Technical Note

Dissimilar Metals May Take Away Your Protection

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There are many different types of metals and each has desirable properties. However, when two dissimilar metals are joined to make an electrical connection there can be problems. Corrosion will begin when the connection is exposed to moisture or any other liquid acting as an electrolyte.

Corrosion is an electro-chemical process resulting in the degradation of a metal or alloy. Oxidation, pitting or crevicing, de-alloying, and hydrogen damage are a few descriptions of corrosion. Most metals today are not perfectly pure and consequently, when exposed to the environment, will begin to exhibit some of effects of corrosion.

Aluminum, as used in PolyPhaser's coaxial protectors, has an excellent corrosion resistance due to a 1 nano-meter thick barrier of oxide film that instantaneously forms on the metal. Even if abraded, it will reform and protect the metal from any further corrosion. Any dulling, graying, or blacking that may subsequently appear is a result of pollutant accumulation.

Normally, corrosion is limited to mild surface roughening by shallow pitting with no general loss of metal. An aluminum roof after 30-years only had 0.076mm (0.003 inch) average pitting depth. An electrical cable lost only 0.109mm (0.0043 inch) after 51-years of service near Hartford, Connecticut. Copper such as C110 used in our equipment shelter coax cable entrance panels has been used for roofing, flashing, gutters, and downspouts. It is one of the most widely used metals for atmospheric exposure. Despite the formation of the green patina, copper has been used for centuries and has negligible rates of corrosion in unpolluted water and air. At high temperatures some copper alloys are better than stainless steel.

If copper were joined to aluminum or copper to galvanized (hot dipped zinc) steel with no means of preventing moisture from bridging the joint, corrosion loss will occur over time. This is the accelerated corrosion (loss) of the least noble metal (anode) while protecting the more noble (cathode) metal. Copper, in this example, is the more noble metal in both connections. (See the Noble Metal Table for a ranking of commonly used metals.)

Where the connection is with galvanized steel, the zinc coating will be reduced allowing the base steel to oxidize (rust), which in turn will increase the resistance of the connection and eventually compromise the integrity of the mechanical structure.

The aluminum will pit to the copper leaving less surface area for contact. The connection could be become loose, noisy, and even allow arcing. This type of corrosion problem can be prevented by using a joint compound, covering and preventing the bridging of moisture between the metals. The most popular compounds use either zinc oxide or copper particles embedded in silicone grease. As the joint pressure is increased, the embedded particles dig into the metals and form a virgin low resistance junction void of air and its moisture.

The use of a joint compound is the recommended means for joining our coaxial protectors to our bulkhead panels for non-climate controlled installations. We have tested this compound with a "loose" 1 square-inch (6.5 sq-cm) copper to copper joint and have found it to handle a 25,500 ampere 8/20 waveform surge with no flash over and no change in resistance (0.001 ohms). We have even moved the loose joint before and after the surge and experienced no change in resistance.

The connection of a copper wire to galvanized tower leg should be avoided even if joint compound is used. The primary problem here is the low surface-area contact of the round wire with the (round) tower leg. Consider using a PolyPhaser TK series stainless steel interface clamp.

The TK clamp will help increase the surface area of the connection as well as provide the necessary isolation between the dissimilar metals. Use joint compound on exposed applications of the TK clamps. For an even more effective connection, use copper strap in place of wire with the TK series clamp.

Noble Metal Table Discussion

Some Galvanic Corrosion matrices use the standard, defined, Galvanic Series by listed EMF (see below). The rate of (accelerated) corrosion is determined by the difference in EMF Volts. Even Copper and Copper Nickel alloys will corrode when acting as a cell with a controlled electrolyte, but very slowly. As the delta EMF numbers between metals spreads out, corrosion will predictably accelerate if the electrolyte is always the same. The +0.6 Volts usually quoted is determined by agreement ("with chemists) about how much corrosion is acceptable over time with the published standard Galvanic series.

Quote from BUREAU OF RECLAMATION FACILITIES INSTRUCTIONS, STANDARDS, & TECHNIQUES Volume 4 - 5 "USE OF CATHODIC PROTECTION OF BURIED AND SUBMERGED METALS IN CORROSION PREVENTION IN ELECTRIC POWER SYSTEMS"

"The galvanic series should not be confused with the electromotive series (EMF) used by chemists. The latter is referred to standard conditions which rarely occur in nature, and the order of the metals in the electromotive series does not exactly coincide with that of the galvanic series."

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When dissimilar joints are subjected to environments that can affect the electrolyte (e.g. acid rain pH 4.5), the corrosion rate can accelerate. Since rain water now has a "normal" (by consensus) pH of 4.5 - 5.6 (Google) it can also effect the overall corrosion rate, but not in the exposed joint if sealed by a proper joint compound. When dissimilar joints are in the earth, the accelerated corrosion rate is determined by rainfall and the amount of salts and minerals resident in the soil where the joint is buried.

To safely compensate for a variable electrolyte in an exposed or buried dissimilar metal joint, we use 0.3 Volts to determine if the metals are too dissimilar to be bonded.

A correlation has been established with the resistivity (measured in Ohm-cm) of the soil. (see below document paragraph 2.6). This is a measurement done on the soil before calculating the amount of copper, and how it must be configured to meet the target "fall of potential" impedance (in Ohms) for the completed site ground system. The lower the resistivity, the more corrosive the "electrolyte" becomes, the greater the accelerated corrosion.

Unfortunately, the better your ground system is (lower Ohms), the faster the system corrodes unless the ion flow is distributed over a large area (radials and rods).

	Magnesium	Aluminum	Zinc	Iron	Cadmium	Nickel	Tin	Lead	Copper	Silver	Palladium	Gold
MAGNESIUM	0.00	-0.71	-1.61	-1.93	-1.97	-2.12	-2.23	-2.24	-2.71	-3.17	-3.36	-3.87
ALUMINUM	0.71	0.00	-0.90	-1.22	-1.26	-1.41	-1.52	-1.53	-2.00	-2.46	-2.65	-3.16
ZINC	1.61	0.90	0.00	-0.32	-0.36	-0.51	-0.63	-0.64	-1.10	-1.56	-1.75	-2.26
IRON	1.93	1.22	0.32	0.00	-0.04	-0.19	-0.30	-0.31	-0.78	-1.24	-1.43	-1.94
CADMIUM	1.97	1.26	0.36	0.04	0.00	-0.15	-0.27	-0.28	-0.74	-1.20	-1.39	-1.90
NICKEL	2.12	1.41	0.51	0.19	0.15	0.00	-0.11	-0.12	-0.59	-1.05	-1.24	-1.75
TIN	2.23	1.52	0.63	0.30	0.27	0.11	0.00	-0.01	-0.47	-0.94	-1.12	-1.64
LEAD	2.24	1.53	0.64	0.31	0.28	0.12	0.01	0.00	-0.46	-0.93	-1.11	-1.63
COPPER	2.71	2.00	1.10	0.78	0.74	0.59	0.47	0.46	0.00	-0.46	-0.65	-1.16
SILVER	3.17	2.46	1.56	1.24	1.20	1.05	0.94	0.93	0.46	0.00	-0.19	-0.70
PALLADIUM	3.36	2.65	1.75	1.43	1.39	1.24	1.12	1.11	0.65	0.19	0.00	-0.51
GOLD	3.87	3.16	2.26	1.94	1.90	1.75	1.64	1.63	1.16	0.70	0.51	0.00

(Left axis label: LESS NOBLE ↑ — Bottom axis label: ← LESS NOBLE)

Noble Metal Table: Accelerated corrosion can occur between unprotected joints if the algebraic difference in atomic potential is greater than ± 0.3 volts.

Galvanic-type corrosion

2.1. Description.- Galvanic-type corrosion occurs as the result of the tendency of metals to revert to their natural state. If this is to occur, the metals must be so arranged as to form a complete cell, which may be termed a battery or corrosion cell or galvanic cell. Since corrosion may stem from other causes, it is important to note that the type described as galvanic may be recognized from the fact that the cell provides the forces causing corrosion, rather than external currents, etc. The cell is comprised of an anode and cathode immersed in an electrolyte. When the anode and cathode are metallically connected (as when a wire is connected across the terminals of a battery), current flows and corrosion of the anode occurs. When the anode happens to be a metallic part of a structure, piping, or cable system, severe damage may result.

2.2. Natural corrosion cells.- The environment form any electrical power structures provides conditions favoring formation of natural corrosion cells. The metal or metals of a structure serve as anode, cathode, and the necessary metallic conductor between the two. Water, either as such or as moisture in soil, provides the electrolyte required to complete the cell circuit. Such cells develop their driving force or electrical potential from differing conditions at the interfaces between metal and electrolyte of the anode and cathode.

These differences fall into three categories:

(a) Dissimilar metals comprising the anode and cathode

(b) in-homogeneity of a single metal, which causes one area to be anodic to another area

(c) inhomogeneity of the electrolyte.

The following are a few of many possible examples in which the essential requirements of a complete cell are satisfied in a structure.

(a) Iron will be anodic to copper ground matsor to brass bolts or other brass parts.

(b) An iron plate having some mill scale present may rust because the iron is anodic to the mill scale.

(c) An apparently homogeneous iron plate may rust because tiny areas of the surface contain impurities or grain stresses which cause them to be anodic to other areas of the surface.

(d) Weld areas of a welded pipe may rust because the weld metal is of different composition, and may contain impurities, or may cause stress which make it anodic to nearby metal areas.

(e) Corrosion may be observed on the bottom of a pipeline while the top remains nearly undamaged. This may be attributable to higher oxygen concentration in the soil moisture (electrolyte) at the top of the pipe, leaving the bottom anodic. The soil being undisturbed at the bottom of the pipe provides a lower oxygen content and a lower resistance to current flow than is present in the backfill covering the top of the pipe.

(f) Exposed iron areas in contact with concrete. Encased or embedded iron may rust because the concrete creates a different and special electrolytical environment which causes the exposed iron to become anodic to the embedded iron.

2.3. Factors influencing corrosion rates.-

From the above examples and the many other environmental differences which could be visualized, it might appear that almost no metalwork could survive burial in soil or immersion in water. Such is not the case because the rate at which a cell functions and corrosion occurs is controlled by several factors; these factors may virtually halt the cell action. Some of the more important factors affecting corrosion are inherent or associated with the metal itself, such as the effective potential of the metal in the solution, physical and chemical homogeneity of the metal surface, and the inherent ability of the metal to form an insoluble protective film. Environmental factors affecting corrosion rates are formation of protective coatings on metal, temperature, influence of oxygen in the electrolyte, effect of electrode potential, and others. No attempt has been made to list these factors in the order of their importance. The environmental aspect of corrosion is the more unpredictable and one that makes it impossible to describe a single, positive method of controlling a specific corrosion problem without detailed investigation.

2.4. The galvanic series.- The differing vigor with which different metals tend to dissolve in electrolytes provides the driving force for galvanic cells and gives rise to the galvanic series. This is a listing of metals in decreasing order of their corrosion when any two of them are the electrodes of a complete cell. That is, the metal higher on the list will be the anode and will be corroded while the lower will be the cathode and will be protected in the cell. A galvanic series tabulation developed by the International Nickel Company is shown in table 1. This series was developed by actual field and laboratory tests using electrolytes likely to be encountered under operation conditions. It takes into account that certain metals from protective oxides which cause these metals to assume more noble positions in the series than the clean metal would have. This series, then considers practical corrosion aspects as well. However, it cannot anticipate all service conditions and reversals of position which may occur. (The galvanic series should not be confused with the electromotive series (EMF) used by chemists. The latter is referred to standard conditions which rarely occur in nature, and the order of the metals in the electromotive series does not exactly coincide with that of the galvanic series.)

2.5. Use of the galvanic series.- The metals grouped together in the galvanic series create cells having low driving force (voltage) when connected together and little tendency for galvanic corrosion. Therefore, in general, they can be used in direct contact with each other without damaging effects. When coupled as a cell, two metals from different groupings create a source of potential, the amount of which is indicated by the separation between the metals on the listing. As shown in table 1, the most anodic or "least noble" metals are at the top of the list, and the most cathodic or "most noble" metals are at the bottom. It should be remembered that the series is a guide as to what can be expected and is not intended to replace actual experimental tests in assessing specific problems under consideration.

2.6. Characteristics of soil which affect the corrosion rates.

Three prime factors that affect the severity and acceleration of corrosion of metals in soil are moisture, salt and/or acid content, and aeration. Corrosion, as mentioned before, is an electrochemical process. It has been found that the chemical approach in analyzing soil corrosiveness is too involved to be practical. However, a correlation exists between what is called "soil corrosivity" and "soil electrical resistivity." Soil moisture in conjunction with soluble soil salts constitutes the electrolyte of the corrosion cell and is, therefore, the cell's internal circuit. Consequently, the higher the resistance of the soil electrolyte, the lower the rate at which the corrosion cell functions. The soil resistivity is especially indicative of soil corrosivity in alkaline soils and is useful as a guide in acid soils. The commonly used unit of soil and water resistivity is the ohm-centimeter, which is the resistance in ohms of a 1-centimeter cube of the material in question measured between two opposite, parallel faces. In considering soil as an electrolyte, the salt and water content determines the cell resistance. The moisture content will normally change radically with seasons. This one factor alone can give soil resistivity variation from a minimum of 2500 to a maximum of 10 000 ohm-centimeters, where extreme dryness occurs.

2.7. Soil resistivity.

In correlating the resistivity readings obtained with expected corrosion action, the following soil resistivity values can be used as a guide

(a) Values of 1000 ohm-centimeters or lower indicate very corrosive conditions.

(b) Values from 1000 to 5000 ohm-centimeters usually indicate moderately corrosive conditions.

(c) Values from 5,000 to 10,000 ohm-centimeters indicate mildly corrosive conditions.

(d) Values above 10,000 ohm-centimeters indicate slightly corrosive conditions.

Values between the 1,000 and 10,000 ohm-centimeters should be compared to those in immediately adjacent sections of the structure. For example, if resistivity readings are running at 10,000 ohm-centimeters and there is in a short distance a drop to 2,000 ohm-centimeters, corrosion is likely to occur in the 2000-ohm-centimeter area. These areas of low resistivity are referred to as "hot spots." Also, changes in high soil resistivity can sometimes be conducive to corrosion; for example, a change from 10,000 to 100,000 ohm-centimeters.

2.8. Characteristics of water which affect the corrosion rates.-

The effect of the electrolyte on the corrosion rate depends on the temperature, on the dissolved oxygen concentration, and on the nature and concentration of the dissolved salts which may or may not tend to make the water scale forming. The interrelationship of these factors with respect to corrosion is not fully understood. Therefore, we do not have firm and specific criteria for evaluating the corrosion property of water on the basis of its chemical characteristics.

2.9. Polarization.-When corrosion occurs, chemical reactions take place at the electrodes. These reactions may "plate out" the reaction products on the electrodes; for instance, hydrogen ions may be converted to uncharged hydrogen or calcium ions which ultimately may be converted to a calcium carbonate scale on the cathode. Such deposits often act to increase the electrical resistance of the internal circuit, with the result that the flow of current and the corrosion rate are reduced. Opposing chemical reactions tend to depolarize. For instance, oxygen in the electrolyte may react with hydrogen to form water. This reverse reaction tends to negate the beneficial effects of polarization.

2.10. Minimizing galvanic corrosion in design.-

Galvanic corrosion can be minimized in design. Corrosion engineers have found the following practical rules invaluable in this respect:

(a) Select combinations of metals which will be in electrical contact from groups as close together as possible In the galvanic series.

(b) Electrically insulate from each other metals from different groups, wherever practical. If complete insulation cannot be achieved, paint or plastic coating at joints will help.

(c) If you must use dissimilar materials well apart in the series, avoid joining them by threaded connections as the threads will probably deteriorate excessively. Brazed or thermit joints are preferred, using a brazing alloy more noble than at least one of the metals to be joined.

(d) Avoid making combinations where the area of the less noble, anodic metal is relatively small compared with the area of the more noble metal.

(e) Apply coatings with judgment. Example: Do not paint the less noble metal without also painting the more noble; otherwise, greatly accelerated attack may be concentrated at imperfections in coatings on the less noble metal. Keep such coatings in good repair.

(f) Consider use of cathodic protection.

3. Stray current corrosion

3.1. Description.

Stray currents which cause corrosion may originate from direct-current distribution lines, substations, or street railway systems, etc., and flow into a pipe system or other steel structure. Alternating currents very rarely cause corrosion. The corrosion resulting from stray currents (external sources) is similar to that from galvanic cells (which generate their own current) but different remedial measures may be indicated. In the electrolyte and at the metal-electrolyte interfaces, chemical and electrical reactions occur and are the same as those in the galvanic cell; specifically, the corroding metal is again considered to be the anode from which current leaves to flow to the cathode. Soil and water characteristics affect the corrosion rate in the same manner as with galvanic-type corrosion. However, stray current strengths may be much higher than those produced by galvanic cells and, as a consequence, corrosion may be much more rapid. Anotherdifference between galvanic-type currents and stray currents is that the latter are more likely to operate over long distances since the anode and cathode are more likely to be remotely separated from one another. Seeking the path of least resistance, the stray current from a foreign installation may travel along a pipeline causing severe corrosion where it leaves the line. Knowing when stray currents are present becomes highly important when remedial measures are undertaken since a simple sacrificial anode system is likely to be ineffectual in preventing corrosion under such circumstances.

3.2. Detection of stray currents.

Detection of stray currents which may be causing corrosion is somewhat involved and involves technical operations for which field staffs are usually not equipped. Their presence may be suspected when large direct-current installations are in the vicinity of the structure experiencing corrosion and especially when very rapid corrosion occurs. The services of a corrosion specialist should then be requested.

Please contact us for questions or further information on this topic.

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