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Study of cathodic protection shielding under coating disbondment on pipelines

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ABSTRACT

In this work, the cathodic protection (CP) shielding behavior of pipeline coatings, *i.e.*, high density polyethylene (HDPE) and fusion bonded epoxy (FBE), was investigated. While the HDPE is a CP-shielding coating, the FBE is permeable to CP. The structure of HDPE does not change upon CP permeating test, and water molecules are not absorbed into the coating. Conversely, there are obvious changes of the functional groups in FBE. Water uptakes into the coating occur continuously with time. The CP permeation through FBE coating is time dependent. A more negative CP potential level enhances the CP permeation.

1. Introduction

Pipelines are protected from external corrosion by both coating and cathodic protection (CP). While the coating provides the first line of protective barrier, CP serves as a backup to prevent corrosion attack either at coating faults such as pinholes and holidays or under coating disbondment [1–5]. However, pipeline corrosion and corrosion induced cracking have been widely documented [6–8]. When coating is disbonded at small faults, such as pinholes or holidays, CP current can be shielded, either fully or partially, to reach the disbonding crevice, especially at the crevice bottom. As a result, the CP could not protect the area that is in a corrosive environment. This is called "CP shielding". Another scenario encountered in reality to cause CP shielding is the disbondment of a defect-free coating due to either an inadequate coating application process or the lost adhesion of the coating to the steel substrate during service. For example, spirally wrapped tape coatings can experience disbonding over pipeline welds. In this situation, the CP shielding is attributed to the coating property [9,10]. It has been reported [11] that up to 85% of all the external corrosion of pipelines is under disbonded CP shielding coatings. Non-shielding coatings are those which do not prevent distribution of CP current to the steel substrate through the disbonded coating [12].

It is generally accepted [13] that the widely used fusion bonded epoxy (FBE) and coal-tar enamel coatings exhibits evidence of passage for CP current, while the high performance composite coating and polyethylene tape block CP current in long-term tests [13]. There have been works to measure and model environmental chemistry and electrochemistry of the electrolyte trapped under CP shielding or non-shielding coatings [14–17]. Moreover, lab tests have been conducted attempting to understand the CP shielding behavior of some pipeline coatings through electrochemical measurements, including potentiostatic current and electrochemical impedance spectroscopy [18–20]. However, the majority of the testing did not duplicate the reality of pipeline corrosion under disbonded coating in the field. For example, the solution pH trapped under the disbonded coating was generally measured *ex-situ* by sampling small amount of electrolyte [21–23].

In this work, a test rig was designed and constructed to simulate disbondment of defect-free coatings on pipelines encountered in reality. The pH of the electrolyte under disbonded coating was monitored *in-situ* by a micro pH meter which was installed into the disbondment crevice. Two pipeline coatings, *i.e.*, FBE and high-density polyethylene (HDPE), were used in this work. Measurements of potential and potentiostatic current, optical characterization, and Fourier transform-infrared spectroscopy (FT-IR) were combined to study the mechanistic aspects associated with the compatibility of coatings with cathodic protection.

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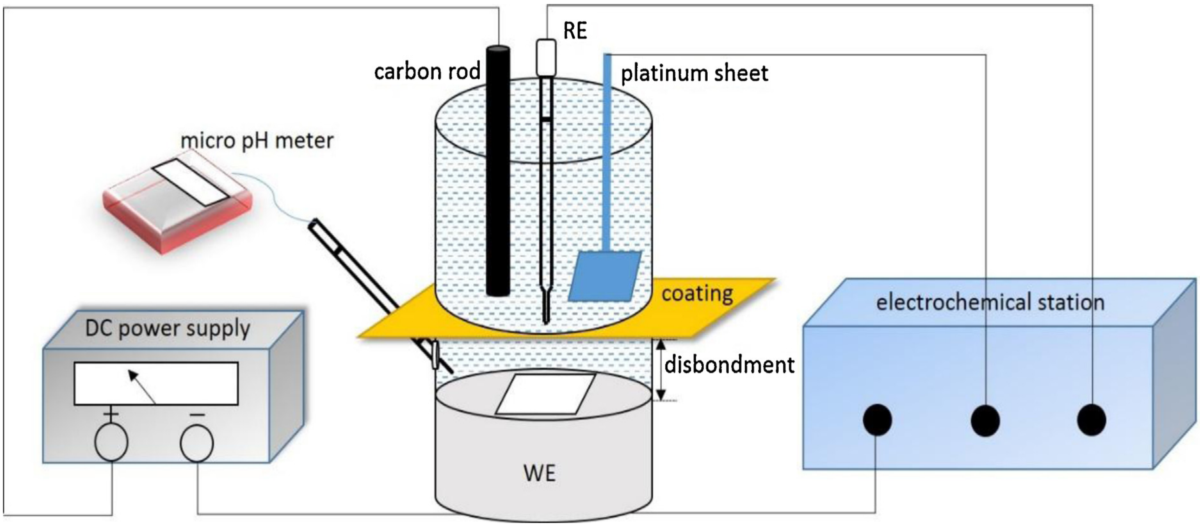

Fig. 1. Schematic diagram of the experimental setup to measure the permeability of coatings to CP, where WE and RE refer to working electrode and reference electrode, respectively.

2. Experimental

2.1. Coatings, steel and solution

The FBE and HDPE membranes, with a thickness of 250 μm and 850 μm, respectively, were used in this work. All coating membranes, supplied by Bredero Shaw, were cut into circular shape with a diameter of 5 cm.

The steel used in this work was X65 pipeline steel, with a chemical composition (wt.%): C 0.04, Si 0.2, Mn 1.5, P 0.011, S 0.003, Mo 0.02 and Fe balance. The steel coupons were sealed with LECO epoxy, leaving a working area of 1 cm^2. Prior to test, the electrode was subsequently ground with 400, 800, 1000 and 1200 grit sand papers, and cleaned in distilled water and acetone.

A diluted bicarbonate solution, *i.e.*, 0.01 M $NaHCO_3$, was used to simulate the ground water. It was made from analytic grade reagent and ultra-pure water, with a pH of 7.5. All tests were conducted at 23 °C.

2.2. Measurements of CP permeability of coatings

A test rig was home-designed and constructed for testing of the CP permeability of coatings, as shown in Fig. 1, where two test chambers were separated by a coating membrane. This setup was to measure the compatibility of defect-free coatings with CP. A carbon rod was placed in the top chamber and used as the auxiliary anode. The steel electrode was installed in the bottom chamber. Two CP potentials of −0.85 V(copper/copper sulphate, CSE) and −1.00 V(CSE) were applied, respectively, through an external direct current power supply. A gap between the steel electrode and the coating was created to simulate a disbondment crevice, which was 1.5 mm in height. A Loctite-495 instant adhesive was used to seal the coating with the two cylindrical chambers.

Electrochemical measurements were conducted using a Solartron 1280C system, where a platinum sheet and a saturated calomel electrode (SCE), which was installed in the top chamber in Fig. 1, were used as counter electrode and reference electrode, respectively, and the steel electrode installed in the bottom chamber was used as working electrode. Both chambers contained the prepared 0.01 M $NaHCO_3$ solution. The potential of the steel electrode and the potentiostatic current between working electrode and counter electrode under CP application were measured. Moreover, an Orion 9810BN micro pH electrode was installed in the disbondment between the coating membrane and steel electrode to monitor the solution pH.

After testing, the morphology of the steel electrode was observed by an optical microscope.

2.3. Coating characterization

The coating samples were characterized by FT-IR with a Nicolet iS10 Spectrometer. For all the spectra recorded, the samples underwent a 64-scan data accumulation in the range of 500–5500 cm^{-1} at a spectra resolution of 4.0 cm^{-1}.

3. Results

3.1. Morphological observation of steel electrodes

Fig. 2 shows the optical morphology of the steel electrode in 0.01 M $NaHCO_3$ solution trapped under the disbonded HDPE coating after various times of testing at an applied CP potential of −0.85 V(CSE). It is seen that the steel experiences serious corrosion after 5 days of testing. With the increase of the testing time, more corrosion products are generated and deposited on the steel surface. Obviously, the applied CP cannot provide effective protection to the steel under disbonded HDPE coating.

Fig. 3 shows the optical morphology of the steel electrode in 0.01 M $NaHCO_3$ solution trapped under the disbonded FBE coating after various times of testing at an applied CP potential of −0.85 V(CSE). It is seen that mild corrosion occurs on the steel electrode. Particularly, the corrosion product generated is much less than that observed in Fig. 2, where the steel corrodes under disbonded HDPE coating. A few isolated corrosion pits are formed on the electrode surface. The pits become bigger with the increase of the testing time. It is thus seen that FBE can permit CP current to penetrate to protect the steel from corrosion. However, under the given testing condition, the steel under the disbonded FBE cannot be fully protected by the applied CP, as evidenced by occurrence of localized corrosion.

To further investigate the effect of the elevated CP level on corrosion protection to steel under disbonded FBE, a more negative CP potential of −1.00 V(CSE) is applied. The optical morphology of the steel electrode after testing is shown in Fig. 4. It is seen that there

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