DoD CORROSION CONFERENCE 2011

DoD 2011-20463

AC-INDUCED CORROSION AND INTERACTIONS WITH CATHODIC PROTECTION

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ABSTRACT

For many years, the tribal knowledge within the corrosion community was that alternating currents (AC) had little or no detrimental effects on the corrosion of metal structures. More recently, it has been recognized that AC-induced corrosion can have major deleterious effects. An exemplar of the problem is buried pipelines that are co-located with high-voltage transmission lines for electrical distribution, although other applications are likely to apply where there is a combination of alternating currents and cathodic protection. The controlling parameters are not fully defined, and their relationship to corrosion rates is not well established. For Induced AC plus DC for cathodic protection, the trends are to exacerbate the problem with greater magnitude of induced current density, fewer and smaller coating defects (holidays) and higher levels of cathodic protection. The objective of this work is to examine the effects of AC-induced corrosion and interactions with cathodic protection under controlled laboratory conditions. The findings will better inform mitigation methods, monitoring techniques, risk assessment and integrity management.

Keywords: Corrosion, induced AC, cathodic protection

INTRODUCTION

Induced alternating current (AC) degradation has become more widely recognized as a threat to the integrity of underground structures, e.g. pipelines co-located with high-voltage transmission lines, AC-powered rail transit systems, and structures where there are stray AC currents. High induced AC voltages on the pipelines lead to AC current discharge at coating defects, which can cause severe corrosion even when the cathodic protection criteria is deemed to be satisfied. However, the mechanisms of AC corrosion are still not completely understood, empirical results for factors affecting AC corrosion are in the early stages of development. Mitigation methods are available but technical basis and validation can be improved.

The objective of this work is to examine the effects of Alternating Current (AC) induced corrosion, AC/DC effects, and interactions with cathodic protection under controlled laboratory conditions. A primary focus is to determine the effects of surface films and corrosion products on metals on the modulation of the AC/DC currents. In particular, the work includes analyses of metal-oxide-metal (MOM) junctions which can have semiconductor properties and nonlinear effects on the currents. Further, the effects of local environment changes, such as pH, on the AC induced corrosion are examined. The relationships among AC/DC polarization, surface films, the aqueous environment and corrosion are to be determined. The initial work is in the context of buried pipelines that are co-located with high-voltage electrical transmission lines, however, the enhanced understanding of these effects are relevant to a broader range of applications.

This paper presents a description of the AC Induced corrosion risk for buried pipelines, an overview of some relevant corrosion principles, and description of the laboratory program to examine this corrosion degradation.

AC Induced Corrosion of Buried Pipelines

Buried pipelines are often co-located in shared right-of ways with high-voltage transmission lines for electrical distribution. **Figure 1** shows the electromagnetic coupling of transmission line currents with buried pipeline. The magnetic field associated with transmission lines induces AC currents in the steel pipeline which is insulated by a protective coating and buried in a conductive medium (soil). The induced currents can flow to soil at defects in the external coating. The induced AC currents, depending upon their magnitude, can present personnel safety hazards and also present a corrosion risk to the pipeline.

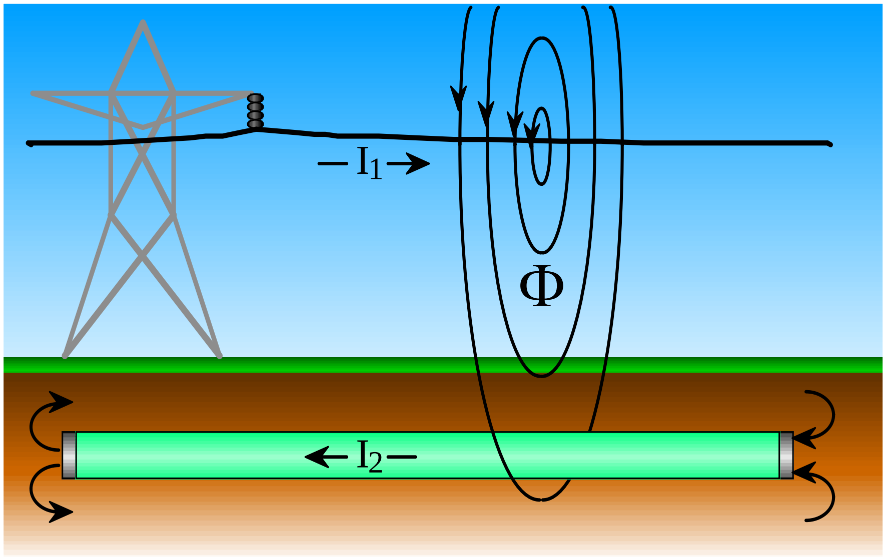
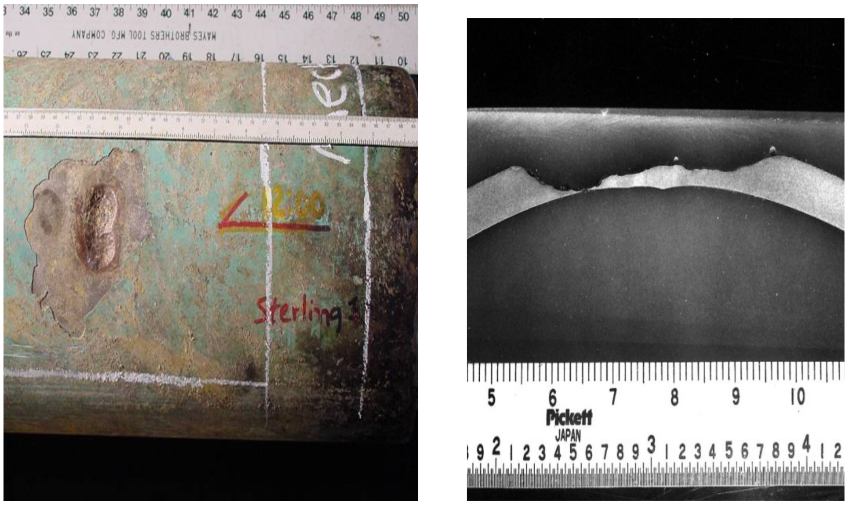


FIGURE 1 – Electromagnetic coupling of transmission line currents with a buried pipeline (*Source: K. Garrity, Mears Group, Inc)*

Figures 2 and 3 show AC-induced corrosion damage that caused a leak in a fusion bonded epoxy coated pipeline in 18 months of service. The pipeline ran along a right-of-way with high-voltage electrical transmission lines. The pipeline was cathodically protected at levels deemed to be protected by normal pipeline practices.



a. **b.**

Figure 2 – AC corrosion leak in a FBE coated pipeline after 18 months of service (*Source: Mears Group, Inc)*: a) corroded area on outer surface and b) cross section through corroded area.

Based on field observations and experience, it is found that AC-induced corrosion is exacerbated by

-- greater magnitude of induced current density
-- fewer and smaller coating defects (higher current density)
-- higher levels of cathodic protection
-- Higher chloride concentration or de-aerated environments

So, a well coated pipeline and higher level of cathodic protection increase the corrosion risk. While these and other trends are observed, the technical basis for understanding the complex and coupled processes that control the degradation process are not well established. A sounder technical basis would better inform mitigation methods, monitoring techniques, risk assessment and integrity management.

Overview of Corrosion Principles

Figure 3 shows sketches of the three behaviors of metals in an environment and the four requirements of a corrosion cell. When a metal (steel pipeline) is exposed to an environment (soil) the metal can be immune (no reaction), active (corrode) or passive (covered by a protective corrosion product).

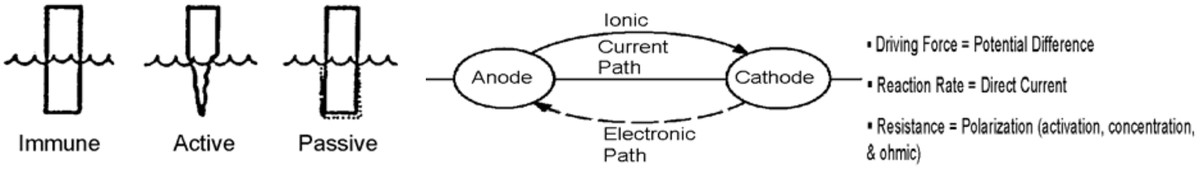


Figure 3 – Sketches of the three behaviors of metals in an environment and the four requirements of a corrosion cell.

The four requirements of a corrosion cell include an anode (where corrosion occurs), a cathode (where a reduction reaction occurs), an electronic current path through the metal, and an ionic current path through the environment. The driving force for corrosion is the potential difference between the anode and cathode. The corrosion rate is proportional to the magnitude of current flowing through the corrosion cell. The total of all resistance elements around the cell will determine the magnitude of current for a given potential driving force. As the resistance increases, the corrosion current decreases. So for corrosion protection, the strategies are to favor immune or passive behavior, lower the potential difference and increase the cell resistance.

Figure 4 maps the regions of corrosion, immunity and passivity for iron depending on the oxidizing/reducing power (potential) and acidity/alkalinity (pH) of the environment. Iron is immune at reducing potentials (green, lower portion of the diagram) and has two corrosion regions (red), one for oxidizing acidic conditions (low pH) and another for highly alkaline conditions (high pH). There is a large region of passivity (blue) for mildly alkaline, oxidizing conditions. Many soils have conditions in the acidic corrosion zone.

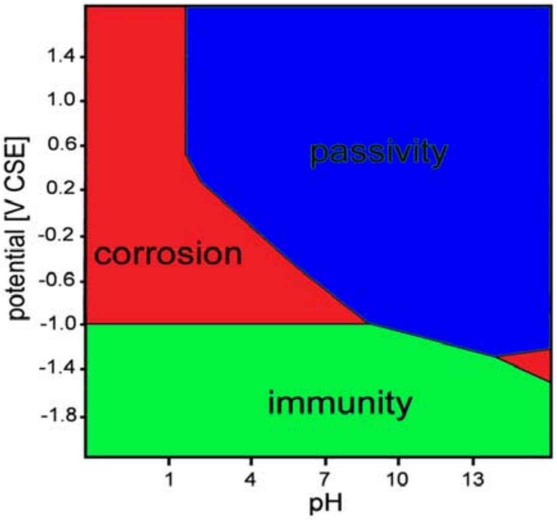


Figure 4 – Map of the regions of corrosion, immunity and passivity for iron depending on the oxidizing/reducing power (potential) and acidity/alkalinity (pH) of the environment.

Figure 5 shows strategies to protect iron exposed to corrosive conditions at "X" on the potential-pH diagram. A common mitigation method is to apply cathodic protection indicated by arrow B, where iron is moved from a corrosion region to an immune region by applying a cathodic current to the iron. In addition to the shift in potential, a result of applying cathodic current is the environment at the steel surface becomes more alkaline. So another major effect of cathodic protection is to move the iron from an active to a passive region. Too strong alkalinity can be dangerous and shift iron into the alkaline corrosion zone.

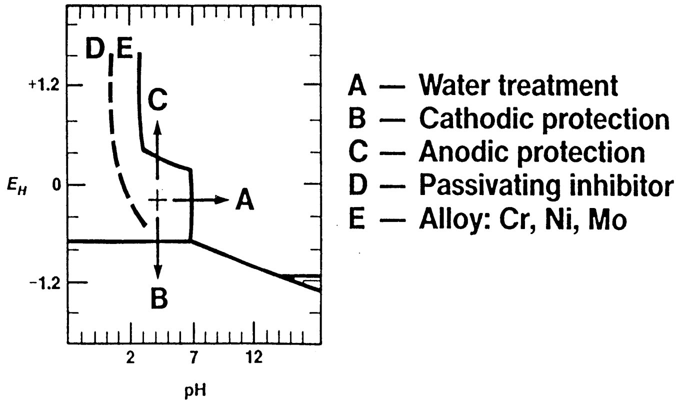


Figure 5 – Strategies to control corrosion of iron exposed to corrosive conditions “X”.

For this study, we are concerned with the effects of AC-induced currents on the corrosion behavior of the steel pipeline (iron). The protected steel is either passive or immune. Some ways that the AC current could cause damage are

-damage the protective passive film by favoring a non-protective film
-generate high levels of alkalinity to move steel into the corrosion region
-shift the potential to non-protective regions

Moreover, it is known that corrosion product films can have semiconductor properties and therefore modulate and rectify AC currents as they pass from soil to metal. The resulting rectified current can have a sizeable DC component whose magnitude and direction depend upon the AC level and properties of the metal/corrosion product junction. **Figure 6** shows the DC and AC components of a complex waveform.

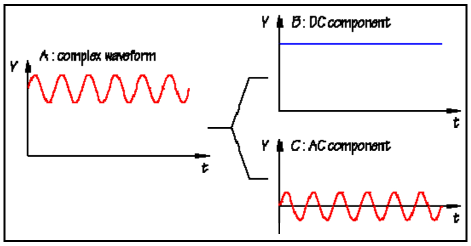


Figure 6 – A complex wave form can be described as a combination of DC and AC components

Additional processes may contribute detrimental effects of AC-Induced currents as well, e.g. kinetic and transport effects, agitation of electrolyte, and shifts of surface energies.

Experimental Program for AC-Induced Corrosion

The experimental program is designed to examine the effects of Alternating Current (AC) induced corrosion, AC/DC effects, and interactions with cathodic protection under controlled laboratory conditions. The project tasks include

-- Design and construct an apparatus for controlled AC and DC exposures
-- Experimental examination of controlling parameters on AC-Induced corrosion, e.g. DC potential/current density, AC potential/current density, defect sizes, solution composition and exposure conditions
-- Experimental determination of the effects of AC current density on corrosion products, passive films and polarization behavior of metal/metal oxide surfaces
-- Theory and modeling of AC-induction and its effects on corrosion

-- Integration of experiments and models for increased understanding and guidance to control AC-induced corrosion, performance assessment and integrity management

The experimental set-up is shown in **Figure 7.** Levels of AC and DC can be controlled and measured independently. **Figure 8** presents an array of test methods are used to examine multiple facets of the behavior.

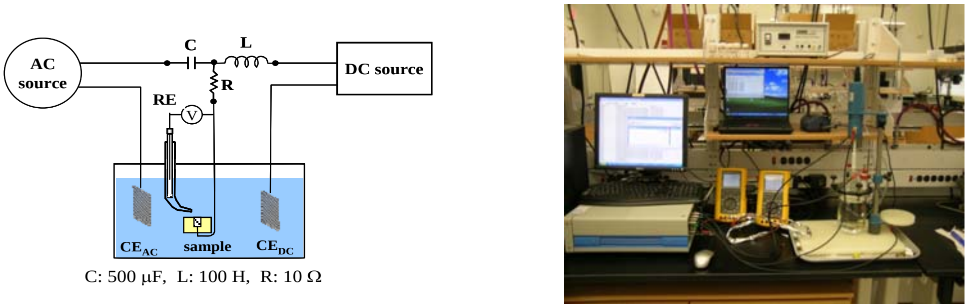


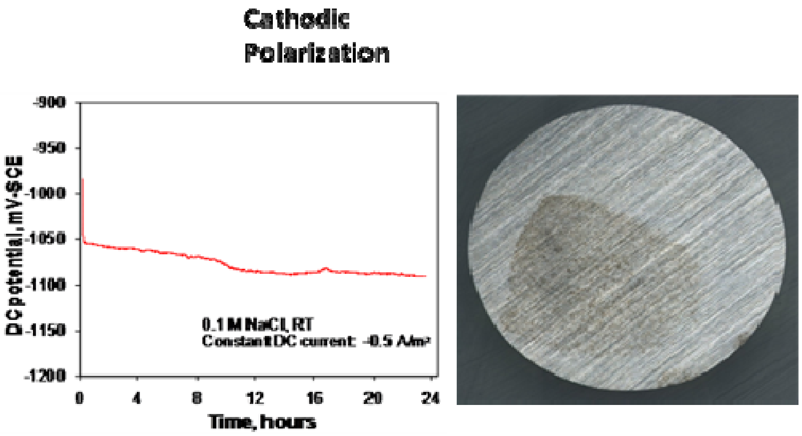
Figure 7 – Experimental set-up to independently control AC and DC and determine the effects of AC-induced corrosion.

Test Methods

- For controlling parameters: AC and DC levels, frequency, duration, environment, specimen size
- Controlled DC and AC polarizations
- Measure AC and DC potentials and currents
- To characterize films and corrosion products
  - Electrochemical impedance spectroscopy
  - I-V behavior
  - Analysis: SEM, EDS, XRD, Raman
- To monitor damage evolution
  - Metallography
  - 3D reconstruction for quantitative
- For examination electrochemical and chemical effects
  - Multi-electrode array
  - Rotating Disk Electrode

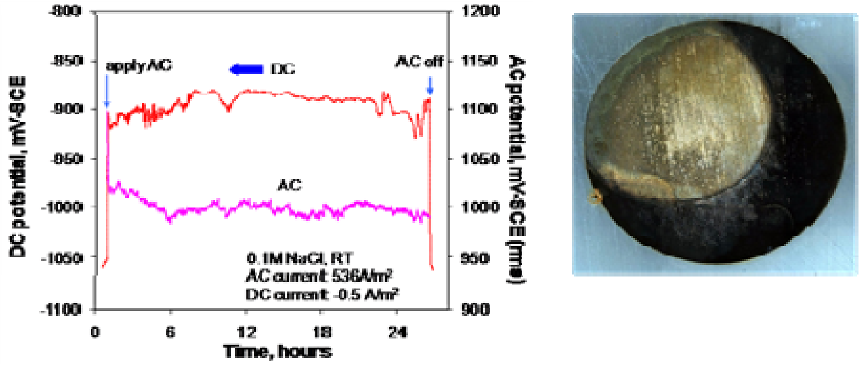
Figure 8 – Test methods to examine multiple facets of AC-induced corrosion

The results in **Figure 9 and Figure 10** show that the application of high levels of AC to cathodically polarized steel coupon can result in corrosion, whereas with no AC the specimen showed no corrosion. Initial DC polarization was -1050 mV-SCE [-970 mY-$CuCuSO_4$], which would be considered to be cathodically protected by normal practice



- 0.1M NaCl, RT
- C1018, 6.4 mm in diameter, 600 grit
- OCP for 1.5 hrs, Constant DC: -0.5 A/m², 24 hours
- No corrosion after test

Figure 9 – Steel exposed with cathodic polarization (DC) and no applied AC; the specimen showed no corrosion. whereas



- 0.1 M NaCl, RT
- C1018, 6.4 mm in diameter, 600 grit
- -0.5 A/m² DC + 1000 mV SCE (rms) AC, 24 hrs
- Black tarnish, isolated brown precipitations

Figure 10 – Steel exposed with cathodic polarization (DC) and applied AC. The steel corroded with the high level of AC applied to the cathodic polarized steel coupon.

SUMMARY

The objective is to examine the effects of AC-induced corrosion and interactions with cathodic protection under controlled laboratory conditions. The findings will better inform mitigation methods, monitoring techniques, risk assessment and integrity management. The initial work is in the context of buried pipelines that are co-located with high-voltage electrical transmission lines, however, the enhanced understanding of these effects are relevant to a broader range of applications. A description of the AC Induced corrosion risk for buries pipelines, an overview of some relevant corrosion principles, and description of the laboratory program to examine this corrosion degradation were presented.

ACKNOWLEDGMENTS

This work is associated with the Corrosion and Reliability Engineering program at The University of Akron and in participation with the DoD University Corrosion Collaboration supported by the U.S. Department of Defense Office of Corrosion Policy and Oversight. The research is administered by the US Air Force Academy under agreement number FA7000-10-2-0013.