

Classification of Active and Passive Surface Conditions Based on Different Relaxation Response for External Corrosion Coated Pipelines

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ABSTRACT

The energy transportation network of the United States consists of over 2.5 million miles of buried pipelines. It is of prime importance the integrity of the metallic assets due to degradation in soil conditions because of their constant exposure to the aggressive, dynamic, and heterogeneous environment. This degradation process, involves a sequence of process starting with the coating damages/failures and the following electrochemical reactions. External corrosion can result in gradual and usually localized metal loss on the exterior surface of failure coating, resulting in reduction of the wall thickness of the metallic asset. Indirect technologies, such as DC basis have been able to detect and pinpoint two conditions in the pipeline, intact and holiday (active surface or coating anomaly) with good confidence. In this work we consider different levels of corrosion *surface severity* when a coating holiday (anomaly) exists. Different X52 metallic samples were characterized by using DC polarization and AC impedance to distinguish the differences in terms of capacitive and surface corrosion severity when the metallic samples get a coating failure. Two different coatings were used to characterize different activity surface conditions when there is a coating holiday. The performed set of laboratory experiments include the effects of the applied cathodic protection potential and the metallic surface condition in the presence of holidays (specifically active and passive state) under cathodic protection and simulated soil conditions. Functional correlations and plot results could be found with the fundamentals of electrochemistry and electrical signals by following the DC polarization, relaxation plots and Electrochemical Impedance Spectroscopy results performed in the laboratory. In light of the differences between each surface condition founded experimentally we are able to screen and distinguish the

severity conditions of the surface under anomaly coating conditions and potential detection methods/tools for potential pipeline inspection practices.

Key words: external corrosion, severity detection, potential decay, impedance properties, electrochemical characterization.

INTRODUCTION

External corrosion on buried pipelines can result in gradual and usually localized metal loss on the exterior surface of failure coating, resulting in reduction of the wall thickness of the metallic structure. Indirect technologies, such as DC basis (i.e. DCVG, CIPS) have been able to detect and pinpoint two conditions in the pipeline, intact and holiday (active surface or coating anomaly) with good confidence. Classic DC methodologies monitor and characterize the state of the coating and effectiveness of cathodic protection by using transfer function principle (i.e. resistance). The formation of an electrochemical cell, such as buried coated pipeline with cathodic protection (steel in electrolyte) is formed at macro scale conditions [1-2]. The expected damage evolution of the coated pipeline includes the electrolyte (soil+water) uptake within the coating. Once the water uptakes the coating it reacts at the coating/metallic interface. When the activation of the metallic surface starts the dissolution and surface is modified. Either by third party damage or natural damage process, the surface activation is influenced by the soil conditions. The anodic or corrosion reaction when occurs due to the direct bridge or interaction between the soil and steel surface can have different dissolution rates. The conditions and contents of the soil promote and influence the electrochemical reactions and as consequence the surface conditions, also the corrosion rate is proportional to the surface modification following electrochemical reactions. DC technologies can identify the anomalies resulted due to the bridge between the soil and the metallic structure, the detection considers different resistances between coating (high impedance) and steel surface (low impedance). The surface exposed to the soil will help to resolve such gradient. CIPS and DCVG are clear examples of transfer function methods assuring the identification of such gradient due to the difference between two surfaces (metal and coating) [3-5] in contact with the electrolyte or soil.

Different levels of surface severity might be present when the survey method is deployed and is not able to capture the state of the metal surface. The lack of metallic surface severity detection can lead to mis-interpretation of the threat resulted by the corrosion process and makes the maintenance prioritization difficult. The corrosion rate is influenced by the surrounding soil environment, the surface conditions existing at specific time and location might be in the intact state, passive state (corrosion products), active state (corrosion dissolution) or in somewhere in between active-passive state. Steel degradation in soil conditions leads to higher metal and wall loss in buried pipelines, the detection, recognition, and assessment of the severity level is the key to take important repairing decisions. Electrochemical characterization [5-6] and capacitance behavior can be a route to distinguish the corrosion severity and the distinction between different levels of dissolution.

In this work we consider a new approach based on the DC polarization and time relaxation (potential decay) monitoring with and Electrochemical Impedance Spectroscopy technique and data analysis based on charge/discharge capacitance. We performed a series of testing conditions in coated buried metallic structures (steel pipeline) to detect and rank the active severity of the metallic structure when it is in contact with the soil. In light of the differences between each severity condition founded experimentally we were able to screen and interpret the severity conditions of the surface under anomaly coating conditions in four different levels (intact, passive, active and surface active). Functional mappings and correlations could be found with the fundamentals of electrochemistry and electrical signals by following the DC polarization and potential relaxation and Electrochemical Impedance Spectroscopy techniques performed in the laboratory scale.

EXPERIMENTAL PROCEDURE

Several API X52 metallic samples were characterized by using DC polarization and AC impedance to distinguish the differences in terms of active surface vs. severity when the metallic samples include a coating failure. Coal tar and fusion bonding epoxy were used to characterize different activity surface conditions when there is a coating failure. The performed set of laboratory experiments include the effects of the applied cathodic protection potential and the metallic surface condition in the presence of holidays (active, pitting and passive state) under simulated soil conditions.

Materials

Fusion Bonded Epoxy (FBE) and coal tar epoxy coating were applied on API X52 steels. An induced holiday with size of 0.5 cm × 0.5 cm was created on the surface. Three types of defects were considered in this work as shown in Figure 1. An active defect means the natural state of defect. The passive surface was controlled by applying an external potential to form a passive film on the metal surface. The pitting defect was created by following the potentiodynamic curve where the pitting potential is met. The external potential was determined by potentiodynamic polarization curves. The experimental design is shown in Table 1. NS4 solution (KCl: 0.122 g/L, NaHCO₃: 0.483 g/L, CaCl₂: 0.093 g/L and MgSO₄: 0.131 g/L) was used to simulate the soil environment.

Table 1 shows the experimental parameters simulating the soil or buried conditions consider the cathodic protection, in combination with the coating and the holiday.

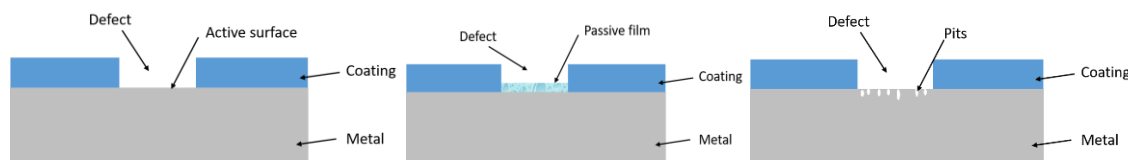


Figure 1: Schematic view of coating with active, active/passivated and pitting defect

Table 1
Experimental matrix

Substrate metal	Coating	Soil Composition	Cathodic polarization (V/CSE)	Severity based on the active-passive concept
API X52	FBE	NS4	-0.85	Holiday with pitting
API X52	FBE	NS4	-0.85	Active Holiday
API X52	FBE	NS4	-0.85	Passive Holiday
API X52	FBE	NS4	-1	Holiday with pitting
API X52	FBE	NS4	-1	Active Holiday
API X52	FBE	NS4	-1	Passive Holiday
API X52	FBE	NS4	-1.4	Holiday with pitting
API X52	FBE	NS4	-1.4	Active Holiday
API X52	FBE	NS4	-1.4	Passive Holiday
API X52	Coal tar	NS4	-0.85	Holiday with pitting
API X52	Coal tar	NS4	-0.85	Active Holiday
API X52	Coal tar	NS4	-0.85	Passive Holiday
API X52	Coal tar	NS4	-1	Holiday with pitting
API X52	Coal tar	NS4	-1	Active Holiday
API X52	Coal tar	NS4	-1	Passive Holiday
API X52	Coal tar	NS4	-1.4	Holiday with pitting
API X52	Coal tar	NS4	-1.4	Active Holiday
API X52	Coal tar	NS4	-1.4	Passive Holiday

Electrochemical measurements

The X52 steel was polarized in a sodium carbonate-bicarbonate buffer solution with a pH of 10 at a scan rate of 0.167 mV/s. The scanning range starts from -0.25 V to 1.2 V versus open circuit potential (OCP). Potentiostatic polarization with a constant external potential was applied on the metal surface for 3 hours to ensure the formation of a passive layer. To characterize the formation of the passive film, the electrochemical impedance spectrum (EIS) method was used with the frequency range starting from 100 kHz to 10 mHz with an amplitude of 10 mV.

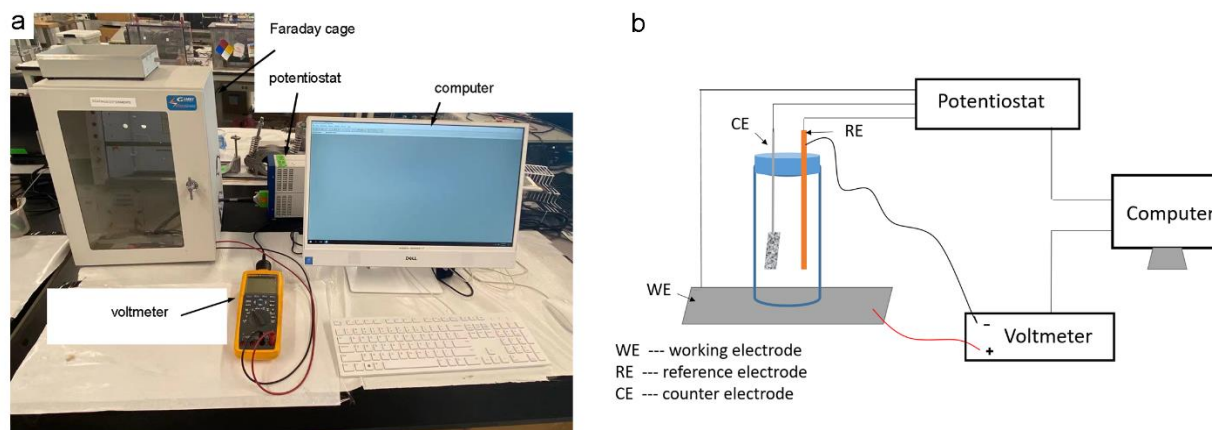


Figure 2: (a) Experimental setup and (b) connection with electrochemical cells

The cathodic protection is conducted on the sample surface with different potentials – 0.914 V/SCE (-0.85 V/CSE), -1.064 V/SCE (-1 V/CSE) and -1.464 V/SCE (-1.4 V/CSE). A sequence of EIS and 10-minute potentiostatic polarization with the biased potential was performed. After cutting off cathodic protection, the potential change of the electrochemical system was recorded by the voltmeter. The experimental set up testing system was presented in Figure 2. The potentiostat and voltmeter was used to apply cathodic potential and record potential output after cutting off the cathodic protection. Three electrode system was used with a platinum gauze and a saturated calomel electrode (SCE) used as a counter electrode (CE) and reference electrode (RE) respectively as illustrated in Figure 2b. The positive and negative poles of voltmeter connected to the specimens (WE) and RE, respectively.

RESULTS AND ANALYSIS

Potentiodynamic polarization

A wide passivation zone between 0 V/SCE to 0.8 V/SCE was observed as displayed in Figure 3a, where 0.3 V/SCE was selected to form a passive film by polarizing samples surface for 3 hours. A final current density of around 150 nA/cm² was observed in Figure 3b. Based on Figure 3a we have different active states and one passive state region condition.