Role of Coatings in Direct Assessment and Risk Analysis

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Calgary, Alberta

OPS Workshop on Advanced Coatings R&D, June 9-10, 2005

The Challenge and The Approach

- DA and other maintenance activities rely on our ability to identify locations for direct examination of the pipe
- Site selection is typically based on data from a number of techniques and sources, including:
  - Pipe, coating and other operational data
  - Above-ground electrical measurements
  - Site characteristics (Soil, slope, drainage, land use, depositional mode, etc.)
- But, of course, the rate and extent of external corrosion and SCC depend on the local environmental conditions <u>at</u> the pipe surface under the disbonded coating
- The challenge, therefore, is to predict conditions at the pipe surface based on above-ground measurements and observations
- The approach, a combination of experimental mechanistic studies + mathematical modeling + field studies

Recent PRCI and TCPL projects

- The Role of Coatings in the Generation of Environments that Promote Environmentally Assisted Cracking (PRCI)
  - ✓ High pH
  - ✓ Near-neutral pH
- Factors Affecting the Rate and Extent of Disbondment of FBE Coatings (TCPL)
- Laboratory and Field Investigations of the Performance of HPCC Coatings (TCPL)
- A New Technique for the Characterization of High Impedance Coatings (TCPL)
- The Effect of Degradation Treatments on CD of HPCC and Two Common Joint Coatings (TCPL – current project)

Effect of Aging Coating

Degraded pipeline coatings are generally classified as either CP shielding or permeable

Asphalt coating ⇒ more permeable with time

- more groundbeds, more current needed

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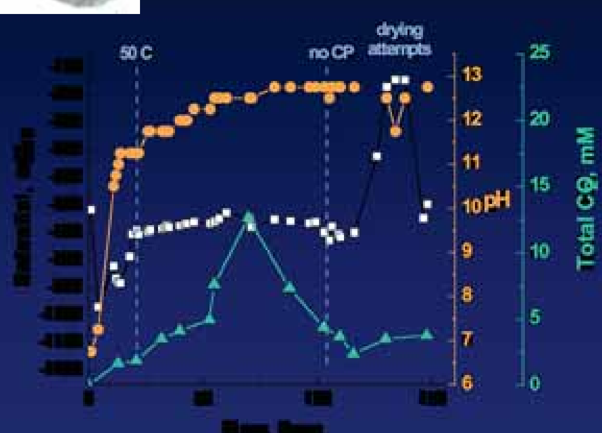
Pipe surface conditions underneath a permeable coating

- High-pH SCC is associated with concentrated electrolytes produced by evaporation or the action of CP on permeable coatings:
  - ✓ pH > 9.3
  - ✓ Potential between –600 to –750 mV_{CCS}
  - ✓ Bicarbonate concentration > 0.1 M
- To identify those coating properties and environmental conditions that can lead to the development of SCC environments under degraded coatings

Pipe surface conditions underneath a permeable coating

Asphalt coating, 50 C, -0.001 mA/cm^2



- **Outer Compartment:**
  - 0.437 M NaCl + 0.005 M $NaHCO_3$, 5% CO_2
- **Inner Compartment:**
  - distilled water
- **Could not get carbonate concentration to increase**

Pipe surface conditions underneath a permeable coating

- It seems that an extremely permeable coating with pinholes or holidays may be more conducive to high pH SCC
- Transitional conditions provide easier access of atmospheric and soil gas to the disbondment environment
- Results were modeled by the Permeable Coating Model (PCM)
- PCM simulations suggest that the rate of CO_2 generation in the disbondment, coating, and/or soil is important in generating the concentrated HCO_3^-/CO_3^{2-} conditions necessary for high-pH SCC
- CO_2 generation rate could be a useful site-selection criterion for high-pH SCC

Field study on large diameter gas lines

Worthingham, Cetiner, paper IPC04-0570, IPC Proceedings (2004)

- Despite excellent protection and long-term service, blistering and disbondment FBE have been observed in the field
- A series of pipeline excavations were performed to investigate the causes and effects of operational parameters on the long-term performance of FBE
- No correlation was found between the extent of disbondment and:
  - pipeline age
  - soil type
  - temperature
  - CP potential
  - coating adhesion
- It was concluded that disbondment of FBE did not present an integrity threat as long as CP was present
- Most of the damage likely happened during the first years of operation as determined by initial coating quality and construction damage

Laboratory study on Factors Affecting the Rate and Extent of Disbondment of FBE Coatings

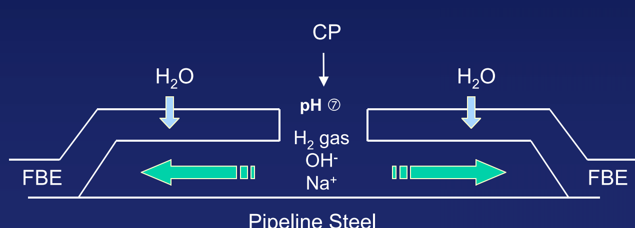
Been, Given, Ikeda-Cameron, Worthingham, paper 05138, CORROSION 2005

- Typical Cells
  - ✓ 0.4 to 6.0 mm holidays
  - ✓ 15 cm dia. coating area
  - ✓ 1.5 L volume
  - ✓ 300 cm^3 sand (to restrict mixing)
- Solutions:
  - ✓ Fresh Water
  - ✓ Salt Slough
  - ✓ Sand
  - ✓ Clay
- -0.85 to -3.0 V
- RT and 60 C
- 1 - 18 months
- Measurements included potential, current, EIS, CD area

Rate-of-disbondment-controlling factors

- An increase in pH at the holiday site as a result of cathodic reduction reactions
- High pH environment will attack the coating / metal bond
- Rate of disbondment controlled by:

1. The creation, diffusion and migration of hydroxyl ions
2. Movement of cations to the coating/metal interface
3. The diffusion of water molecules through the coating



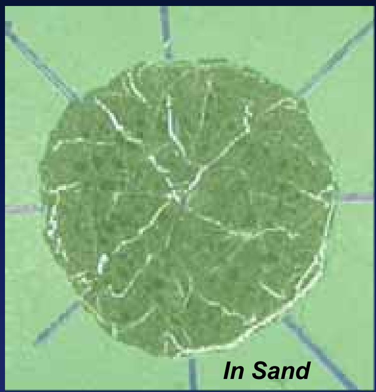
Effect of 60 C Temperature

- A 60 C temperature increased the coating permeability, where the passage of water and current through the coating was facilitated by high osmotic pressure gradients
- Blister formation may result in continuous disbondment with blisters turning to new pinholes


In Salt Slough

Effect of –3.0 V_{CCS} CP potential

- A high CP potential can have the same effect as high T in very low ionic strength media → high osmotic gradient
- The appearance of dark spots underneath the disbonded coating in sand at –3.0 V_{CCS} and RT


In Sand

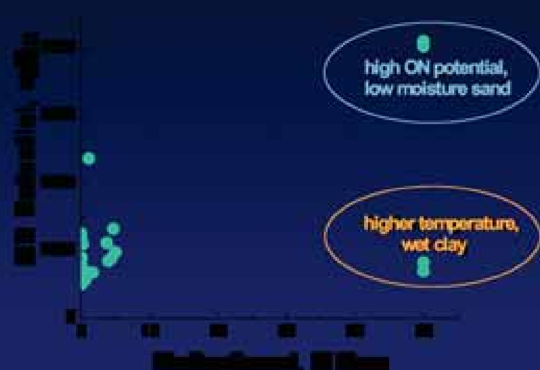
Implications to FBE Disbondment in the Field

Summary of conditions resulting in no further disbondment growth or continuous growth in the presence of a defect

Conditions				Observed Behavior
Potential	Temperature	Ionic Strength	Duration	Disbondment
-1.5 V_{CCS}	RT	all		no further growth
	60	Intermediate	3-4 months	
			> 6 months	continued to grow
		Low or high		
-3.0 V_{CCS}	60	Clay		continued to grow
	RT	Low		
		Intermediate and high		growth may level off

Implications to FBE Disbondment in the Field

- Correlations of disbondment area with T and V were not observed in the field study
- Consideration of multiple parameters may provide further insight
- In the field, all operating conditions should be considered, including upset conditions

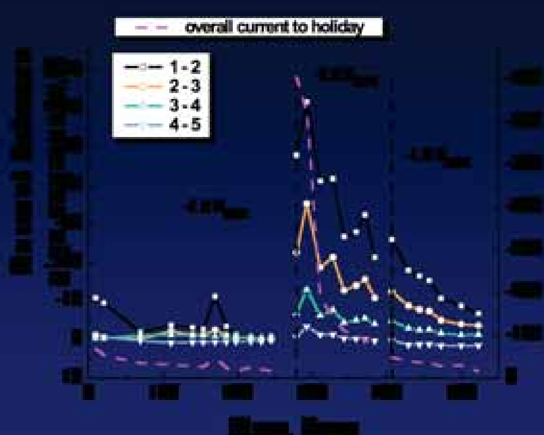


- The pipe will remain protected in the presence of CP and blistering and coating disbondment does not present an integrity threat to a pipeline

Pipe surface conditions underneath a shielding coating

- Dilute near-neutral pH SCC environment, CO_2
- 3 soils in 3 Plexiglas soil boxes
- Exposed for ~18 months
- Anaerobic chamber: **5% CO_2 / N_2**
- 3 PE coated CS pipe assemblies in each box
- 1 cm^2 holiday was cut into the coating
- CP potential was applied
- Measurements included potential, current along the pipe assembly, pH and dissolved CO_2.

Pipe surface conditions underneath a shielding coating



In Clay till

- Current reaching the steel decreased as a result of deposit formation at the holiday site (higher local pH)
- The pH tended to stabilize at near-neutral pH values

Pipe surface conditions underneath a shielding coating

- Near-neutral pH SCC environments are supported by shielding coatings and intermediate conductivity soils:
  - A high conductivity soil (clay till) provides better current penetration, which results in a slightly higher pH → less susceptible to NNpH cracking
  - A soil with a low carbonate content (sand) has a low buffering capacity and applied current increases the pH
- Results modeled by TECTRAN (SWRI)
- TECTRAN simulations suggest that it is necessary for CO_2 to permeate through coating to maintain near-neutral pH at tip of disbondment
- Coating CO_2 permeability, soil conductivity, carbonate concentration, and drainage could be used as site-selection criteria for near-neutral pH SCC

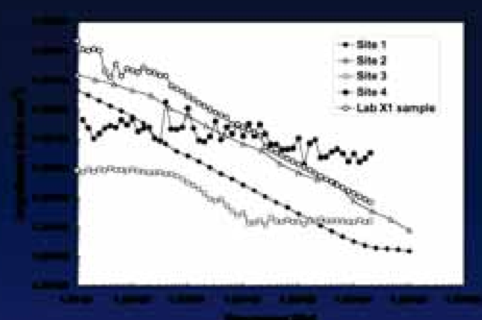
The performance of HPCC coatings

- Interested in long-term performance in the field
  - Standard QA/QC tests do not indicate long-term performance
  - Instead, we have used a combination of:
    - lab tests with simulated field exposure (impact damage + 60 C hot water or microbially active soil exposure + CD)
    - field measurements on HPCC exposed to service conditions for 11 years
  - Developed new impedance-based technique for studying the dielectric properties of high impedance coatings (EIS*Plus*)
- Laboratory Results:
  - A combination of impact and environmental exposure gave greater disbondment radii than without degradation treatments
  - Standard CD disbondment tests at 65 and 95 ^{o}C were more severe yet

Assessing Coating Condition

- Visual inspection and holiday detection
- Electrochemical Impedance Spectroscopy (EIS) can be used to assess coating condition

Impedance and Pipeline Coatings



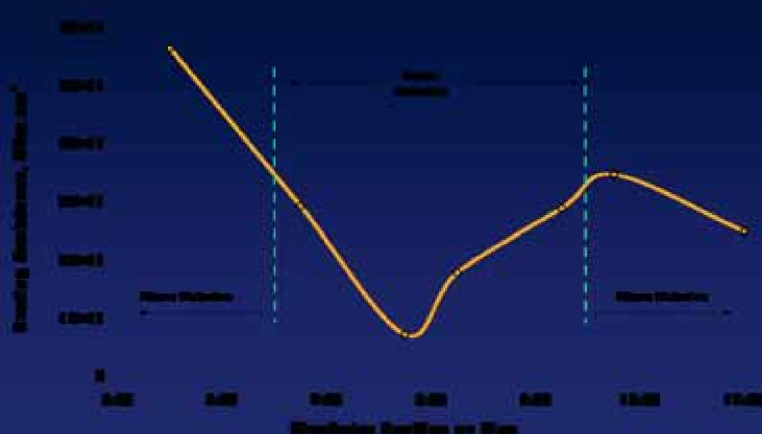
excellent coating		good coating		coating with pinholes			poor coating with holidays	
	10^9		10^7		10^5	10^4		characteristic coating impedance ($\Omega.cm^2$) at 0.1 Hz

Inspection of excavated HPCC coated pipe using EISPlus

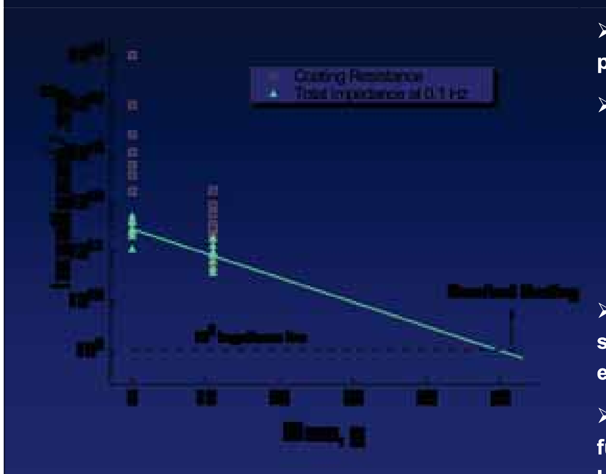
- dielectric interface enhances the capabilities of the FRA to yield valid low frequency data
- 2-electrode system
- no liquid electrolyte
- EIS*Plus* measurements were made
- Belt can be replaced with a magnet
- HPCC coating was in excellent condition after 11 y of service

Inspection of excavated HPCC coated pipe using EISPlus

- **EIS*Plus* measurements were obtained around the circumference of the pipe**
- **There may have been some damage at the 12:00 0’clock position**



Prediction of coating condition into the future



- Impedance of HPCC coated pipe extrapolated into the future
- Assumptions:
  - lab data represents initial data
  - field data represents 11 y data
  - coating degradation is linear
- Actual life will be affected by service temperature and environment
- Projection of the data into the future requires additional data at longer time intervals

Summary

- Combination of mechanistic studies + field studies + mathematical modeling results in an understanding of factors affecting coating performance and a better understanding of coating performance in the field.
  - → Improved site selection for maintenance and direct assessment
  - → Will assist in risk analysis