Laird

Smart Technology. Delivered.™

Corrosion of EMI Gaskets

White Paper

Table of Contents

Galvanic Corrosion

Corrosion can manifest itself in many forms. Some common forms are galvanic, pitting, and crevice corrosion. However, galvanic corrosion is the major concern in shielding applications. Galvanic corrosion is driven by the interaction of the gasket and the electronic enclosure, since in a shielded joint there are often two dissimilar materials in intimate contact.

Basic Galvanic Conditions

There are three conditions that must exist for galvanic corrosion to occur:

1. Two electrochemically dissimilar materials present
2. An electrically conductive path between the two materials
3. An ionic conduction path (typically a corrosive environment) between the materials

If any of these three conditions is missing, galvanic corrosion will not occur. If we examine each of these conditions in detail, we will not only understand galvanic corrosion, but also know how to prevent it.

Electrochemically Dissimilar Metals

Of the three conditions necessary for galvanic corrosion, the most important is the electrochemical difference between metals. Commonly available materials have different electrochemical potentials; even pure metal at the microscopic level. This is why a block of steel sitting by itself corrodes. The order in which metals will corrode is always from the most anodic (active) to the most cathodic (noble). This means that when two dissimilar metals are put together, only the more anodic metal will corrode.

This method is used extensively in preventing corrosion by plating a more anodic metal over a more cathodic metal. The more anodic metal will then sacrifice itself (corrode first) and protect the metal underneath from corrosion. This is the reason for the good corrosion resistance of zinc plated steel. Even when scratched, the zinc coating that surrounds the scratch protects the exposed steel from corroding until the zinc near the scratch is consumed.

Electrical Conduction

The second condition required for galvanic corrosion, electrical conduction, is the hardest to prevent. Metals are all good conductors of electricity, and most joints between metals are made with metal fasteners. The amount of electrical current that flows is dependent on the rate of corrosion, but in most cases is very small.

Dramatically reducing the conductivity of an electrical path between two metals has little effect on the corrosion rates except where very strong electrolytes are involved.

Generally, effective RF joints depend on having very high conductivity; therefore, reducing conductivity to decrease corrosion may greatly reduce shielding effectiveness. Some new research has produced materials that are good RF conductors, but poor D.C. conductors. These materials may be able to reduce corrosion and still maintain high shielding levels. Laird is in the forefront of this research.

An Ion Conduction Path

The ionic conduction medium that is most responsible for corrosion is water. There are other ionic conductors such as moist air, but the majority of corrosion problems will be caused by water or water-based solutions. The basic principle is that the metals are slightly soluble in water. You can sometimes taste a metallic taste in water, especially if the water is a little acidic. In a good ionic conductor like salt water, or water with a high acid content, the ions are relatively stable, and more metal will dissolve into the water. A good ionic conductor like salt water will also allow dissolved ions to move freely in the solution. The dissolved ions tend to migrate through the water toward the electrode of opposite polarity. The positively charged ions will migrate towards the cathode while the negatively charged ions will migrate towards the anode.

The only way to totally prevent dissolved ions from migrating is to interrupt their path, such as with a vacuum or by maintaining them at very low temperatures. The speed at which they migrate can also be reduced by many orders of magnitude by using poor ionic conductors as barriers. Placing metals in dry air, or coating the metals with a poor ionic conductor such as paint, greatly reduces corrosion rates. Some metals form their own barriers that prevent or restrict ion migration. For example, under normal atmospheric conditions aluminum corrodes in air, producing a thin coating of aluminum oxide. The aluminum oxide is an extremely poor ionic conductor and chokes off the flow of oxygen to the aluminum metal beneath the oxide coating. This demonstrates how by-products of corrosion can dramatically reduce corrosion rates.

As in the above example of zinc coating on steel, the anodic material does not need to completely cover the more cathodic material to offer protection. It only needs to be close by. The effective distance between the anodic metal and the cathodic metal depends on the environment. This distance is generally dependent on the conductivity of the electrolyte. In the case of typical electronic equipment this distance is usually the size of the microdroplets of water formed by condensation. In severe environments, this distance can be 0.250 in. (6,4 mm) or more.

Galvanic Corrosion of Electrically Conductive Elastomers

The galvanic series provides a relative ranking for selecting compatible metallic couples. However, electrically conductive elastomers are a composite material that behaves differently from metals due to diffusion rates and elastomeric nature of the gaskets. In addition, the presence of corrosion inhibitors which continuously coat the exposed flanges also affects the corrosion rate. Therefore, the direct application of the metallic-based galvanic series to the conductive elastomers could be misleading. The corrosion behavior of the conductive elastomers is affected by the nature of the filler particles, the permeability of the elastomer matrix, and the presence of corrosion inhibitors.

Electrically conductive elastomers are effective shielding materials because they provide good attenuation to electromagnetic radiation, while at the same time providing an environmental seal. When conductive elastomers are assembled in an enclosure, they are in intimate contact with some type of metal flange and readily conduct current. These two conditions, intimate contact with a metallic substrate and electrical conductivity, create a galvanic couple. Significant corrosion of one of the components of this couple can occur under suitable conditions of: 1) conductive environment (i.e., salt water, acid, etc.) and 2) corrosion potential difference between the elastomer-metal couple (the difference between the Electromotive Force (EMF) values of the two materials). If the elastomer corrodes, an insulating corrosion product is formed that reduces the conductivity of the elastomer.

On the other hand, if the metal substrate corrodes, the metal loss could threaten the integrity of the flange and the corrosion products could adversely affect the performance of the elastomer. When designing the enclosure it is important to avoid conditions that can lead to significant corrosion. The following data are intended to be a guide to help in choosing the appropriate type of couple(s) so as to avoid or minimize these conditions.

Corrosion Test

To evaluate the impact of corrosion on the elastomer/metal galvanic couples test samples were exposed to 500 hours of salt spray in accordance with missile specification MIS-47057. The test fixtures were assembled as per Figure 1. The dimensions of the electrically conductive elastomer washers are shown in Figure 2 and the metal coupons are shown in Figure 3.

The volume resistivity of the elastomers and the weight of the metal coupons were measured before, and then again after the salt spray test. From this data, the change in volume resistivity for the elastomer and the weight loss for the metal coupons were calculated. With these two pieces of data it is possible to assess the compatibility of the various elastomer/metal couples. This information can then be used as a design guidance tool to determine which combinations of conductive elastomer gasket and metal flange are appropriate for a particular application. The following corrosion data indicate the performance of the galvanic couples in a very corrosive environment and thus represent a worst-case scenario.

Weight Loss of Metal Coupons (Part 1 of Galvanic Couple) — Five different metallic materials were evaluated. The five metallic materials included chromated aluminum, Galvalume® (a 55% Al-45% Zn hot-dip coated steel), tin plated steel, zinc plated steel and stainless steel (Table 1). These materials represent some of the common types of sheet metal used to manufacture enclosures.

Figure 1. Test Assembly per MIS-47057

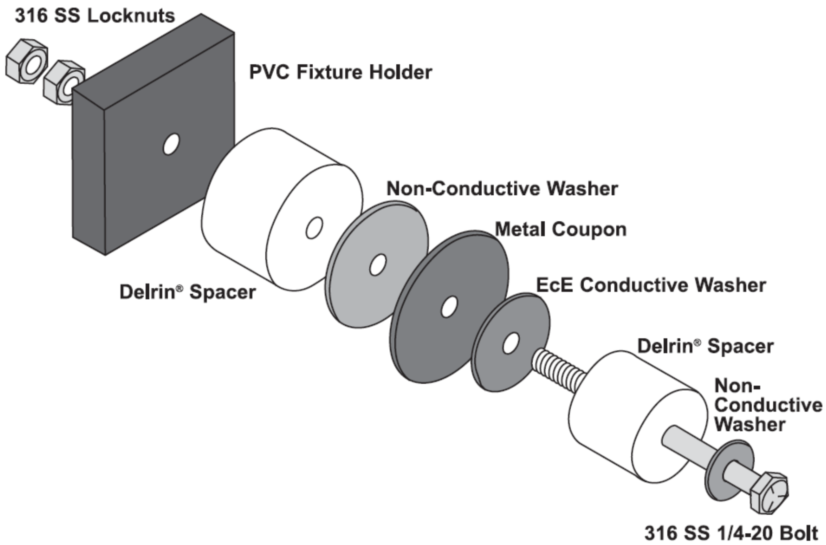


Figure 2. Conductive Washer

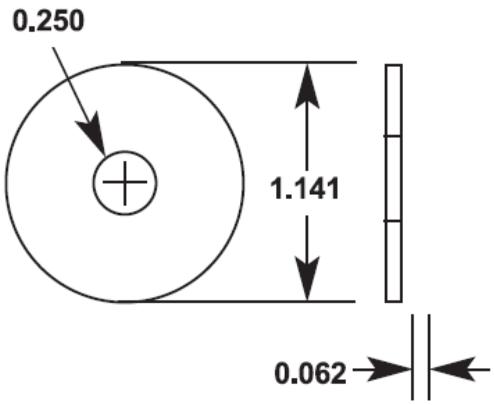


Figure 3. Metal Coupon

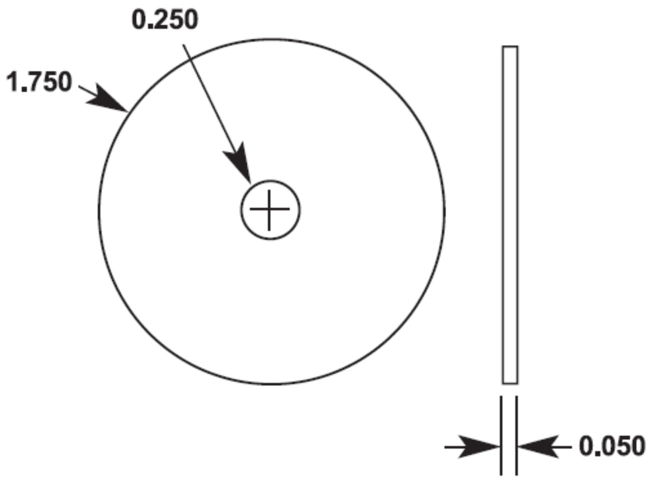


Table 1. Metal Coupons Tested

METAL COUPON	BASE METAL	COATING
Aluminum	6061-T6	Chromate
Galvalume®	1006	55% Al-45% Zn hot-dip coated
Tin Plated Steel	1010	Electroplated Tin
Zinc Plated Steel	1010	Electroplated Zinc
Stainless Steel	304	None

The percent weight loss was calculated for all of the metal coupons according to equation 1.

Equation 1

$$\% \text{ Weight Loss} = \frac{\text{Weight}_{\text{Before}} - \text{Weight}_{\text{After}}}{\text{Weight}_{\text{Before}}} = \text{x } 100\% \quad (1)$$

In equation 1, Weight Before is the weight of the metal coupon before the test and Weight After is the weight after the test once the corrosion products were removed. In Table 3 (page 55), a corrosion performance rating was developed from this data for the metal coupon part of the galvanic couple only. This table does not provide any information on how the elastomer part of the galvanic couple will hold-up.

The corrosion performance ratings, color coded for ease of recognition with a legend, are provided below the table. The divisions for the corrosion performance ratings were established by visual assessment to differentiate significant differences of metal loss on the coupons. The elastomer compound numbers are listed in columns across the top of the table, including the elastomer and filler material. The metal coupons are listed in rows along the side of the table. The intersection of a row and a column gives the weight loss rating for the metal coupon when used with that particular elastomer. For the galvanic couples in which the metal coupon experiences little weight loss (yellow rating), the metal coupon is probably the cathode (electrode where reduction occurs) and/or the couple has a small potential difference. In this case the metal substrate would not experience much corrosion, even in very corrosive environments.

At the other extreme, the galvanic couples in which the metal coupon experiences a large weight loss (dark green rating), the metal coupon would be the anode (electrode where oxidation occurs). In this case the metal substrate would experience extensive corrosion in the very corrosive environments. A large metal coupon weight loss (dark green rating) does not preclude the use of this galvanic couple, but in the design it would be critical to look at the relative anode (metal) to cathode (elastomer) areas, the thickness of the flange and the corrosiveness of the environment. It is not recommended that the galvanic couples with an extreme metal coupon weight loss rating (gray) be used under any conditions.

Volume Resistivity of Conductive Elastomers (Part 2 of Galvanic Couple)

Conductive elastomers are essentially a composite material made up of an elastomer matrix and small filler particles, usually metallic. Even the filler particles can have a composite nature since many are coated. This composite structure can result in a corrosion behavior that may not follow the well-known galvanic series. The elastomer compounds that were evaluated are listed in Table 2.

Table 2. Elastomers Tested

ELASTOMER	FILLER
Silicone	Inert Al
Silicone	Ag Plated Cu
Silicone	Ag Plated Al
Silicone	Ag Plated Ni
Silicone	Ag Plated Glass
Fluorosilicone	Ag Plated Al
Fluorosilicone	Ni Plated Graphite
Silicone	Ni Plated Graphite
EPDM	Ag Plated Al

When exposed to a corrosive environment one of the most important characteristics of a conductive elastomer is its ability to maintain its initial shielding effectiveness. As corrosion products form in the elastomer it usually results in a loss of shielding effectiveness. Generally, as shielding effectiveness decreases there is a tendency for the conductivity of the elastomer to decrease (or resistance to increase). To assess the effect of very corrosive environments on the elastomer part of the galvanic couples, the volume resistivities of the elastomers were measured before and after the corrosion test. In Graphs 1–5 on page 11, a side-by-side comparison is presented for each elastomer of its volume resistivity before and after exposure to the corrosive environment. The change in volume resistivity is the difference between these bars (before and after). It is important to note that the Y-axis is a log scale. Each chart corresponds to a different metallic substrate. The change was usually positive which means a loss in conductivity. These charts do not provide any information on how the metal coupon part of the galvanic couple will hold up.

For some of the elastomers, the increase in the volume resistivity is large. In these cases, the conductive elastomer was probably the anode. This condition results in a significant amount of corrosion of the elastomer filler particles, which makes it much less conductive.

At the other extreme there were a number of elastomers in which there was only a very small percent increase in volume resistivity. In these cases, the conductive elastomer was probably the cathode or the galvanic couple had a very small corrosion potential difference. Under these conditions there was very little loss of conductivity after exposure to a corrosive environment.

Design Considerations

When choosing a conductive elastomer for a particular design, especially in a potentially corrosive environment, it is important to look at shielding requirements and the type of galvanic couple that will be created. In deciding which couple best serves the design requirements, two factors will have to be considered:

1. The impact of the galvanic couple on the enclosure material (Table 3).
2. The impact of the galvanic couple on the volume resistivity of the elastomer, Graphs 1–5 on page 11.

The impact of the galvanic couple on the corrosion of the enclosure material can be gauged by the metal coupon weight loss rating on Table 3 (page 55). As the color changes, the flange area on the enclosure will experience increasing amounts of corrosion.

Metal substrate factors to consider when choosing a elastomer/metal couple:

- Allowable enclosure material(s)
- Effect of weight loss/corrosion on the function of the enclosure
- Area of exposed enclosure material close to elastomer

The impact of corrosion on the shielding effectiveness of the elastomer can be gauged by the change in volume resistivity, see Graphs 1–5 on page 47. The greater the increase in volume resistivity after exposure to a corrosive environment the greater should be the drop-off in shielding effectiveness.

Elastomer factors to consider when choosing an elastomer/metal couple:

- Shielding requirements
- Change in volume resistivity of elastomer in corrosive environments
- Environmental sealing requirements
- Required compression properties

How to Use the Charts

When deciding on a conductive elastomer, it is important to examine the potential impact of galvanic corrosion. From a corrosion standpoint, the best design is an elastomer/metal flange galvanic couple that will result in the lowest corrosion rate. The charts (Table 3 and Graphs 1–5) in this section are intended to be used as a guide for choosing the least corrosive galvanic couple (other design considerations should also be taken into account when using these charts, such as restrictions on enclosure materials and environmental sealing requirements). To arrive at the best choice(s) for a particular application the impact of corrosion on both halves of the galvanic couple must be examined. One half is the weight loss on the metal substrate and the other half is the change in volume resistivity for the elastomer. The combined effect will dictate the corrosion performance of the galvanic couple/finished component.

In Table 3, pick out the appropriate row(s) based on the choice of the enclosure material(s) and then note the elastomer compound(s) that has the lowest metal coupon weight loss. Then go to the appropriate Graphs 1–5, based on the metal substrate(s) of choice, and find the change in volume resistivity for the elastomer compound(s) that you have just identified from Table 3.

The elastomers that have the lowest change in volume resistivity will represent the elastomer/metal substrate combination(s) that will create the least corrosive couple. If a combination of metal substrate with a very low weight loss and elastomer with a very small change in volume resistivity is not identified, then a compromise will have to be made. In that case go through the same process but, now look at metal substrates with slightly higher weight losses and/or elastomers with slightly larger changes in volume resistivity. After a candidate is selected it is always best to test the elastomer(s) in the specific application.

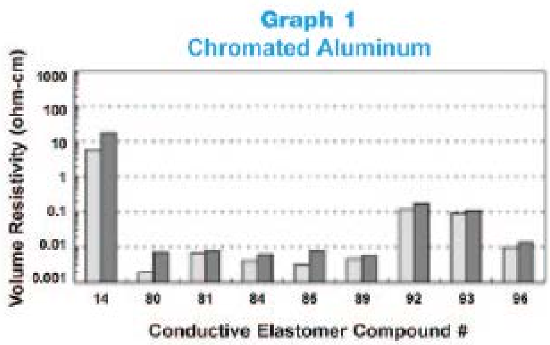
Example

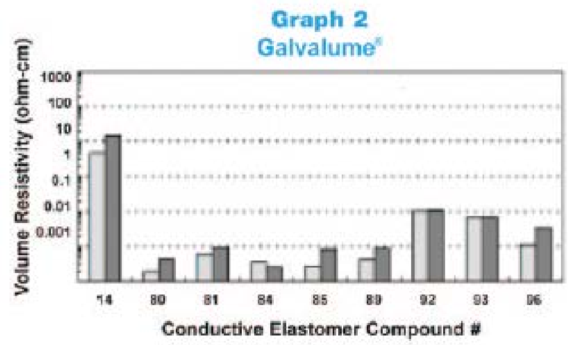
Assume the enclosure is aluminum.

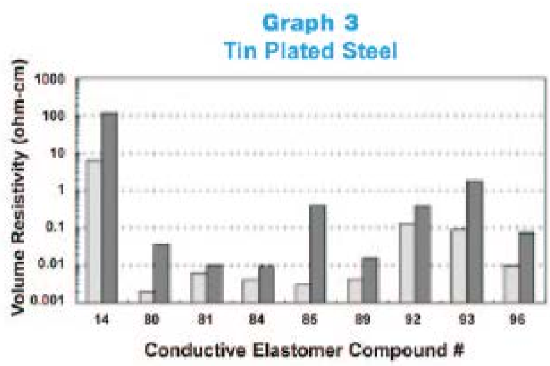
1. From the aluminum row in Table 3, elastomer compounds #14, 89 and 96 will cause the lowest weight loss on the aluminum metal substrate.
2. From Graph 1 (Chromated Aluminum) compound #89 has the lowest change in volume resistivity and 96 is a close second (compound #14 has extremely large changes in volume resistivity).
3. As long as the elastomer matrix and initial attenuations are acceptable, choose either compound #89 or 96.

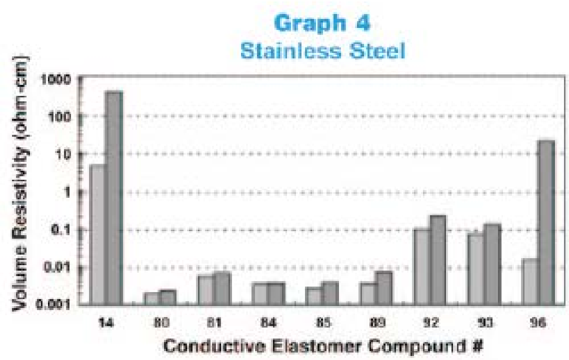
Elastomer Volume Resistivity

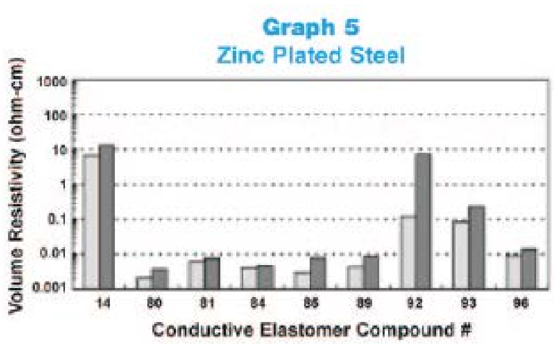
(Salt spray is considered a very corrosive environment and represents a worst-case scenario)

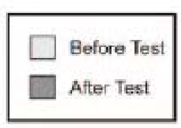












Laird designs and manufactures customized, performance-critical products for wireless and other advanced electronics applications. The company is a global market leader in the design and supply of electromagnetic interference (EMI) shielding, thermal management products, signal integrity components, antenna solutions, as well as radio frequency (RF) modules and wireless remote controls and systems.

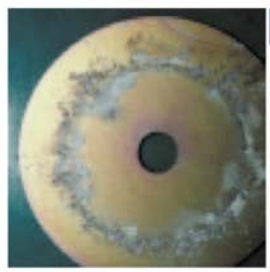
Elastomer Galvanic Compatibility Chart

Table 3. Metal Coupon Weight Loss Rating * Compound Number: Elastomer and Filler Material

METAL SUBSTRATE	80 SIL AG/CU	81 SIL AG/AL	84 SIL AG/NI	85 SIL AG/GLASS	89 FSIL AG/AL	92 FSIL NI/ GRAPHITE	93 SIL NI/ GRAPHITE	96 EPDM AG/AL
Chromated Al	• (red)	• (purple)	• (red)	• (red)	• (orange)	• (purple)	• (purple)	• (orange)
Galvalume®	• (red)	• (purple)	• (red)	• (red)	• (teal)	• (purple)	• (purple)	• (orange)
Tin Plated Steel	• (purple)	• (orange)	• (purple)	• (teal)	• (orange)	• (teal)	• (teal)	• (orange)
Zinc Plated Steel	• (purple)	• (orange)	• (teal)	• (teal)	• (orange)	• (orange)	• (orange)	• (orange)
Stainless Steel	• (orange)	• (orange)	• (orange)	• (orange)	• (orange)	• (orange)	• (orange)	• (orange)

*This chart to be used in conjunction with Graphs 1–5 on page 11.

(Orange) Little to no weight loss on metal coupon; less than 0.25%. Acceptable in all environments.



(Purple) Substantial amount of weight loss on metal coupon; between 0.50% and 1.25%. Not acceptable in corrosive environments; for less corrosive applications consult with Laird Technologies applications engineer.

(Teal) Moderate amount of weight loss on metal coupon; between 0.25% and 0.50%. May not be acceptable in very corrosive environments.

(Red) Extreme amount of weight loss on metal coupon; greater than 1.25%. Not recommended in any environments.

Contact Laird

R&F Products, *a Laird Business*
1825 Diamond Street
San Marcos, CA 92078
United States
Contact R&F Products at www.lairdtech.com/military-contact

LAIRD-ABS-WP-CORROSION-OF-EMI-GASKETS-123115