments [8].

1.2. Turbulent flow and disturbed flow over weld beads

Research considering the effect of flow rate on PWC is available in literature [1,8]. One topic which appears to be overlooked

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http://dx.doi.org/10.1016/j.triboint.2012.11.015

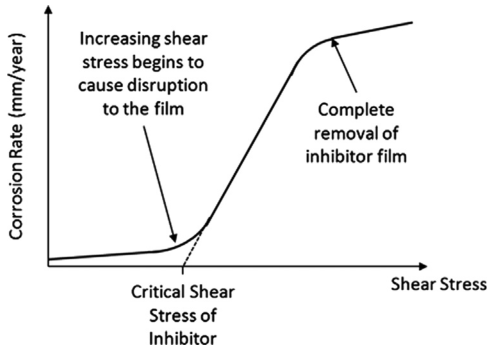

Fig. 1. The effect of flow intensity on corrosion inhibitor efficiency.

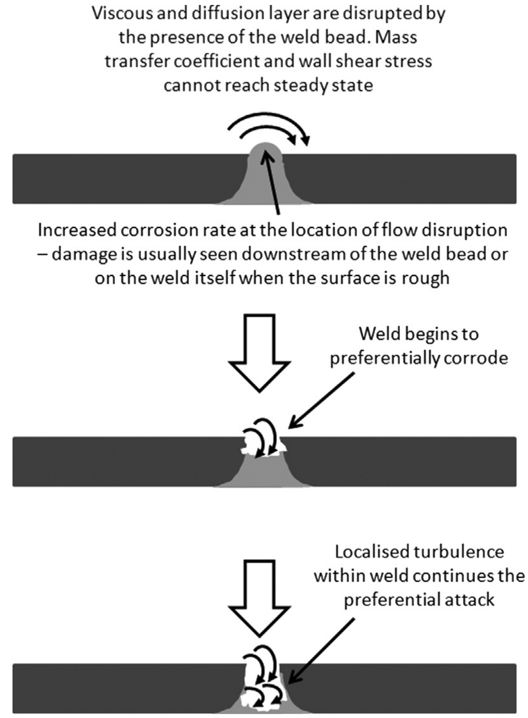

Fig. 2. Effects of wall shear stress and mass transfer changes for turbulent flow over an internal weld bead.

are the implications of having local peak wall shear stresses at sites of flow disturbances such as weld beads, which can intensify the shear stress between factors of 3 and 7 [11]. Schmitt [11] demonstrated that the efficiency of corrosion inhibitors in flowing media depends on local flow intensities. Inhibitor efficiency tends to reduce as the shear stress in the system rises, up to a point (termed the 'critical shear stress') where inhibitors experience a dramatic reduction in efficiency, as shown in Fig. 1 [11,12].

Efird [13] demonstrated that disruption to the boundary layer in turbulent flow occurs mainly by the formation of turbulent bursts. These bursts are an ejection of fluid which result in impingement on the wall by the simultaneous formation of sweeps from the occurrence of vortices.

Corrosion failures often occur in areas where the steady state flow patterns are disrupted (termed 'disturbed flow'). One likely location for disruption to occur is over internal weld beads on pipework [13]. The effect of a weld bead on wall shear stress and mass transfer coefficient is illustrated in Fig. 2. This condition causes disruption to the hydrodynamic and diffusion boundary layer over the weld bead, leading to a disturbance in wall shear stress and mass transfer, respectively. No steady state can be reached in this region and high corrosion rates are typically observed downstream of the weld bead or on the weld bead itself. Therefore, welded regions can often be subjected to more severe hydrodynamic conditions than the surrounding parent metal.

Computational Fluid Dynamic (CFD) simulations for flow over internal weld beads were conducted to simulate the flow effects on wall shear stress and are provided in Fig. 3(a) and (b). The simulation results for flow velocities of 5, 10 and 15 m/s in Fig. 3(b) indicate the dramatic increase in shear stress created over the weld in comparison to the surrounding surfaces. The increased turbulent activity could lead to a significantly higher intrinsic corrosion rate of the weld material relative to the parent metal. A situation such as this could also cause significant disruption to the formation of inhibitor films on the surface of the weld if the chemical administered is particularly sensitive to high levels of shear stress. If the turbulent intensity at the weld reduces inhibitor performance at a localised region, PWC will be more likely.

Despite the significant difference in hydrodynamic activity over the welded region in comparison to the surrounding areas of pipework, previous research focusing on preferential weld attack tends to expose both the weld, HAZ and parent metal to the same flow conditions, generally in the form of a rotating cylinder electrode (RCE) setup [1,2,8]. This poses the question as to whether the increased hydrodynamic activity over the weld would result in an increased likelihood of PWC by producing a different galvanic response.

1.3. Presence of sand and erosion–corrosion

It is becoming increasingly common for oil and gas facilities to operate under low levels of sand production. In regions of high local velocity it is important to consider how the presence of sand influences the galvanic interaction between the weld material and the carbon steel parent metal and whether this process has any implications on the performance of the inhibitor in the system. Sand particle impingement is capable of removing protective corrosion products from the surface of the pipeline material as well as inhibitor films which form on the metal surface [14,15]. The removal of these protective films undoubtedly increases the rate of corrosion by exposing unprotected steel to the corrosive environment. In these circumstances, the degradation rate is reliant upon the resistance of the inhibitor film or protective corrosion product to particle impingement and/or the film's ability to regenerate quickly once it has been damaged [14,15].

In this study, the performance of a commercially available film-forming oilfield corrosion inhibitor was assessed in its ability to control PWC in a CO_2-saturated environment. The inhibitor was evaluated in both flow-induced and erosion–corrosion conditions in an effort to establish the influence sand particle presence plays on the galvanic interaction between carbon steel and a 1% Ni–0.25% Mo weld material. A submerged impinging jet (SIJ) was used along with *in-situ* galvanic current measurements. The dual nozzle arrangement of the jet allowed one parent metal and one weld material to be placed under each nozzle of the jet whilst being coupled together.

The originality in this work lies in the fact that the weld material is exposed to higher flow rates than the parent metal, a feature which is not normally considered even though many researchers are aware that higher mass transfer, shear stresses and local velocities are present around the welded region [13]. Additionally, little work has been conducted which focuses on galvanic measurements at such high levels of wall shear stress. Finally, this paper considers the effect that sand production can have on the galvanic interaction between the weld and parent metal, an area which has also received little attention.