John Fildes, Ph.D.
Solution Engineering Group
SolutionEngineering.com
jfildes@SolutionEngineering.com
(331) 302-5521

Corrosion and Coatings Failure Analysis

Dr. John Fildes has conducted electrochemical studies including ones for corrosion that span the beginning of his career at Borg Warner's Corporate Research Center through his most recent research under funding by the Army. Although not a litigation-related investigation, the problem being tackled and the approach, techniques, and outcomes described herein are exactly what would occur in litigation-related situations.

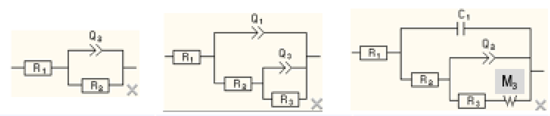
Background

Corrosion engineering provides guidance on the selections of metals to resist corrosion but does not explain why corrosion occurred. Corrosion testing that exposes a sample to an environment with periodic inspection can screen corrosion resistance but is limited for corrosion failure analysis because it may not precisely identify the onset of corrosion and it does not offer insight as to the mechanism by which a coating failed or corrosion occurred. Electrochemistry is required to gain more insight.

Electrochemistry provides the underpinnings for corrosion science and the means to effectively determine the cause and origin of corrosion and coating failures. There are several electrochemical techniques to measure corrosion rates, which differ in their complexity, the equipment needed, the mathematical methods used for analyzing the data, and their effectiveness in different situations. Sometimes these techniques are complementary, and sometimes certain techniques are not applicable such as using dc methods for painted metals.

Electrochemistry may be complex, but the outcome can be easy to understand and provides compelling insight as to the reason for corrosion or coating failure.

The following coating failure analysis results were obtained by the electrochemical methods described on the next page. Electric circuit models were obtained for bare steel and for the same steel with two different types of protective coatings. The table below the models shows (1) the corrosion rate (*Icorr*) from harmonic analysis, and (2) the values over time for the most relevant electrochemical circuit element (*uniformity factor* for bare metal and *diffusion resistance* for the coated samples) in each model to simplify this discussion, although values were obtained for all circuit elements and additional insight can be extracted from them.



time, hr	Bare Steel		Coating A on Steel		Coating B on Steel	
	Icorr, uA	Uniformity Factor	Icorr, uA	Diffusion Resistance, ohms	Icorr, uA	Diffusion Resistance, ohms
1.4	16.3	0.71	1.1		0.2	
17.5	14.0	0.64	7.6	687	0.4	52635
23.25	16.9	0.62	14.9	338	0.6	49418
41.5	19.3	0.60	13.5	171	0.4	52635
47	32.0	0.59	17.8	142	0.9	36705
68			42.5	105	0.8	35490
71.5					1.1	41984
90.5					1.6	18488
95					1.3	16837
162					2.4	23933
164					2.4	28543

Uncoated steel has the simplest model and the highest corrosion rate. The uniformity factor characterizes if corrosion is uniform. A value of 1 is uniform, and lower values are increasingly non-uniform. The results establish that this steel does not corrode uniformly, which is consistent with this steel's metallurgy.

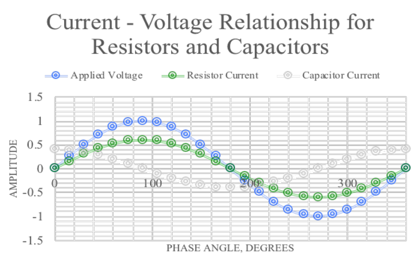
Coating A is of a type that builds up with a columnar structure. The model shows that a circuit element representing a diffusion process is needed and this indicates that the columns form channels that allow water and sodium and chloride ions to reach the metal, which is represented by the value of the diffusion resistance. A larger diffusion resistance indicates less penetration of water and ions to the metal, which should result in a lower corrosion rate. This coating initially provides some corrosion protection, but by allowing access of water and ions to the metal, corrosion occurs, which destroys the integrity of the coating until the corrosion rate is similar to bare steel.

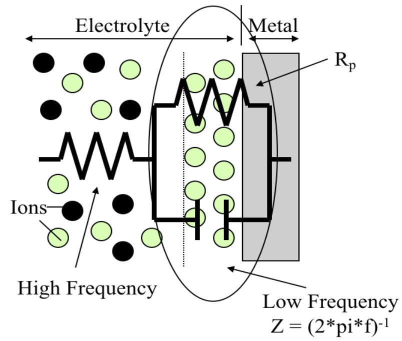
Coating B is a very thin, dense, and durable coating known to provide excellent corrosion protection. The results show why this is so. This coating provides excellent resistance to penetration of water and ions as indicated by very high diffusion resistance. This protects the metal from corrosion for a lengthy period of time, which is essential for a coating's durability.

John Fildes, Ph.D.
Solution Engineering Group
SolutionEngineering.com
jfildes@SolutionEngineering.com
(331) 302-5521

Electrochemical Impedance Spectroscopy (EIS)

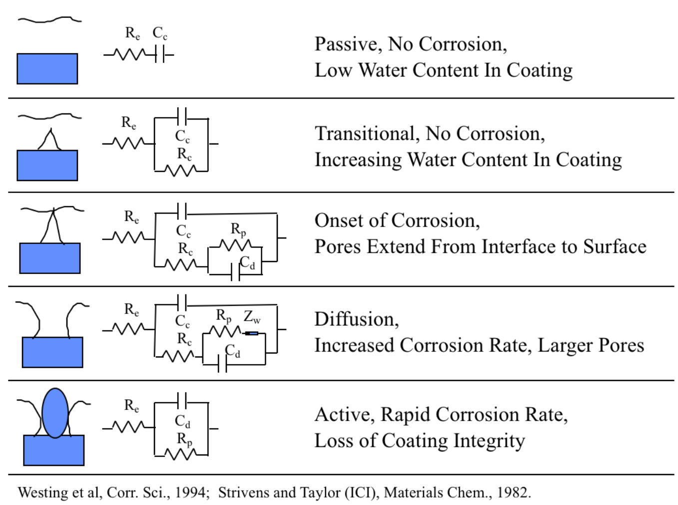
EIS involves applying an alternating voltage to a sample and this causes an electric current to flow due to various electrochemical processes such as corrosion. The electrochemical processes act like electric circuit elements such as resistors and capacitors so the current that flows changes in its magnitude and phase relative to the applied voltage as the coating takes up water, degrades, and allows corrosion to begin.





The rate of chemical processes sets limits on the frequency that each process can follow, so the voltage-current data is collected over a wide range of frequencies, allowing the various processes to be measured independently. The voltage-current data is modeled as an electrical circuit of resistors, capacitors, and other elements, which is fit to the data using non-linear least squares. Each element of the circuit models a particular chemical process as shown above.

The result of an EIS test of a painted metal in a salt solution often follows a progression of models as follows from top to bottom.



Westing et al, Corr. Sci., 1994; Strivens and Taylor (ICI), Materials Chem., 1982.

Dr. John Fildes has a Ph.D. in physical chemistry, a B.S. in chemistry, and he was a post-doctoral research associate in a chemical engineering department. Physical chemistry provides the scientific basis for many engineering disciplines. Thermodynamics provides the basis for metallurgy, materials science, fire and explosion science, and others. Chemical bonding provides the basis for the strength of materials and electronic materials and devices. Electrochemistry provides the basis for corrosion science, and chemical kinetics provides the basis for chemical compatibility, reactivity, volatility, and chemical processes. Dr. Fildes has conducted over $27.5 million of R&D and/or litigation-related investigations in these areas because he is well experienced in the fundamental scientific principles as well as in analytics and chemical safety. He led a large group of scientists and engineers at Northwestern University and two scientific/engineering firms licensed to practice professional and structural engineering that conducted thousands of litigation-related technical investigations, so he is also an expert in the conduct of these types of investigations.