Galvanic Corrosion Acting on Aluminum

at Magnetic Shield Penetrations

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Author Note

This document's accuracy has been thoroughly evaluated to the best of my abilities based on my prior studies and current data analysis. However, some sources may have been unintentionally omitted due to discrepancies in what is considered common knowledge and what is applied research. For comments or citing recommendations please email me at Jferro@vitatech.net

Abstract

Dissimilar metals in electrical contact will corrode faster than any individual metal alone in an environment. This is caused by differing chemical reduction potentials of each metallic surface, that is, how easy it is for that material to transfer ions to or from solution to the metal surface. In magnetically shielded environments, aluminum plate is commonly used. In such cases, it is necessary for utilities to penetrate the shielded and often differing metallic components are used which come in contact with the aluminum plate. Therefore, the purpose of this study is to analyze the corrosion potential (Real Cell Potential) of steel, copper, and brass in relation to aluminum. The findings will be useful in determining the best material to use for utility penetrations in aluminum magnetic shielding systems.

Keywords: Galvanic, Corrosion, Penetrations, Magnetic, Shield, Aluminum, Dissimilar metals

Introduction

This study analyzes the potential for increased corrosion rates as a result of creating metal to metal bonds with dissimilar metals. Of specific interest is the increase in corrosion due to pipe penetrations through an aluminum magnetic shield. It is desired to find the pipe penetration that has the least potential for increasing corrosion of the magnetic shield around the penetration. Galvanic corrosion is caused by electrically connecting two dissimilar metals in the presence of an electrolyte so that both electrons and ions may be transferred in the system. As a result of electrons and ions being transferred one metal is preferentially corroded and degraded in the system *(Callister)*. The driving force for this process is electrical potential generated by differing reduction oxidation reactions that are occurring at the cathode and anode. This potential is known as the real cell potential of the system. This generated electrical potential then accelerates the rate of corrosion at the anode material *(Chang)*. It is not desirable for this process to take place because it leads to an increased rate of material degradation and a reduction of system service life.

This is of particular importance because magnetically shielded enclosures require varying types of utility penetrations. It is common for these penetrations to be comprised of dissimilar metals which may come in direct electrical contact with the magnetic shielded. This contact can be in the form of pipe sleeves, brackets, hanging hardware, etc. The degradation of the aluminum shielding has two major negative side effects. First, the degradation of the aluminum shielding will reduce the mechanical properties of the shield due to loss of material. Second, as the degradation proceeds it is likely that rust will develop resulting in perforations in the shield which will reduce its effectiveness.

Common materials for penetration components include steel, copper, and brass. In this study, the increased corrosion rate of the magnetic shield caused by electrical contact with these materials will be assessed. Specifically, the Real Cell Potential is defined here as the cell potential that would be observed at any specific environmental conditions will be described. This information will assist in selecting appropriate metals for use in utility penetrations made in aluminum magnetic shielding systems.

Methods

The first step in the process, of determining which pipe fittings would have the least chance of accelerating corrosion of the aluminum magnetic shield, was to look up each materials standard reduction potential. Once the standard reduction potentials for each material was found the standard cell potential was calculated. Due to the lack of key system information, the cell potential under nonstandard conditions (real cell potential) could not be calculated and is only evaluated empirically. As a result, of the non-analytical evaluation of the real cell potential, a mass corrosion rate was also evaluated empirically. This information was then used to evaluate the material that is best suited for the utility penetrations in an aluminum magnetic shielding system.

Materials

Three aluminum alloys and three types of metallic pipe fittings were analyzed to determine their potential for corrosion acceleration. The grades of aluminum considered included 3003, 1100, and 6061. All three alloys of aluminum consist of 96% aluminum content and therefore was considered pure aluminum metal. Copper and steel pipe fittings also have very low levels of trace alloying materials and are taken to have the properties of the pure base metal. Brass is an alloy of copper and zinc at varying concentrations depending on the desired material properties. Due to the mixture being continuous every different grade of brass will have its own specific reaction potential therefore the standard half-cell potential of brass will be between that of copper and zinc depending on the grade.

Table 1: *Standard Reduction Potentials of Interest*

	Half-Reaction	**E°(Volts)**
Aluminum	Al^{3+} (aq) + 3e⁻ → Al(s)	
1100		-1.66
3003		-1.66
6061		-1.66
Steel	Fe^{2+} (aq) + 2e⁻ → Fe(s)	-.044
Copper	Cu^{2+} (aq) + 2e⁻ → Cu(s)	+0.34
Brass	NA	NA

Calculating Real Cell Potential

Table 1 lists the standard reduction potentials which corresponds with the reduction oxidation reactions that are occurring at each metal. To determine the voltage that would be observed, the following equation was used to relate the voltages on the table to what would be observed across a complete galvanic cell.

(1)

$$E^{\circ}_{cell} = E^{\circ}_{cathode} - E^{\circ}_{anode}$$

E°_{cell} represents the voltage over the entire cell, E°_{anode} represents the standard reduction potential at the anode, and $E^{\circ}_{cathode}$ represents the standard reduction potential at the cathode.

It is important to note that the above equation only applies to situations that are at standard conditions. For the standard reduction potentials listed in the table 1 standard conditions are 25°C, 1 atm, and 1M (Molar) concentration of metal ions at both the cathode and anode. These conditions

are not all that common so to determine what the potential would be at any given condition the following equation was used.

$$E = E°_{cell} - \frac{RT}{nF} In\, Q \; ; Q = \frac{\left[M^{n+}_{anode}\right]}{\left[M^{n+}_{cathode}\right]}$$

(2)

E°cell is the total cell potential, R is the ideal gas constant, T is the temperature, n is the number of electrons involved in the reaction, F is the faraday constant, and [Mn+] is the concentration of the metal ions at each electrode respectively. This equation is known as the Nernst equation and is used to calculate the real cell potential at any given environmental conditions. The final equation was used to fully define the rate of corrosion of any given material acting as the anode in a galvanic cell was as follows.

$$corrosion\, Rate = \frac{C_{p}*(MW/n)}{F*p}$$

(3)

Here Cρ is the current density, MW is the molecular weight of the anode in a system, n is the number of electrons involved in the reaction at that electrode, F is the faraday constant, and ρ is the density of the anode.

Results

For steel pipe fittings attached to and aluminum shield it was found that the cell potential under standard conditions is 1.22 Volts. Copper fittings attached to an aluminum shield under standard conditions has a cell potential of 2.0 Volts. These numbers can be found by using equation (1) and the values on table 1. For example aluminum steel cell potential is

$$E°_{cell} = -0.44 - (-1.66) = 1.22$$

Due to brass being an alloy there are many different kinds of brass and each one has its own standard potential. The lowest cell potential that can be hoped for would result from using brass designed for marine environments. Using these types of brass results in a standard cell potential of 1.26 Volts in the best case scenario. The worst case for brass is 1.46 volts for standard brass fittings not designed for marine use.

Discussion

As can be seen by examining the equations above the rate of corrosion observed for any given system is highly dependent on the environmental conditions that are present around the metal/metal bond. Just being in contact is not enough to cause the anode in any given system to corrode. Each situation must be looked at individually to determine the risks associated with that particular metal to metal junction.

There are some general rules that are valid for most situations and can be applied with some caution. The first rule that generally will lead to increased corrosion rates is: *increased cell potential will increase corrosion rate of the anode in the system.* The second rule that generally will lead to increased corrosion rate is: *the presence of any moisture at the metal to metal junction will increase corrosion rate of the anode in the system.* In all the situations analyzed in this paper aluminum is the anode and will be the material that is preferentially corroded due to galvanic action.

These criteria are only general and are not applicable to every situation. It is important to note that keeping the joint between the aluminum and the steel fittings dry is very important. Keeping the fittings dry will substantially reduce any corrosion that may occur so every effort should be made to eliminate temperature gradients across the shield to prevent condensation on the shield near the fittings.

The fittings that will cause the least galvanic corrosion when connected to an aluminum magnetic shield are steel fittings. Steel fittings will generate the smallest cell potential when connected to an aluminum magnetic shield. This will correspond to a smaller Real Cell Potential compared to that of copper and brass. The next best material to use is a well selected grade of brass, one that will generate a small cell potential. Out of all the materials analyzed copper generated the largest cell potential. This will lead to copper fittings generating the most corrosion of an aluminum magnetic shield. Based on this finding, copper fittings will corrode aluminum magnetic shielding at a higher rate and is not ideal for utility penetrations.

References

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