

LESS CORROSIVE EMI SHIELDING MATERIALS FOR AEROSPACE APPLICATIONS

Salt water, temperature, pressure cycling, and high power emitters make military and aerospace environments more aggressive than commercial applications. A review of available materials and design options will assist materials, EMI, and packaging engineers in developing reliable systems. The corrosion data shown for new materials demonstrate substantial improvements in compatibility with aluminum.

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INTRODUCTION

Annual corrosion costs to the U.S. have been estimated at three to five percent of the gross national product.¹ The cost of corrosion to the Navy has been growing and was estimated at \$4.6 billion in 1989.² A breakdown of the equipment or systems affected is not given in these total costs; however, electronic equipment comprises an increasing percentage. Specific data on EMI and EMI/corrosion related failures is not readily available. Codes for these types of failure do not exist within the maintenance database. EMI failures tend to be intermittent in nature and difficult to pinpoint.

Within the armed services, the naval environment imposes the most stringent EMI shielding and materials requirements on electronic systems. During monsoon season, naval avionics are exposed to 95-percent relative humidity, temperatures above 100° F, salt-laden air contaminated with stack gases, and temperature extremes leading to condensation on surfaces. Field strengths on flight decks of 1000 V/m are typical.³ Shielding the longeron area of the F-18 fighter demonstrates an application in which the EMI seal lies in a critical structural area.⁴ Air Force, Army, and commercial aircraft gener-

ally operate in less severe environments depending on their locations.

Traditionally, only the electronic housings and cabling in an aircraft have been shielded. As new designs go to fly-by-wire and older craft are upgraded with new electronics, airframes are being made into Faraday cages using conductive gaskets, coatings, and sealants where nonconductive materials were previously used. The literature contains several references indicating the need for additional shielding in helicopters (e.g., Blackhawk and Apache) and fixed wing craft.^{5,6} These problems have required the retrofitting of EMI fixes onto the craft. However, the placement of conductive materials next to airframes and skins raises serious corrosion concerns.

The metals used in EMI shielding materials are more noble than aluminum, and consequently cause *galvanic corrosion* of the aluminum. Under certain conditions, severe corrosion can occur in hundreds of hours. Corrosion protection has generally been achieved through the exclusion of electrolyte from the dissimilar metals. A major industry goal is to develop new conductive materials with improved compatibility with aluminum, yet which retain the

shielding properties of today's materials.

Corrosion concerns in commercial applications are not discussed in this article. Different base materials (e.g., steel) and coatings (e.g., galvanizing, tin plating)⁷ are used in more benign environments. Lower shielding requirements (less than 60 dB) require less in the way of surface finishes and conductive materials. Cost concerns drive many design choices to the cheapest configuration. In the future, however, long-term stability of EMI joints in commercial systems will demand greater attention as digital electronics are used more frequently.

Several industry groups are looking at the electrical stability of EMI joints. The AE-4G (Electromagnetic Compatibility - EMI Gaskets) Committee of the Society of Automotive Engineers is evaluating measurement techniques to quantify shielding changes due to environmental stresses. The T-9E (Corrosion of Electronic Equipment) Committee of the National Association of Corrosion Engineers is looking at the same issue from a materials perspective. The IEEE,⁸ EIA,⁹ and SAMPE¹⁰ Committees are also considering the effects of environment on electronics.

*See advertisement on page 11.

CORROSION BASICS

Corrosion is the electrochemical oxidation of a metal, resulting in its dissolution. Common forms are described as uniform, galvanic, pitting, and crevice corrosion. Figure 1 portrays a typical EMI joint with the most likely forms of corrosion identified. Galvanic or dissimilar metal corrosion is the most prevalent form found. Its occurrence may lead to other corrosion types. For example, pH changes from galvanic corrosion reactions may cause pitting in areas away from the galvanic couple.

A model galvanic cell is shown in Figure 2. Three conditions must be present for a corrosion cell to develop:

- A potential difference must exist to drive the corrosion reaction. In a galvanic cell, dissimilar metals with different free energies provide the driving force. One material is anodic to the other and undergoes oxidation (loss of electrons). For a metal, this means it changes from a zero valence (metallic) state to an ionic form with a positive valence. The cathodic material is more positive or noble in potential. Typically, the cathode in a corrosion cell provides a surface for a reduction reaction, such as hydrogen evolution (acidic conditions) or oxygen reduction (neutral to alkaline conditions).
- The electrodes (anode and cathode) must be in electrical contact to allow the free exchange of electrons between the anodic and cathodic sites. Electrons released by the corroding metal (anode) are utilized in the cathodic reaction. Consequently, the anodic and cathodic reaction rates are linked through the flow of electrons and must be equal.
- The electrolyte must form a continuous path between the anode and cathode. The electrolyte serves several functions: the electrode reactions involve ionic spec-

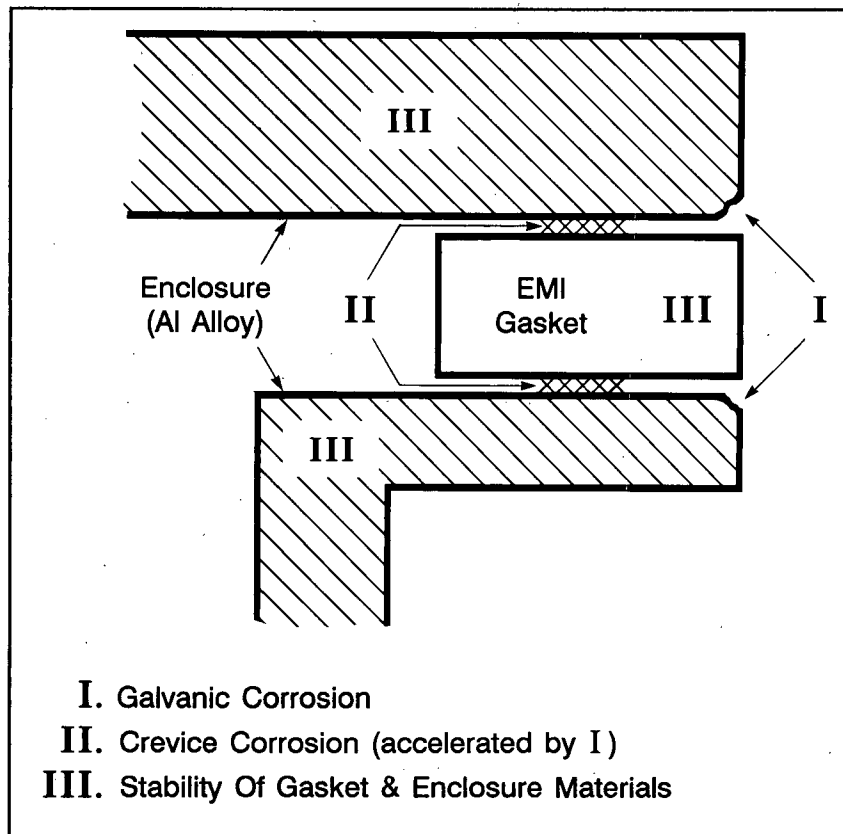


Figure 1. Typical EMI Joint Consisting of Conductive Gasket, Cover, and Flange.

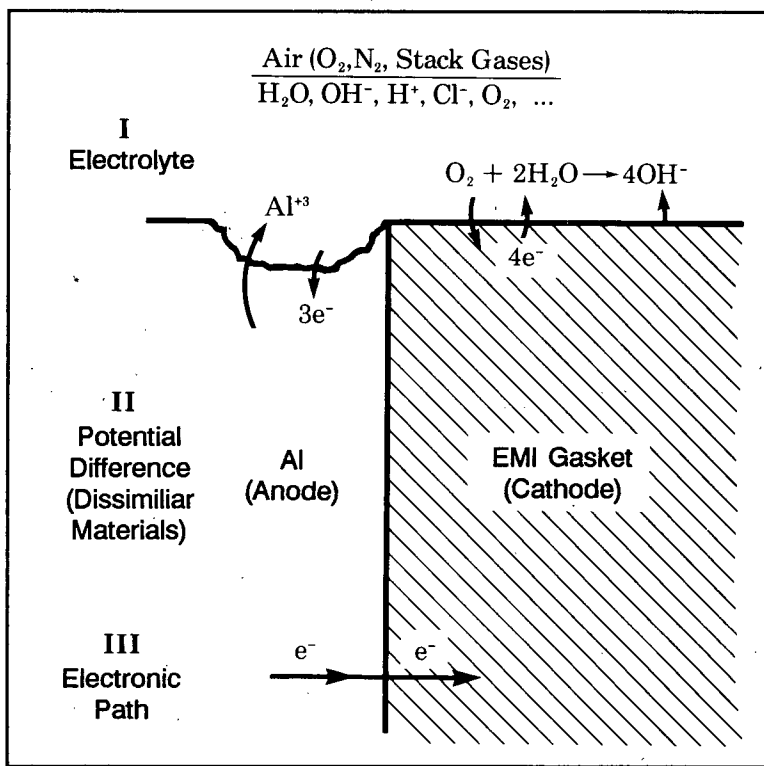


Figure 2. Model of Galvanic Cell. In this Example, Aluminum Corrodes Relative to Gasket Material. Oxygen Reduction is the Primary Cathodic Reaction in Neutral to Alkaline Electrolytes.

ies (M^{+n} , OH^- , ...) in the electrolyte, and it allows ionic charge to flow between the electrodes maintaining charge neutrality in the system.

Frequently, an analogy is made between a galvanic cell and a short circuited battery. In a battery, the resistor or load placed across the terminals determines the current flow or discharge of the battery (within its operating limits). In a galvanic cell, the two electrode materials are in direct contact (shorted). Chemical (electrode kinetics) and physical (diffusion of reactants) processes limit the rate of the corrosion reaction. Material loss is proportional to the corrosion current.

All metals except gold are thermodynamically unstable at ambient conditions. They exist as oxides, sulfides, or other metal salts. Individual metals exposed to a moist environment will corrode at some finite rate; the rate depending on the metal and the nature of the oxide film. Galvanic corrosion is defined as the increase in corrosion rate caused by the presence of a more noble metal. In a galvanic cell, coupling of the two metals protects the more positive, or noble metal of the couple.

Composition of the electrolyte can have a large influence on the rate of corrosion of a system. The pH (acidity or alkalinity) of a solution determines: (1) the stability of oxides which protect metal surfaces, and (2) the primary cathodic reaction. Metal oxides become more soluble as pH becomes more acidic or more alkaline. The presence of chloride ions (Cl^-) lessens the stability of passive films, increasing the possibility of pitting corrosion. Stack gas contaminants, such as hydrogen sulfide (H_2S) or sulfur dioxide (SO_2), acidify the electrolyte.

Galvanic series are a common means of ranking the relative activity or nobility of metals. The potential of the materials in the solution of

Metal	Potential (mV)
Silver	0
Nickel, Monel, Titanium	-150
Copper, Bronzes, 300 S.S.	-200
Tin, Tin-Lead Solders	-500
Aluminum (2000 Series)	-600
Aluminum (Silicon Alloys)	-750
Zinc	-1100

Table 1. Galvanic Potentials of Structural Metals and Alloys (From MIL-STD-1250, Potentials Referenced to Standard Calomel Electrode).

Enclosure	Coatings	EMI Gasket
Steel	Ag	C
Al	Cu	Ag
Mg	Ni	Cu
Composites	Sn	Be/Cu
Plastic	Cd	Phosphor Bronze
	Al(IVD)	Monel
	Zn	Stainless Steel
	Chromate	Steel
	Phosphate	Ni
		Sn
		Al

Table 2. Flange, Coating, and EMI Gasket Metals.

interest (e.g., sea water or 5-percent sodium chloride) are measured versus an electrochemical reference electrode. Table 1 lists values for common metals in 5-percent sodium chloride measured against a standard calomel electrode.¹¹ Galvanic series do not provide a measure of the corrosion current which would flow in a dissimilar metal couple. Additional factors control the actual corrosion rate.

Relative areas of the two metals can influence the rate of corrosion. In neutral solutions, oxygen reduction is the principal cathodic reaction. Low solubility of oxygen (approximately 10 ppm) limits the rate of the cathodic reaction. Diffusion limitations cause the concentration of oxygen to go to zero at the electrode surface as the corrosion rate

increases. Increasing the area of the cathode results in higher total cathodic currents and consequently higher corrosion rates. In this case, the current per unit area remains constant, but the total current increases because of the larger area.

Limiting reactions and electrode kinetics will alter the ranking of corrosivity provided by a galvanic series. Because of diffusion limitations in the cathodic reaction, galvanic potential differences of 200 to 500 millivolts may result in the same corrosion rate on the anode.

The geometry of a galvanic couple, temperature, and the distribution, depth and flow rate of the electrolyte can further influence the rate of corrosion between two unprotected metals. (Practical design of a system, including the use of protective

coatings and sealants, will determine the level of corrosion present during deployment in the field.)

Several methods are available in the laboratory to predict corrosion rates of material couples and system designs. One must first choose the laboratory environment used to simulate the application. MIL-STD-810 describes various temperature/humidity cycles and a salt spray test (Method 509.2) which is identical to ASTM B-117.¹² The salt spray forms a mist by atomizing 5-percent sodium chloride at 95° F. The standards describe the chamber and solution, leaving the duration of the exposure and the pass/fail criteria up to the end-user. Exposure times range from a minimum of 48 hours to thousands of hours. Correlation between hours in salt spray and life in field environments are not available. As a rule, one obtains data relative to a control which may have known performance. For naval applications, an SO₂ salt spray test is used to simulate stack gases.¹³ Mixed flowing gas chambers are finding growing acceptance for simulation of industrial environments.

Ppm levels of contaminants are continuously introduced into a chamber and their effluent concentration kept constant. Corrosion rates of copper and silver coupons in this chamber can be correlated with coupon data from field environments to obtain an acceleration factor.¹⁴

Test assemblies can be designed to provide weight loss data, qualitative photographs of simulated EMI joints, and resistance changes across the joint. Electrochemical tests provide galvanic potentials, polarization data, and galvanic currents between metal couples. In electrochemical tests, test samples are completely immersed in the electrolyte. Interpretation of the preceding data should consider sample geometries and the environment. As a rule, most corrosion studies do not report changes in electrical values of the sample or system.

EMI Shielding Materials

Table 2 lists flange, coating, and EMI sealing materials found in commercial and aerospace systems. Military and aerospace applications predominantly use aluminum enclos-

ures or structures. With the exception of aluminum mesh or screen gaskets, all of the shielding materials incorporate metals more noble than aluminum. Chromate conversion coatings (MIL-C-5541 Class 1 and 3) are the most common finishes used on aluminum. These are inexpensive relative to plated finishes, and make a good paint base. However, they offer minimal corrosion protection in a galvanic couple. If defects are present, corrosion of the aluminum substrate is not accelerated. (Environmental concerns with disposal of hexavalent chromium are forcing the aerospace industry to seek alternatives.)

Plated finishes provide significantly lower contact resistance than conversion coatings and, if defect-free, better salt spray stability. If present, porosity in metal coatings accelerates corrosion of the aluminum substrate. Extremely high current densities (corrosion rates) are possible at the defect due to the small anodic area and essentially infinite cathode surface. Proper surface preparation, maintenance of plating baths and processes, and use of adequate coat-

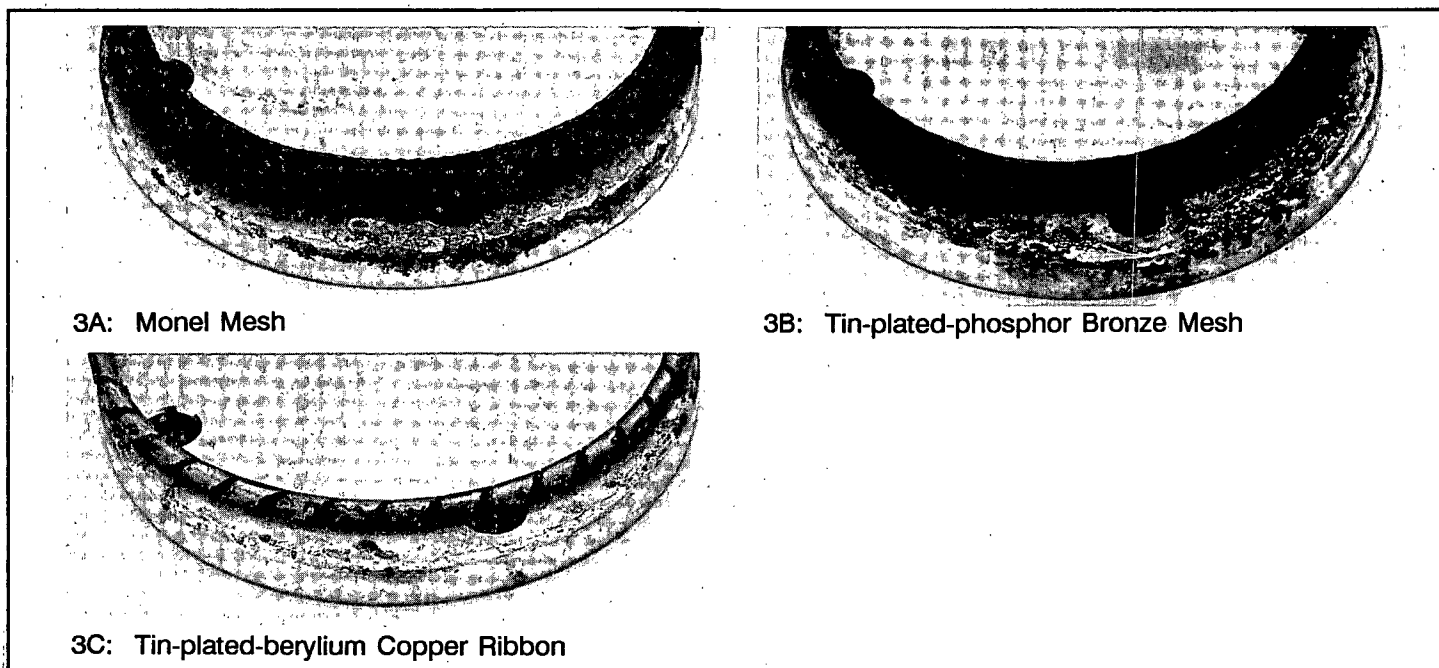


Figure 3. Salt Spray Flanges (6061-T6 Aluminum with Class 3 Chromate Conversion Coating, MIL-C-5541) Containing Mesh and Metal Gaskets After 144 Hours of MIL-STD-810 Salt Spray.

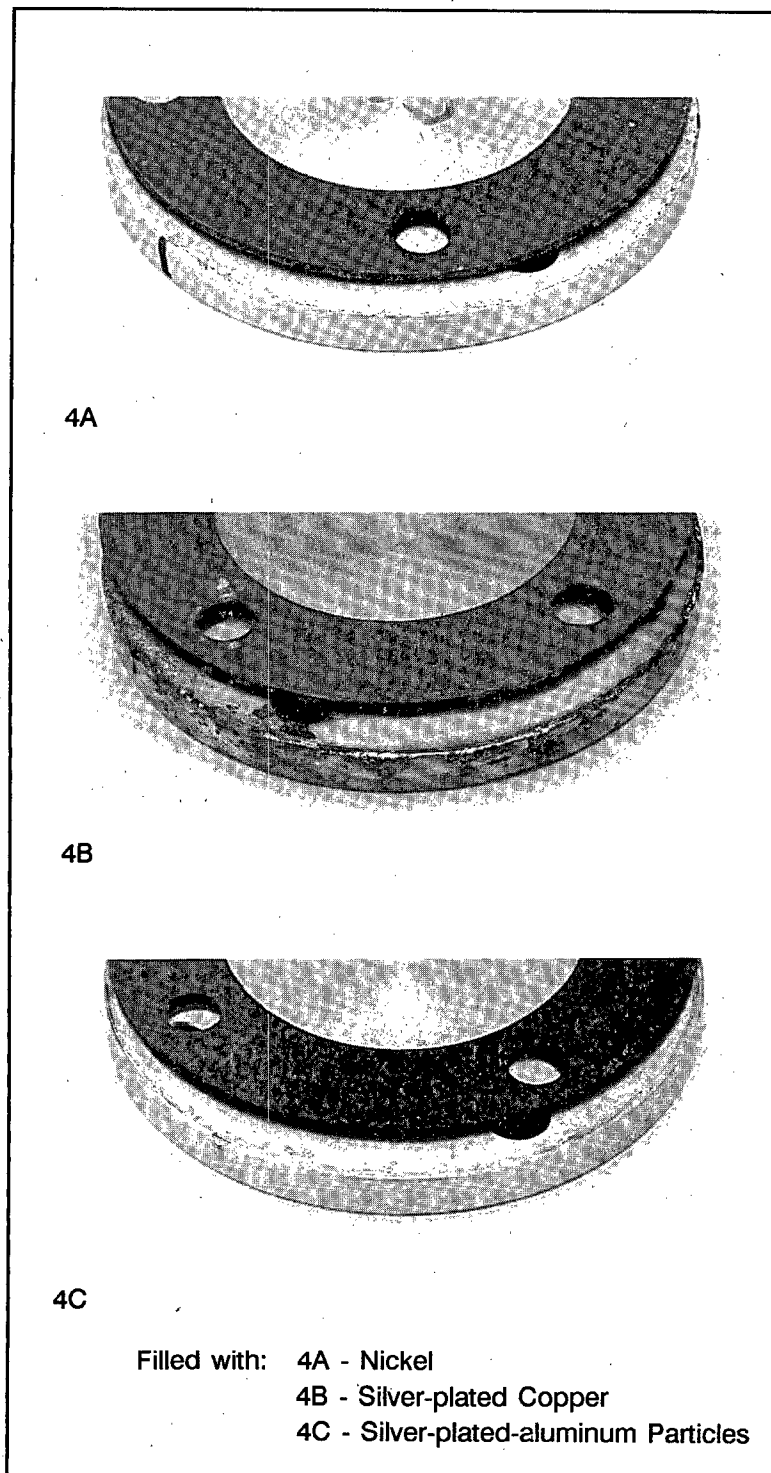


Figure 4. Salt Spray Flanges (6061-T6 Aluminum with Class 3 Chromate Conversion Coating, MIL-C-5541) Containing Conductive Elastomers After 144 Hours of MIL-STD-810 Salt Spray.

ing thicknesses (on the order of 2 mils) minimize the presence of pores. For best salt spray resistance, electroless nickel deposits (nickel phosphorus) should contain more than 10-percent phosphorus. Each vendor of electroless nickel chemicals has a bath designed to provide good salt spray resistance.

EMI Gasket Materials

Figures 3 and 4 show test flanges after 144 hours of salt spray (MIL-STD-810). In this test configuration, the EMI gasket is sandwiched between flanges of 6061-T6 aluminum with a Class 3 chromate conversion coating. This geometry simulates an EMI joint and maximizes the exposure of the aluminum flange to the gasket material.

All the mesh materials galvanically interact with aluminum flanges. Tin is closer to aluminum than monel; however, the substrate of the tin plated materials ultimately determines the extent of galvanic interaction. Tin plating on wire or metal ribbons tends to degrade in salt environments. This is due to defects created by handling, and the problems of plating edges (ribbons) and obtaining nonporous deposits in thin coatings.¹⁵ Abrasion and flexing of the tin surface during the knitting process creates porosity beyond that present in thin deposits.

Figure 3 shows samples of monel mesh, tin/copper plated iron wire, tin plated phosphor bronze mesh and tin plated beryllium copper ribbon after 144 hours of salt spray. Formation of the black oxide on the surface of the aluminum with polished aluminum beneath it indicates high rates of dissolution. (Weather seals were not used in these samples to maximize interaction between flange and gasket material. In actual applications, weather seals must be used.) Corrosion resistance of monel makes it the most stable of the mesh gaskets; however, galvanic corrosion of aluminum next to monel and tin plated materials is similar. In actual

applications, an electrolyte which penetrates to the mesh is distributed along the length of the gasket by wicking.

Mesh and oriented wire gaskets made with aluminum are galvanically compatible with aluminum flanges. However, contact resistance of these gasket materials increases with time due to insulating surface films of aluminum oxide. Sufficient experiments have not been performed with aluminum gaskets to balance the benefits of reduced corrosion versus increases in joint resistance.

Flanges containing conductive elastomers with nickel fibers, silver-plated-copper particles, and silver-plated-aluminum particles are shown in Figure 4. The silver/copper filled gasket causes substantially more corrosion than the other two. Copper leached from the filler into the electrolyte is probably the cause of the increased corrosion. Use of nickel results in galvanic corrosion of

aluminum flanges, as expected from its galvanic potential relative to aluminum. (This point is made because of product claims of compatibility of nickel and aluminum. In those cases where reduced corrosion is found with nickel, high gasket resistance or additions of corrosion inhibitors are the real factors influencing the rate of corrosion.)

After 144 hours of salt spray, aluminum discs pressed against silver/copper and silver/aluminum filled gaskets lost 138 and 37 milligrams respectively. In this experiment, a small disc of the gasket is pressed against a 0.020-inch thick 6061 aluminum disc with a Class 3 conversion coating. The silver/aluminum filler causes 73-percent less weight loss than the silver/copper filler.

Adding corrosion inhibitors to conductive elastomer gaskets reduces corrosivity of the gasket material toward aluminum. Figure 5 shows a comparison of silver/aluminum

gaskets with and without inhibitor at 192, 500, and 1000 hours of salt spray exposure. (Both gasket materials have similar volume resistivities and joint resistances.) In the uninhibited samples, corrosion at the outer edge degrades the seal, allowing the electrolyte to penetrate into the gasket footprint. The aluminum corrodes uniformly in these areas. In the inhibited gasket, a small amount of pitting occurs at the outer edge of the flange. However, the inhibitor prevents propagation of the pitting and the seal is maintained. Conductive elastomers containing corrosion inhibitors are currently under development.

DESIGN

Proper design and use of materials are critical to minimizing corrosion in an EMI joint. Mechanical properties of the gasket and flange must be matched. Many properties of the gasket must be considered when

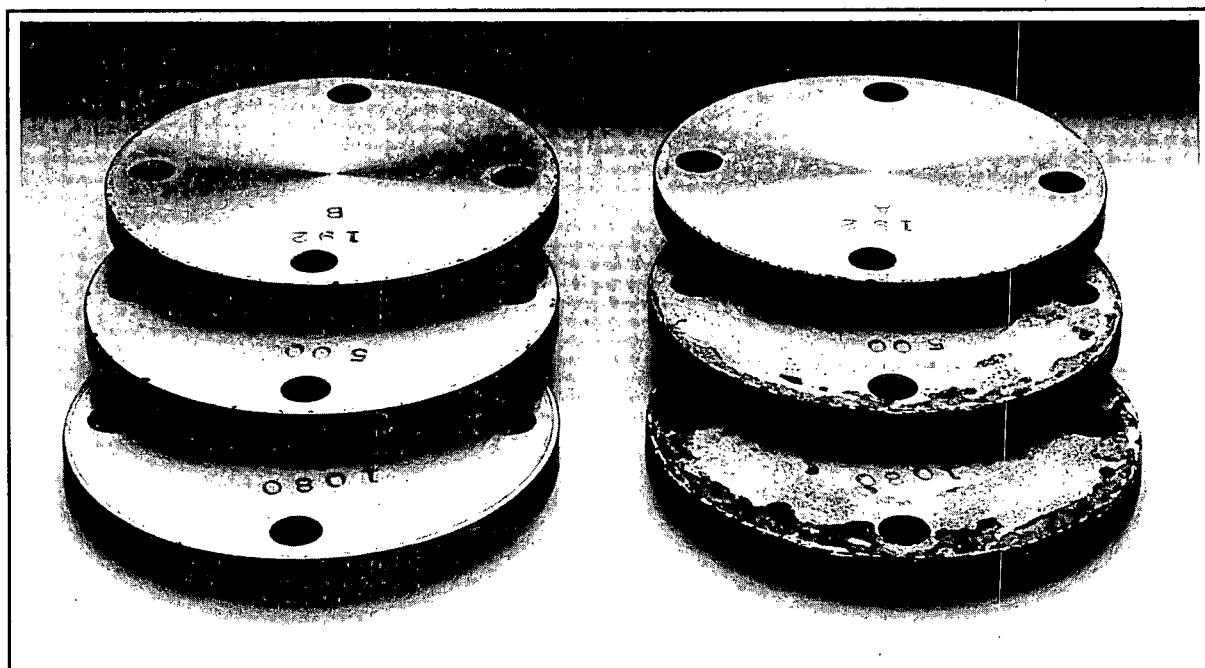


Figure 5. Salt Spray Flanges (6061-T6 Aluminum with Class 3 Chromate Conversion Coating, MIL-C-5541) Containing Silver-plated-aluminum Conductive Elastomers with (Left) and Without (Right) Inhibitor After 192 (Top), 500 (Middle), and 1080 (Bottom) Hours of MIL-STD-810 Salt Spray. Both Gasket Materials Had Similar Volume Resistivities and Flange Resistances.

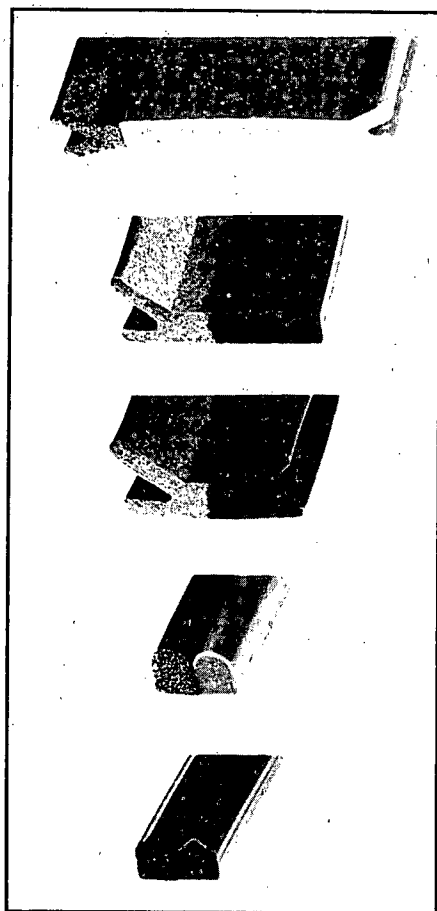


Figure 6. Cross Sections of Gaskets with Coextruded Conductive and Nonconductive Regions. Conductive Area to the Left.

designing the joint: the compression-deflection relationship for the gasket material and form; the deflection range of the gasket; compression set; stress relaxation; and the flex at low temperature. Compression of the gasket should not create voids between the cover and the gasket.

Combinations of nonconductive and conductive material are often used to provide improved environmental seals. Elastomer strips are bonded to mesh or conductive elas-

tomers to form moisture seals. (Mesh and fingerstock gaskets do not have any intrinsic environmental sealing ability.) Figure 6 shows cross sections of gaskets with conductive and nonconductive portions that have been coextruded. Vulcanizing the two materials together eliminates the variability of hand bonding and minimizes crevices where moisture can collect.

Design brings together EMI, mechanical, packaging, and materials engineering to satisfy the system requirements of an application.

SUMMARY

Metals useful as conductive fillers are dissimilar to aluminum, resulting in corrosion if other means of protecting the aluminum flange are not taken.

Inhibitors offer one means of improving the compatibility of the gasket material with aluminum. Use of additional nonconductive seals further enhances the reliability of these systems.

Proper design and testing of the finished system is critical for satisfying the requirements of the application. ■

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