



Short Communication

Effect of cathodic protection on corrosion of pipeline steel under disbonded coating

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ARTICLE INFO

Article history:

Received 25 February 2009

Accepted 19 May 2009

Available online 23 May 2009

Keywords:

- A. Steel
- C. Cathodic protection
- C. Crevice corrosion
- C. Oxygen reduction
- C. Polymer coating

ABSTRACT

In this work, a test rig was developed to study the effect of cathodic protection (CP) on corrosion of X70 pipeline steel in the crevice area under disbonded coating through the measurements of local potential, solution pH and dissolved oxygen concentration. Results demonstrated that, in the early stage of corrosion of steel, CP cannot reach the crevice bottom to protect steel from corrosion due to the geometrical limitation. Corrosion of steel occurs preferentially inside crevice due to a separation of anodic and cathodic reaction with the depletion of dissolved oxygen in the crevice solution. The main role of CP in mitigation of sequential corrosion of steel in crevice under disbonded coating is to enhance the local solution alkalinity. With the increase of distance from the open holiday, a high cathodic polarization is required to achieve appropriate CP level at crevice bottom. A potential difference always exists between the open holiday area and inside crevice, reducing the CP effectiveness.

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1. Introduction

Pipeline integrity is maintained by simultaneous application of protective coating and cathodic protection (CP) [1]. Disbondment is one of the most common failure modes in pipeline coating, while the coating membrane is still highly resistant [2–5]. However, corrosive gases, water and/or chemical species may enter the disbonded crevice area, creating an electrochemical environment supporting pipeline corrosion and/or stress corrosion cracking (SCC) [6–10].

Effects of CP on local electrochemical environment and corrosion of steel under disbonded coating have been paid much attention. For example, Brousseau and Qian [11] found that pH of the trapped electrolyte increases with time due to generation of hydroxyl ions from the reduction of H₂O. Cherry and Gould [12] believed that hydroxyl ions would tend to diffuse out of the crevice under the concentration gradient, altering the electrochemical condition of the trapped solution. Fessler et al. [13] showed that the potential in the disbonded crevice area is always less negative than the applied cathodic potential, and the crevice bottom is thus insufficiently protected. Song et al. [14–16] modeled the electrochemical reactions and mass-transfer steps occurring across the coating, and indicated that the depletion of oxygen under the disbonded coating is not affected by the applied cathodic potential. The increase of solution alkalinity in the crevice is caused

by the water reduction under cathodic polarization. Perdomo and Song [6,17] measured potential, pH and oxygen concentration within a crevice, and concluded that the electrochemical corrosion of pipeline steel is due to the gradual chemical and electrochemical changes produced along the crevice. Dong et al. [18] investigated localized corrosion of steel at coating defect, and determined the effect of CP on local electrochemical environment and the resulting corrosion reaction at the base of defect. It was demonstrated that corrosion of steel is dependent on CP potential and the defect geometry. Mass-transfer of oxygen through the defect with a narrow, deep geometry is the rate-limiting step for the corrosion process of steel. The applied CP is partially shielded by the narrow, deep defect. Furthermore, Stratmann's group [19–21] used scanning Kelvin probe to investigate the delamination of polymeric coatings from steel, and demonstrated that the interfacial electrochemical reactions were responsible for the coating disbondment. During coating disbondment, the electrode potential drops significantly from very positive values, which are characteristic for the intact interface, to negative values, which are typical for disbonded coating under which corrosion reaction occurs.

Corrosion of steel under disbonded coating has been simulated frequently as crevice corrosion [22,23]. To further understand the corrosion behavior of pipeline steel in the crevice solution under disbonded coating in the presence of applied CP, a rectangle crevice assembly was developed in this work to investigate the effectiveness of CP on mitigation of corrosion of X70 pipeline steel under the disbonded coating through measurements of local potential, solution pH and concentration of dissolved oxygen. The electrochemical corrosion mechanism was analyzed.

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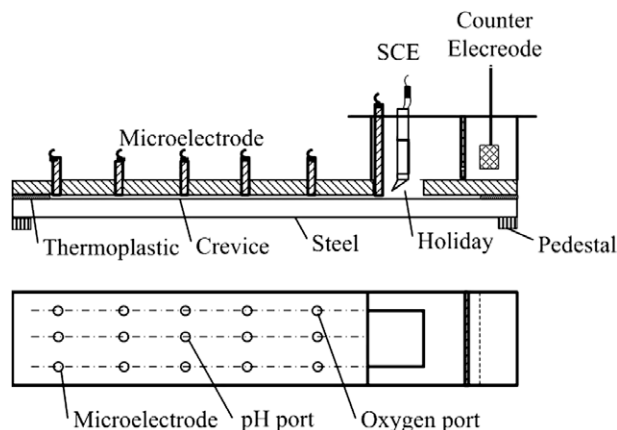


Fig. 1. Test rig for simulation of a crevice under disbonded coating.

2. Experimental

Test specimen was cut from a X70 steel pipe, with the chemical composition (wt.%): C 0.045, Si 0.24, Mn 1.48, S 0.0001, Cr 0.031, P 0.017, Ni 0.16, Mo 0.23, Cu 0.21 and Nb 0.033. A three-electrode cell system was used for simulation of a crevice created by coating disbondment, as shown in Fig. 1. The cell consisted of an X70 steel working electrode with $33.5 \text{ cm} \times 7.5 \text{ cm} \times 1 \text{ cm}$ in dimension, which was ground sequentially to #1000 grit emery paper. A saturated calomel electrode (SCE) was used as reference electrode, and a platinum wire (1 cm in diameter) as counter electrode. A rectangle thermoplastic shim (0.9 mm in thickness) was used to create the crevice, with a Lucite as a coating membrane. The plastic shim was adjustable to control the crevice width. A hole of $3.5 \text{ cm} \times 1 \text{ cm}$ was opened to simulate a holiday. Three ports were then drilled at an interval of 5 cm from the holiday along the Lucite block to position the microelectrodes for measurements of local potential, solution pH and oxygen concentration, respectively. In particular, the local potentials of steel at individual ports were measured by microelectrodes when various CP potentials were applied at the holiday. The local solution pH was measured ex-situ, using a capillary to sample the local solution in a beaker, through a Thermo Orion 9863BN pH meter. The local oxygen concentration was measured in situ through a Unisense OX100 dissolved oxygen micro-glass electrode with a 5 micron tip. The oxygen microelectrodes were sealed tightly with Lucite using a 732 Multi-purpose Sealant (Dow Corning) in order to avoid diffusion of oxygen through the port openings.

The test solution was 0.01 M Na_2SO_4 solution, with a pH of 6.8. The solution was made of analytical agent and distilled water.

All tests were conducted at room temperature ($\sim 22^\circ\text{C}$), and open to air.

3. Results

Fig. 2 shows the local potential, solution pH and the oxygen concentration as a function of distance from the open holiday after 0.5 h of immersion in the solution at corrosion potential ($-680 \text{ mV}_{\text{SCE}}$), $-775 \text{ mV}_{\text{SCE}}$, $-1000 \text{ mV}_{\text{SCE}}$ and $-1200 \text{ mV}_{\text{SCE}}$, respectively. The concentration of dissolved oxygen in the bulk solution was 8.3 mg/L. It is seen that the applied cathodic potential could not penetrate into the crevice bottom. With the increase of distance from holiday, the local potential became positive (Fig. 2b). Even at $-1200 \text{ mV}_{\text{SCE}}$, the potential at 10 cm point was approximately corrosion potential. Moreover, local solution pH decreased (more acidic) with the increase of distance from holi-

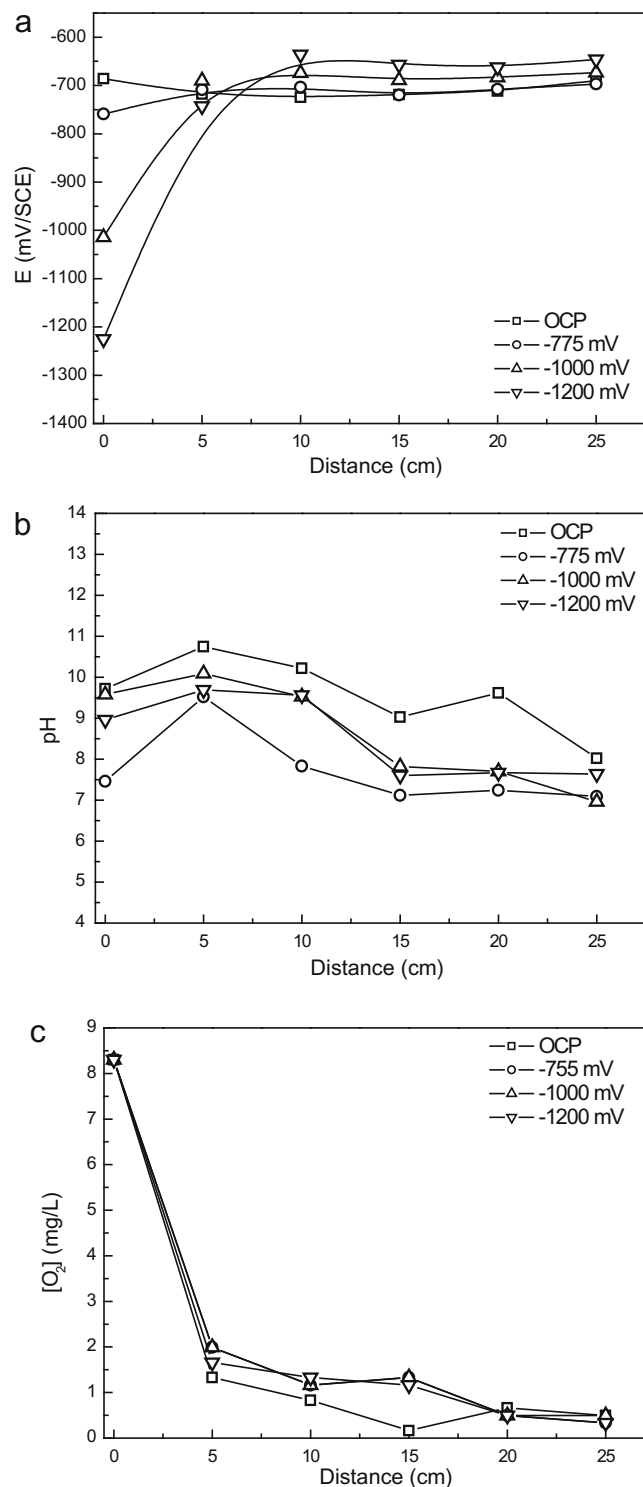


Fig. 2. Potential (a), pH (b) and oxygen concentration (c) profiles within crevice after 0.5 h of test.

day, and there was the lowest solution pH at the crevice bottom (Fig. 2b). Furthermore, the oxygen concentration dropped from 8.3 mg/L at holiday to 1 mg/L at crevice bottom no matter if CP was applied.

Fig. 3 shows the local potential, solution pH and oxygen concentration after 72 h of application of CP potentials. It is seen that there was a similar local potential distribution to that shown in Fig. 2a, i.e., local potential became less negative towards the cre-

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