Progress in Organic Coatings 120 (2018) 79–87

Contents lists available at ScienceDirect

Progress in Organic Coatings

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

Degradation of fusion bonded epoxy pipeline coatings in the presence of direct current interference

Shan Qian, Y. Frank Cheng*

Department of Mechanical & Manufacturing Engineering, University of Calgary, Calgary, Alberta, T2N 1N4, Canada

ARTICLE INFO

Keywords:
Pipeline coatings
Fusion bonded epoxy
Direct current interference
Water permeation
Electrochemical impedance spectroscopy

ABSTRACT

In this work, the effects of direct current (DC) interference on properties and performance of fusion bonded epoxy (FBE) pipeline coating in a simulated soil solution was studied by measurements of water permeation and electrochemical impedance spectroscopy, as well as characterization by scanning electron microscopy and Fourier transform infrared spectroscopy. Results demonstrate that the presence of DC interference increases the water permeation into the coating, and decreases the resistance of the coating for corrosion protection. Moreover, the DC changes the molecular structure of the coating material. Generally, the FBE coating located in the cathodic zone suffers from more serious degradation than that in the anodic area due to the opposite direction of the DC induced electric fields in the two zones, which affect the diffusion and accumulation of water molecules and chemical ions.

1. Introduction

Fusion bonded epoxy (FBE) has been widely used as a pipeline coating for external corrosion protection due to its excellent adhesion to the steel substrate, good chemical resistance, and various processing characteristics [1,2]. However, the FBE can experience degradation and failure during service in soil environments caused by various reasons, such as poor surface preparation, unqualified coating application, soil stress, mechanical damage by backfill, etc. [3,4]. In particular, the parallel adjacency of coated pipelines to electric fields, i.e., either alternating current (AC) or direct current (DC) one, has been paid much attention recently. Accelerated corrosion, reduced cathodic protection (CP) performance and facilitated coating disbondment have been reported to cause the so-called AC corrosion on pipelines [5,6]. Compared to the effect of AC on coating properties and performance [6], there has been so far limited work conducted to investigate the effect of DC on pipeline coatings such as FBE.

With the design and construction of high voltage DC (HVDC) power lines in Alberta, Canada, buried pipelines collocated with the HVDC power lines would be subject to DC interference from leakage current and/or electromagnetic inductive, capacitive and conductive effects [7,8]. This not only induces corrosion to the pipe steel, but also affects the coating performance. Once coatings are failed, the DC current flowing through the coating defect or breakage can result in accelerated corrosion of the steel in the anodic zone, and enhanced reduction of dissolved oxygen or other species in the cathodic zone [9–13].

The adverse effect of CP on coating degradation, especially the cathodic disbonding of the coating, has been investigated extensively [3,14,15]. To date, the effect of simultaneous cathodic and anodic current applications under DC interference on pipeline coatings has remained unknown. This knowledge is critical to the maintenance of pipeline integrity and safe oil/gas transportation.

In this work, the properties and anticorrosion performance of FBE coating in the presence of DC interference were investigated in a simulated soil solution by measurements of water uptake and electrochemical impedance spectroscopy (EIS), as well as the coating characterization by scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FT-IR). The effect of DC voltage on water permeation through the FBE coating at both cathodic and anodic zones was determined. A conceptual model was developed to illustrate the mechanistic aspect of the coating degradation induced by DC interference.

2. Experimental

2.1. Specimen and solution

Specimens used in this work were cut from an X52 steel pipe, with a chemical composition (wt.%): 0.24 C, 1.4 Mn, 0.45 Si, 0.025 P, 0.015 S, 0.10 V, 0.05 Nb, 0.04 Ti and Fe balance. The specimens were sealed by epoxy, leaving a working area of 1 cm^2. The specimen preparation was controlled carefully to ensure that there was no bubble and crevice at the epoxy/steel interface. The working face of the specimen was subsequently ground with 240, 400, 600, 800 and 1000 grit SiC emery papers, cleaned in distilled water and acetone, and dried in high-purity

---

* Corresponding author.
E-mail address: fcheng@ucalgary.ca (Y.F. Cheng).

https://doi.org/10.1016/j.porgcoat.2018.03.012
Received 20 July 2017; Received in revised form 1 March 2018; Accepted 13 March 2018

Table 1
Chemical composition of the extracted Regina clay soil electrolyte (unit: mg/L).

Na^+	K^+	Mg^{2+}	Ca^{2+}	NO_3^-	SO_4^{2-}	Cl^-	HCO_3^-
49.70	27.82	65.21	259.80	1.01	965.85	5.41	55.19

N_2 gas (99.999%). FBE coating membranes, which were cut from the coating samples supplied by industry with an average thickness of 180 μm, were applied on the steel surface, and the boundary of the steel/coating assembly was sealed with epoxy resin and silica gel. To ensure the reproducibility of the obtained results, parallel tests were conducted on multiple coating membranes.

A simulated soil solution was prepared according to the composition of the extracted Regina clay soil electrolyte, with the chemical composition shown in Table 1. The pH of the simulated soil solution was adjusted to 7.6 using 1 M NaOH solution to be consistent with the value of the extracted soil electrolyte. All chemicals used were analytic grade reagents, and ultra-pure water (18 MΩ cm in resistivity) was used to prepare solutions. All tests were conducted at temperature of 65 °C, which was controlled through an oven.

2.2. Measurement of water permeability of FBE coating under DC interference

The water uptake of the FBE coating membrane was measured using the gravimetric cup method [16]. A test cell used in authors' previous work [3] was used for the purpose. As shown in Fig. 1, a FBE coating membrane was mounted on two glass containers, where the simulated soil solution was pre-filled. The two coated containers, which simulated the cathodic and anodic zones during DC corrosion of pipelines, respectively, were bonded on a conductive steel net. The assembly was put in an oven which was kept at 65 °C and a relative humidity of nearly zero. The temperature and relative humidity were measured using an Omega iTH controller kit. Various DC voltages, i.e., 0, 2, 5, 10 and 20 V, were applied between the carbon rods installed in the two containers as shown in Fig. 1. The containers with the sealed FBE coating membranes were weighed at a 48 h of interval. The weight change was used to calculate the water uptake. To ensure the reproducibility of the results, all tests were conducted on at least three parallel specimens.

2.3. EIS measurements under DC interference

Fig. 2 shows the experimental setup for measurements of EIS of the FBE coated steel specimen under DC interference. Similar to the assembly in Fig. 1, two cells were used to simulate the cathodic and anodic zones during DC corrosion of pipelines. The DC voltage was controlled by a DC power supply. In the DC current circuit, the carbon rods, which were used as counter electrodes (CE) in the cathodic and anodic cells, were connected to the positive and negative poles of the DC power supply, respectively. The coated steel electrodes, which were used as working electrodes (WE) in both cells, were connected using a copper wire to form a closed DC circuit. The DC voltage was varied, i.e., 0, 2, 5, 10 and 20 V, by adjusting the voltage output of the power supply.

The EIS measurements were performed by a Solartron 1280C electrochemical system on the cathodic and anodic cells, respectively. The coated steel electrode, the carbon rod and a saturated calomel electrode (SCE) were used as working, counter and reference electrodes, respectively. Prior to EIS measurements, the DC system was temporarily turned off to avoid the potential interference of the system to the electrochemical testing system. The EIS was measured to determine the resistance of the FBE coating upon DC application. After the open-circuit potential (OCP) of the coated steel reached a steady value, the EIS measurement was conducted under a sinusoidal excitation potential of 50 mV in the frequency range from 20 kHz to 0.05 Hz. The impedance data were fitted with appropriate equivalent circuits using the ZSimpWin software.

To ensure the reproducibility of the results, EIS measurements were conducted at least three times under identical conditions.

2.4. Coating characterization

A SEM (FEI XL30) was used to observe the cross-sectional morphology of the FBE coatings after 30 days of testing under DC interference. A FT-IR (Model Nicolet iS50) was used to characterize the functional groups of the FBE coating under DC interference. For all spectra recorded, the coating samples experienced a 64-scan data accumulation in the range of 650–4000 cm^{-1} at a spectra resolution of 4.0 cm^{-1}.

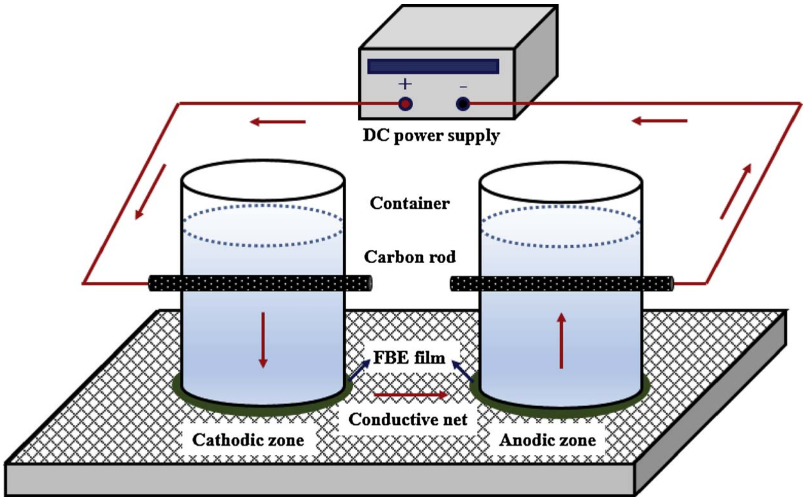

Fig. 1. Schematic diagram of the experimental setup for measurements of water uptake by FBE coating membrane.