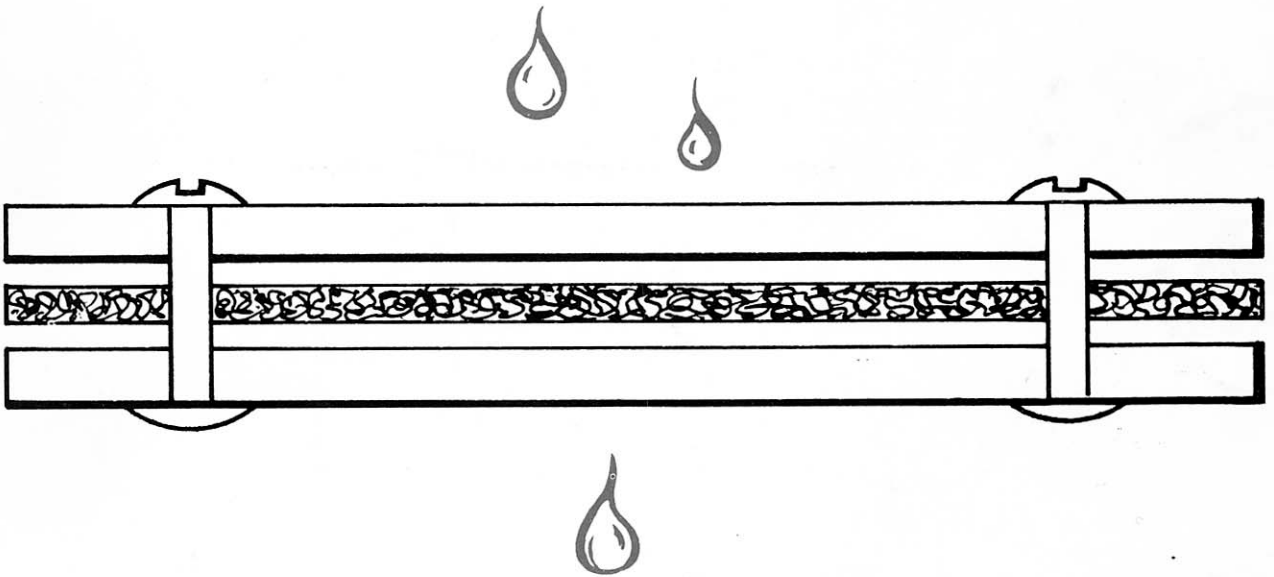




CORROSION AND THE EMI/RFI KNITTED WIRE MESH GASKET

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REPRINTED FROM
FREQUENCY TECHNOLOGY
MARCH 1969

INTRODUCTION

For centuries, engineers have been plagued with a deterioration of metal called corrosion. This type of deterioration appears in many forms, and is especially prevalent in a salt spray or salt water atmosphere. Surface metals on ships have been a problem from as far back as the Civil War "Monitor," to the ships of the line today. Although there is no interest in lining the bottoms of ships with wire mesh gaskets, there is an interest in the fact that both can be subjected to the same type of atmosphere — salt spray or a salt solution.

Since the problem has been present for years, the conclusion can be drawn that no metal is perfect. Therefore, metals will corrode sooner or later, especially when contacting one another in a damp atmosphere.

BASIC THEORY OF CORROSION

Basically, corrosion is a very complex form of material deterioration. One reason for its complexity is that there are so many types. The theory lies in the fact that some elements are electron capturers (chlorine, oxygen, iodine, etc.), and metals are donors in this electrochemical phenomenon. One reason why metals are so susceptible to this type of attack is that metals naturally occur as oxides, carbonates and other compounds of a low free energy state. As ores are refined and made usable for industry, they are in a much higher energy state; that is, a greater potential electron flow. Since it is a normal process for materials to return to their natural states, corrosion can be considered the reverse process of metal processing.

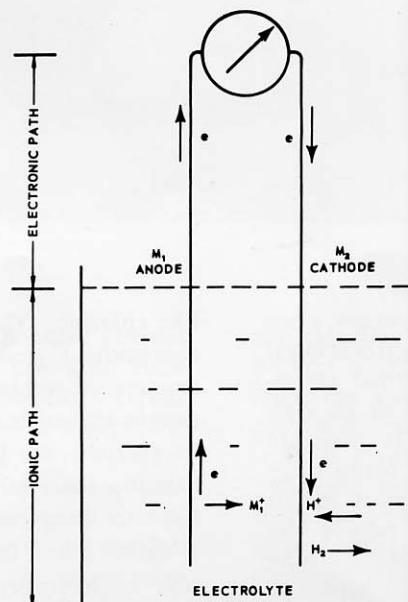
This fundamental can be explained by the corrosion cell concept (Figure 1).

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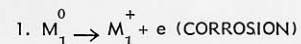
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Figure 1. Basic corrosion cell.

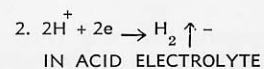


ELECTRODE REACTIONS

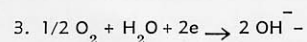
AT THE ANODE - OXIDATION OCCURS



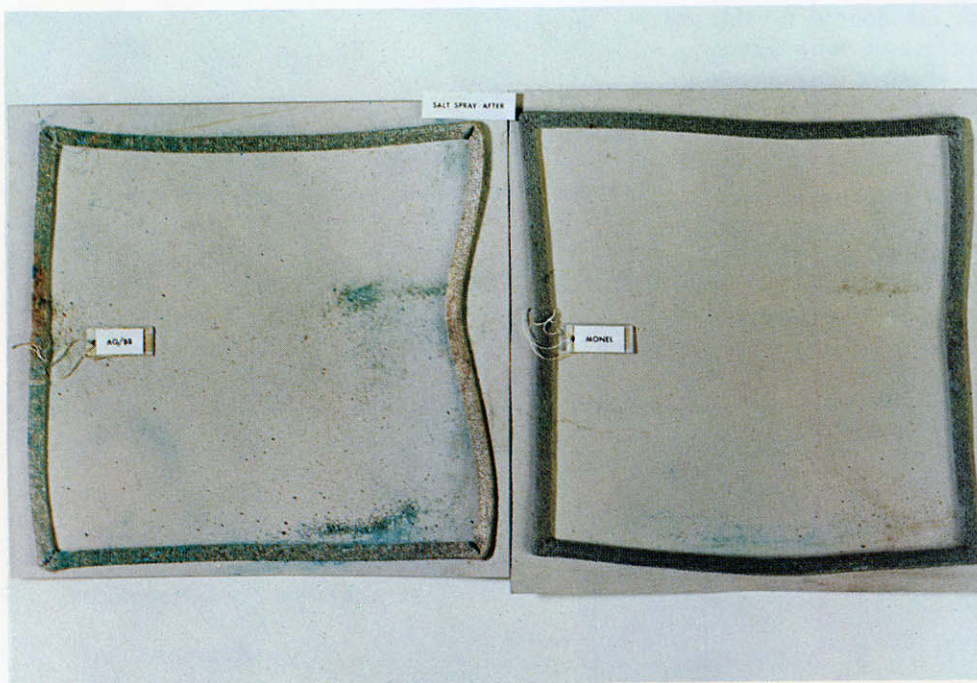
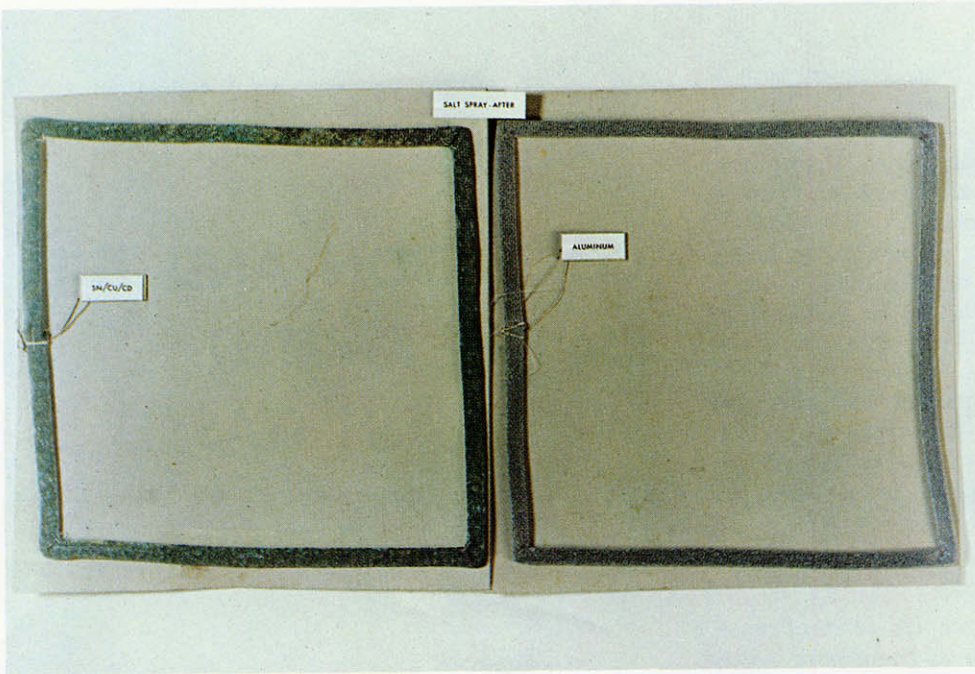
AT THE CATHODE - REDUCTION OCCURS



OR

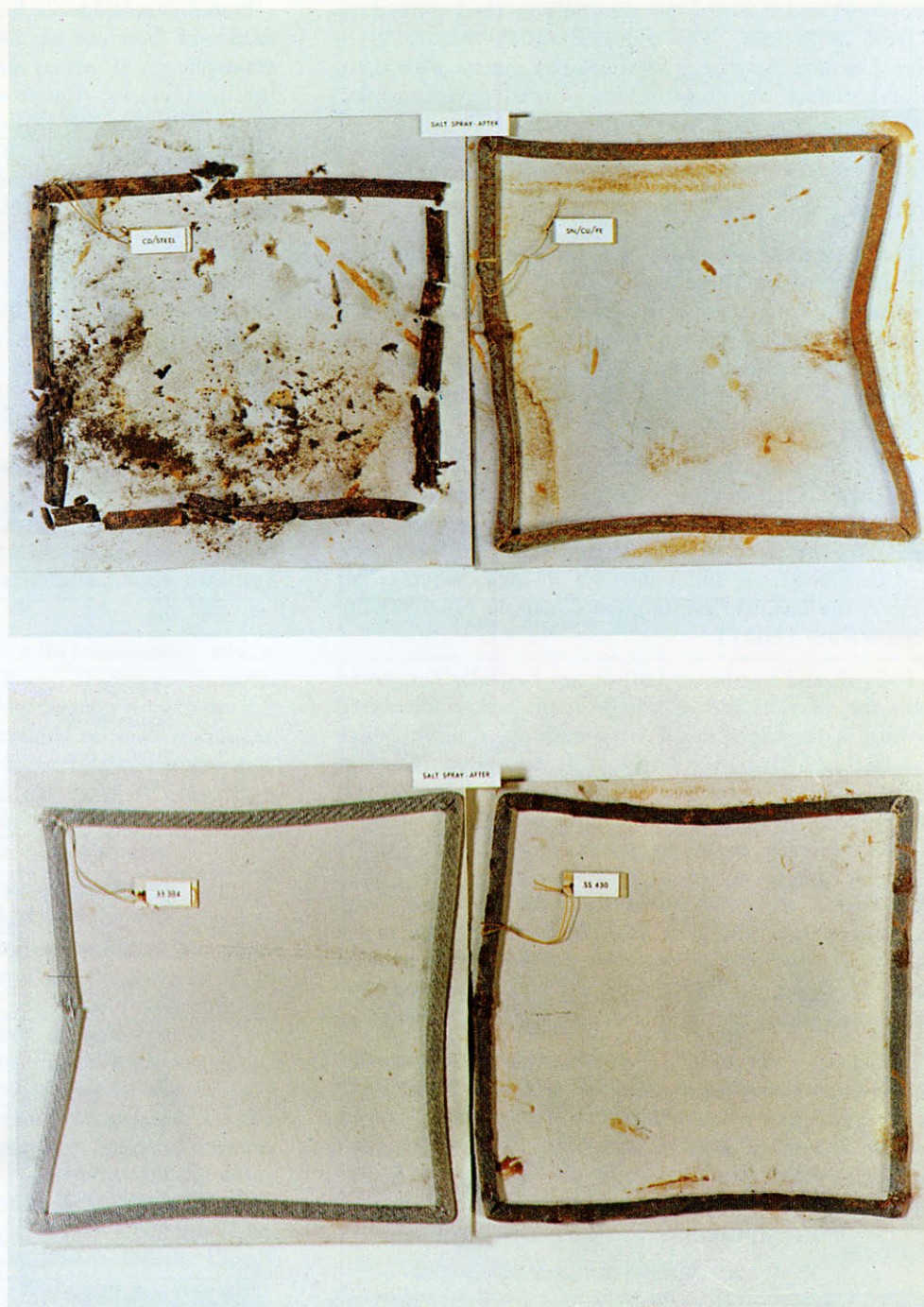


IN NEUTRAL OR BASIC ELECTROLYTES,
THIS REACTION PREDOMINATES



It is not uncommon that wet corrosion occurs since electrolytes, which are the basis of this electrochemical phenomenon, naturally happen in our normal atmospheric environment (salt solution, etc.). With an electrolyte present, the metals have a tendency to pass into solution, with the higher potential metals being more active. However, it must be noted that most metals form thin oxide coatings, which are termed passive and are considered as a protector to the metal. As long as there is sufficient oxygen the oxide will replenish itself when destroyed by some atmospheric contaminant

like chloride. Thus, the metal is still protected. If the contaminant is stagnant, for example in a crevice, the amount of oxygen is restricted. Thus, the oxide film cannot replenish itself, and the underlying metal begins to corrode by forming metal ions. The process of forming these ions releases electrons, which pass from the corroding site to another site where the ions are available for a reduction process — such as the reduction of hydrogen ions to hydrogen atoms which can dissolve in the metal or pass off as gas.



Potential differences can arise easily, the most obvious being with galvanic coupling. Others can arise from the orientation of the metals' individual crystal grains, point to point concentration of alloying elements, different phases of heterogeneous alloys (graphitization), residual and applied stress, impurities, protective oxides and absorbed films, and thermal gradients.

To summarize, the corrosion cell consists of the following: (1) The anode, where the corrosion takes place; (2) The metallic path, which conducts the electrons from one site to another; (3) The cathode, where

the reduction action is occurring; and (4) The all important electrolyte, which presents an electrolytic path from the anode area to the cathode area, thus completing the circuit.

Since a current must flow when there is a potential difference between substances, one can conclude that there must be some relationship between metals. This relationship is expressed in the well known electrochemical series and the galvanic series. This shows that the more active metal has a greater potential. Of these two series, the electrochemical series is more

theoretical and is based on materials in their pure state — free of oxides. The galvanic series, Figure 2, is more practical, because it classifies the metals with their natural surface films and in the normal environmental condition where they will find service.

TYPES OF CORROSION

The fact that metals fail can be broken down into two groups: one, purely mechanical, which is based on fracture toughness upon loading and fatigue; and second, the group known as environmental mechanics — corrosion fatigue, stress corrosion cracking and stress corrosion, crevice corrosion, pitting, dealloying, fretting corrosion, galvanic corrosion.

Since there is no basic set measure throughout the metal spectrum, fracture toughness is dependent on the material. In other words, it is an intrinsic measurement. For example, a measure of toughness for a wire may be elongation and reduction in area; whereas for a plate, the measure of toughness may be Nil Ductility Temperature (NDT).

Fatigue and corrosion fatigue are basically concerned with the service life of the knitted gasket involving cycling. One might say it is an endurance limit, which can be correlated to strength, for example a "damage ratio" (corrosion fatigue strength divided by normal fatigue strength). The great danger of corrosion fatigue is that bending tends to break down the protective films on the metal wires which compose the gasket. This threat, with respect to gaskets, is twofold: one, in the knitting process in manufacture and two, in the fact that a gasket must be compressible in its application. However, at times, in a salt spray environment, corrosion fatigue can be retarded by cathodic protection.

Cathodic protection is based on the principle that the anodic current promotes corrosion, and the cathodic current will prevent corrosion. However, cathodic protection is not as great as it seems, since it can cause hydrogen embrittlement due to the discharge of hydrogen during the process.

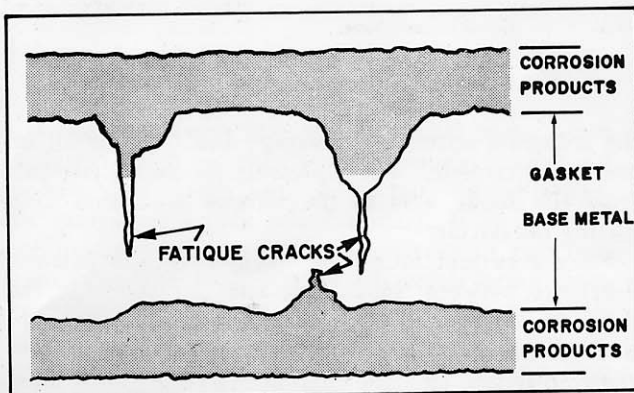


Figure 3. Corrosion fatigue.

Stress corrosion cracking is one of the most rapid modes of deterioration on a mesh gasket in a salt spray atmosphere. It occurs under tensile stress by forming localized cracks similar to corrosion fatigue. A free hanging gasket has little or no tensile stress; however, the mesh gasket when in use will be subjected to loading and fitting residual tensile stresses. This is extremely hard to predict or measure due to the many variables and environmental situations involved.

Stress corrosion can also occur from internal stresses. Damage usually takes the form of localized cracks, as

GALVANIC SERIES OF METALS

CORRODED END (anodic, or least noble)	↑ HIGH POTENTIAL END
Magnesium	↑
Magnesium alloys	
Zinc	
Aluminum 1100	
Cadmium	
Aluminum 2017	
Steel or iron	
Cast iron	
Chromium-iron (active)	
Ni-Resist irons	
18-8 Chromium-nickel-iron (active)	
18-8-3 Cr-Ni-Mo-Fe (active)	
Lead-tin solders	
Lead	
Tin	
Nickel (active)	
Inconel (active)	
Hastelloy C (active)	
Brasses	
Copper	
Bronzes	
Copper-nickel alloys	
Monel	
Silver solder	
Nickel (passive)	
Inconel (passive)	
Chromium-iron (passive)	
Titanium	
18-8 Chromium-nickel-iron (passive)	
18-8-3 Cr-Ni-Mo-Fe (passive)	
Hastelloy C (passive)	
Silver	
Graphite	
Gold	
Platinum	
PROTECTED END (cathodic, or more noble)	↓ LOW POTENTIAL END

Figure 2. Galvanic series of metals.

shown in Figure 4. The magnitude of the failure depends on the type of gasket, its density and the yield strength of its base wire.

Crevice corrosion is one of the most familiar types of corrosion. From common experience we know that corrosion is more likely to occur in a crevice where there is a lack of oxygen due to a stagnant solution. Crevices or grooves can also lead to greater differences in metal ion concentration. Although small crevices may occur in the wire of the mesh gasket, this is not the major concern. The major concern is with the grooves that the gaskets are placed in. If not properly sealed these are the real danger areas, since they cannot contain moisture and cause the corrosion process to occur not only in the groove but on the mesh gasket.

Pitting, another form of corrosion, is generally caused by porous areas in the plating or metal. This can happen in wires that are plated, however, it is not a normal occurrence. Pitting is more prevalent in the surfaces that contain the mesh gasket, and thus has an indirect effect on the gasket.

Fretting corrosion is produced by movement, which results in the striking or rubbing of the wire mesh gasket by the surfaces of the enclosure in which the gasket is placed. This action creates unprotected areas which are susceptible to galvanic corrosion, fatigue and structural failure. This type of corrosion is present to one degree or another in all mesh gaskets due to the gasket's necessary movement in application.

Galvanic corrosion is the electrochemical process that results when two different metals are coupled together in an atmosphere containing ionized salts. The metal with the most negative electrolytic potential, (less noble), is anodic to the other metal, and will tend to corrode. An electric current must flow for the reaction to take place. Thus, the rate of corrosion is related to the current flow which, in turn, depends on the concentration of the electrolyte solution, the relative masses of the materials and the temperature. In an aluminum enclosure with a copper mesh gasket, the anodic component, (the aluminum), goes into solution and deposits at the cathode, (the copper mesh gasket), in the form of a complex hydrated aluminum oxide, with the simultaneous evolution of hydrogen. Although the build-up of the corrosion products at the cathode will tend to slow corrosion by polarizing the surface, the corrosion will continue as long as there is an electrolyte or until the aluminum is consumed.

Galvanic corrosion can, basically, have two effects on a mesh gasket: (1) The contact area between the enclosure's surface and the gasket can be attacked, causing electrical discontinuity; (2) The gasket could severely corrode, causing mechanical failure. Most often the failure is electrical, causing leaky areas in the shield.

Although there are many other types of corrosion like hydrogen embrittlement, dealloying, intergranular corrosion, etc., those mentioned above directly affect the gasket itself.

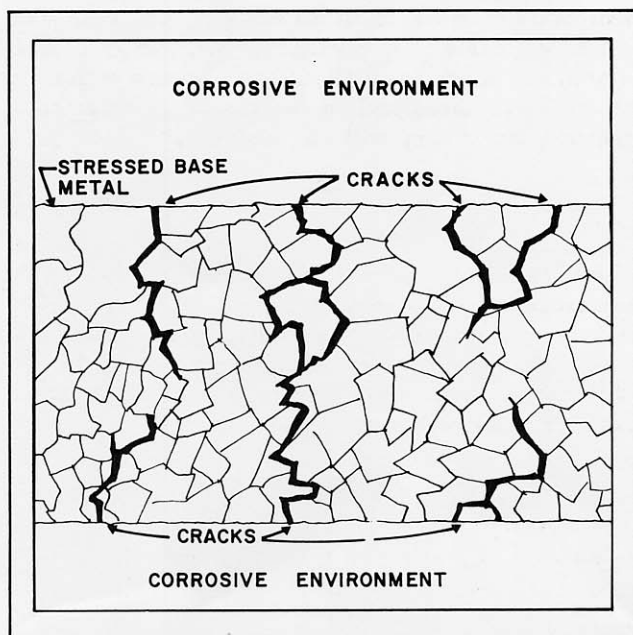


Figure 4. Stress Corrosion.

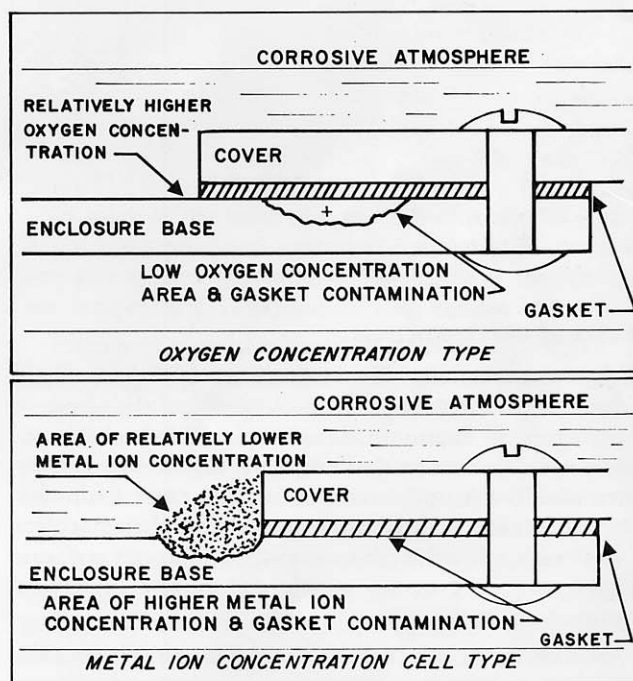


Figure 5. Crevice corrosion.

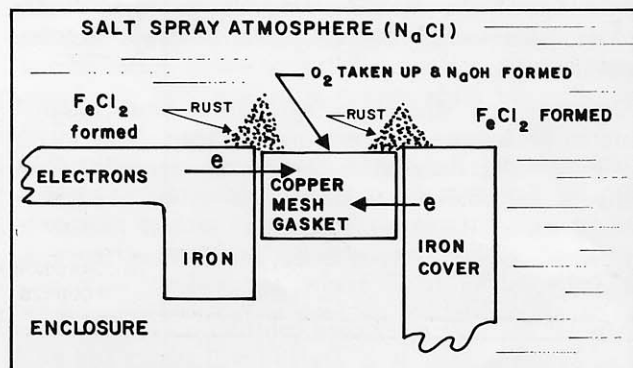
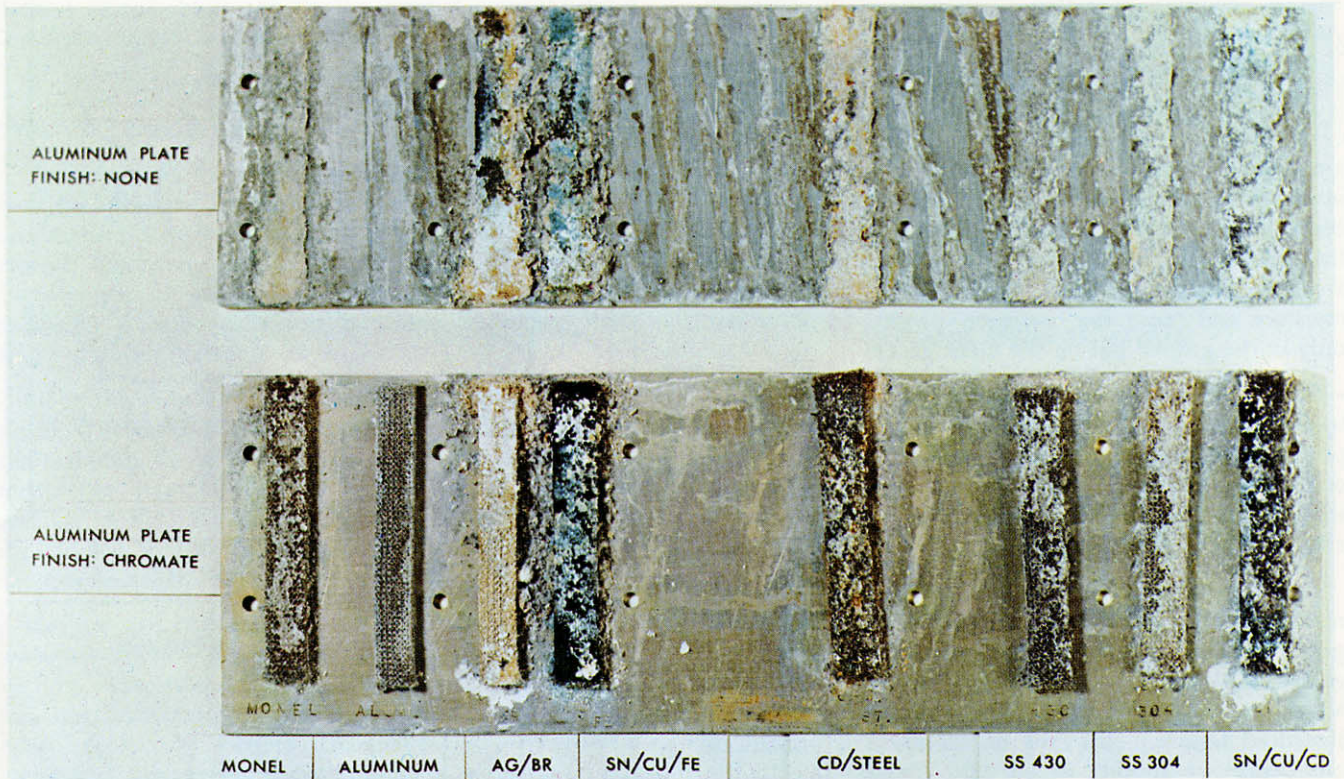


Figure 6. Galvanic corrosion.



CAUSES OF DETERIORATION

Moisture, whether it be in the form of liquid, vapor or humidity, and the lack of oxygen are the greatest contributors to corrosion deterioration. Moisture is always present in a normal atmosphere, and contains many contaminants that aid corrosion. It can cause flash-over between surfaces and change the electrical characteristics of materials. Besides this, moisture and oxygen can support microorganisms which can create a severe deterioration problem.

Another factor which can contribute to the corrosion problem is temperature. A variation in temperature can cause condensation within equipment resulting in the production of the moisture necessary to the galvanic process. Remember, as temperature drops relative humidity rises.

Pressures and stresses in application cause internal material breakdown and external cracking. This leaves the gasket base material susceptible to corrosion, especially in contaminated atmospheres. Also, non-homogeneity within the metal will cause residual stresses in which the stressed area is more anodic than the non-stressed.

One of the least recognized contributors to the causes of corrosion is dust. It is dry and will attract and hold moisture, thus providing an electrolyte for galvanic

corrosion and the growth of fungus. The presence of dust on surfaces can cause an abrasive action when the surfaces are moved or vibrated. This removes the protective oxide coatings, and leave the base metal exposed for the corrosion process.

Living organisms like molds, bacteria, and fungi are another cause of corrosion. To live they must have moisture, thus creating an electrolyte. In many cases they themselves will carry a current, causing a potential difference from one area to another, consequently helping the corrosion process. At times, these organisms create acids which destroy protective coatings, leaving the base metals exposed. Also, in porous materials these microorganisms can seep into the pores and, with growth, will expand and rupture coatings and cause internal stresses.

Last but not least is chemical attack. Certain types of glues and gases in the atmosphere, when combined with moisture, will form mild acids to aid the corrosion process. Even the chemicals secreted in the hands can leave deposits on surfaces, and aid corrosion.

BASIC METHOD TO CONTROL OR PREVENT CORROSION

The ultimate way to protect a mesh gasket from corrosion is to remove the system from its environ-

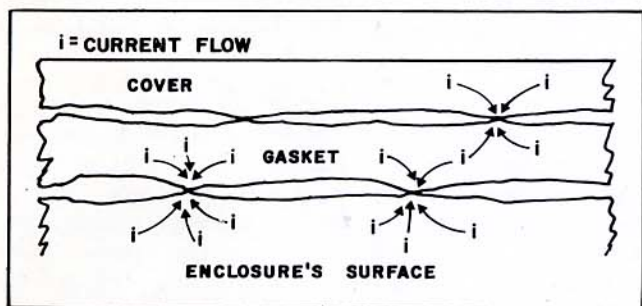
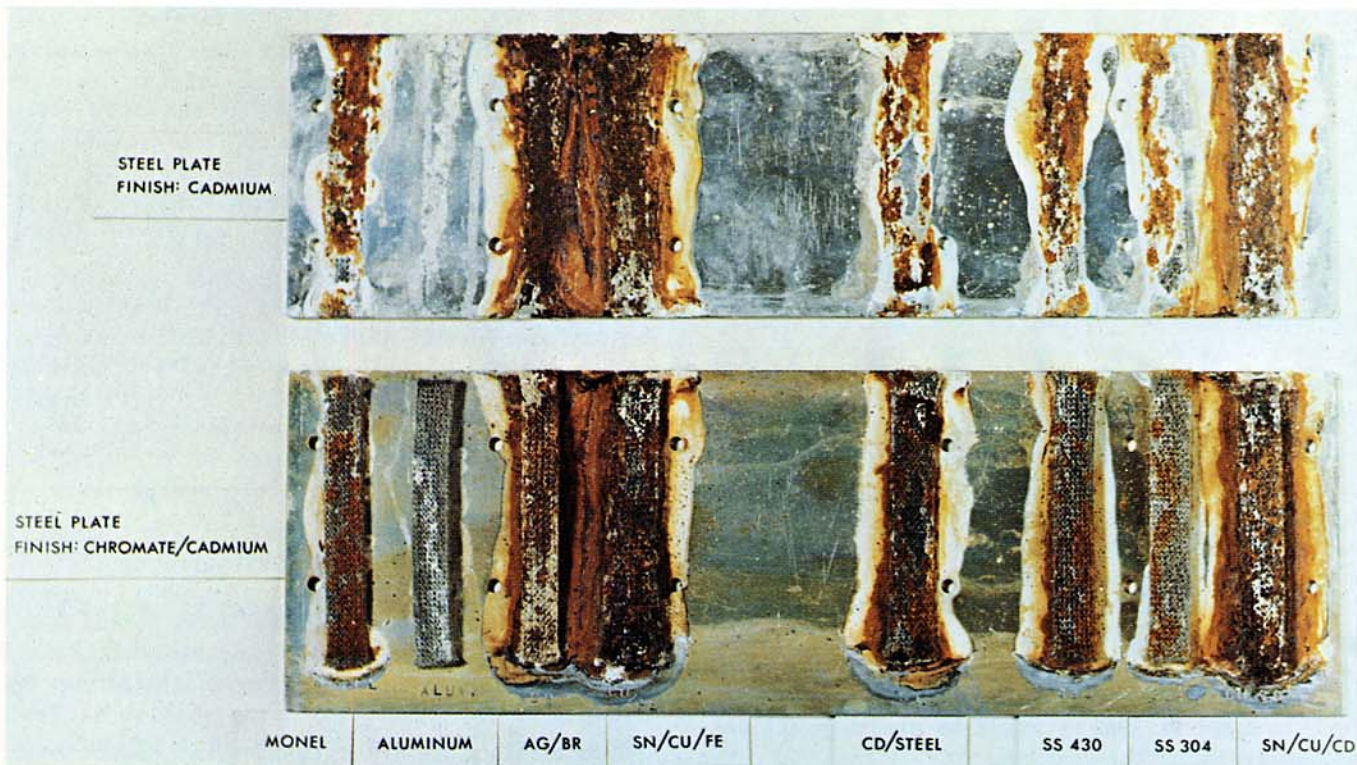


Figure 7. Convergence of current.

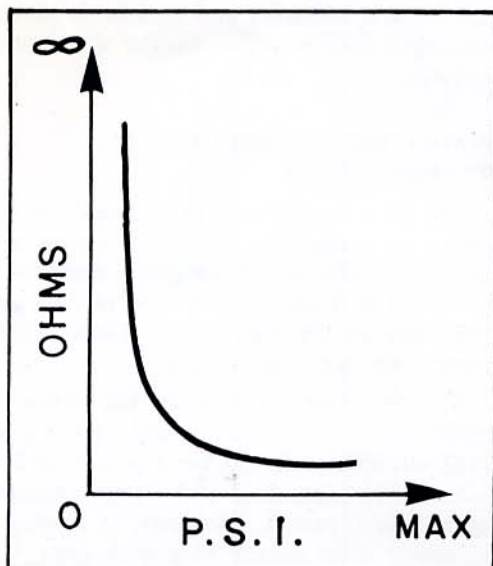


Figure 8. Resistance vs. load.

ment, for example, by placing the system in an inert gas or vacuum. However, this usually is not practical, so the next best approach is to seal the mesh gasket from its environment by using a moisture tight seal on both sides of the mesh material. In this way the gasket is not only protected against the external environment, but also against the internal environment in case there are temperature variations causing condensation.

Plating the surfaces that the mesh gasket will contact during application with a conductive coating will not only help shielding, but will protect both the gasket and the enclosure. However, it must be remembered that in choosing a plating for a base material, the plating be compatible with the base material with reference to the galvanic series.

Also, when choosing a wire mesh gasket for an enclosure, choose metals that are relatively close in the galvanic series. However, do not ignore area, because this is also important. For example, a larger area of a cathodic metal, high potential, coupled with a small area of anodic metal, low potential, causes an intensified attack on the anodic metal. On the other hand, a small area of cathodic metal coupled with a large area of anodic metal causes very little reaction on the anodic metal; (a steel nail in a copper sheet corrodes very quickly).

Possibly, in the future, there will be high-quality protective lubricants that are conductive and will save wear and tear on gaskets and the surfaces they contact. A step in this direction has already been made with connector applications, where ODA HCL (octadecylamine-hydrochloride) is used on gold contacts. It does not affect the resistance, and decreases the coefficient of friction by 75%.

CONTACT RESISTANCE

The resistance of contact between a mesh gasket and the surface of its enclosure is broken down into two factors: (1) Constriction Resistance; (2) Film Resistance.

Constriction resistance is due to the convergence of current flow lines to the points of contact, Figure 7. It can vary with the resistivity of the contact materials, the contact load or pressure to bear, and the contact geometry. As the load is increased, the constriction resistance will decrease, as does contact resistance. (Figure 8).

Film resistance is due to the impedance to electrons offered by surface films. These contact films are the result of the gasket or enclosure's material reaction with one or more contaminants in the system's environment, and the absorption of impurities due to cracks and holidays (gaps) in the surfaces of the materials. In general, this is true for all metals except gold. Thus, as these reactant films build up, resistance increases due to their non-conductive nature. If a plot was made of film resistance vs. time it would be similar in appearance to a capacitor charge curve.

Figure 9 shows results of a test conducted by IBM on several different materials with respect to contact resistance. However, it must be noted that the readings indicate resistance rather than resistivity and, therefore, the values should only be used in a comparative nature.

CONTACT RESISTANCE
(Average of Several Test Sites)

Metal	Initial Resistance (ohms)	Resistance After One Year (ohms)
Aluminum	0.01 to 100	> 100
Nickel-Silver	0.01 to 100	> 100
Phosphor Bronze	0.01 to 100	> 100
Brass	0.01 to 100	> 100
Nickel	0.01 to 100	> 100
Beryllium Copper	0.001 to 0.01	> 100
Copper	0.001 to 0.01	> 100
Red Gold	0.001 to 0.01	0.01 to 100
Green Gold	0.001 to 0.01	0.01 to 100
Silver	< 0.001	0.01 to 100
Silver-Cadmium Oxide	< 0.001	> 100
Tin	< 0.001	0.001 to 0.01
Tin-Lead	< 0.001	0.001 to 0.01
Rhodium	< 0.001	0.001 to 0.01
Platinum	< 0.001	0.001 to 0.01
Platinum-Iridium	< 0.001	0.001 to 0.01
Gold*	< 0.001	< 0.001

* From this table it can be seen that only gold maintained its resistance value of < 0.001.

Figure 9. Contact resistance.

Examine the results obtained with silver — a variation of 0.001 to 100 ohms is indicated. At first this does not seem acceptable since films on the surface of silver tend to be highly resistive, coherent, and tenacious — the major ingredient being a sulfide. However, if a chloride (silver chloride) is present the film may be non-adherent and moderately low resistivewise. Thus, the variation in measurements.

As corrosion on a gasket or on the surface of an enclosure is increased, so will contact resistance. Therefore, a lack of continuity will result between surfaces, and shielding efficiency will decrease. Thus, the greater the corrosion, the less the attenuation.

POROSITY

A great number of metallic materials are plated or finished with some type of conductive coating for protection. However, at times there is a problem in application, in that the plating process leaves porous areas. These porous areas expose the base material to contaminants, resulting in degradation of the surface by corrosion.

Contaminants like sulfur, chlorine and nitrous oxide attack the base metal by migrating into the open areas and under the plating surface. This causes high resistance films to disrupt the surface continuity and decrease shielding.

A second phenomenon created by porous plating is an electrolytic activity at the base material in the presence of moisture. The plating then begins to flake, and corrosion starts to build high resistance films as before. Again, this disrupts the surface continuity and attenuation is destroyed. Therefore, the plating thickness and type should be carefully chosen with respect to application and material types.

Although mesh gaskets are seldom plated, the surfaces with which they come in contact are. If these surfaces are contaminated, the gaskets themselves may become contaminated and unable to perform their attenuation functions due to the discontinuity between surfaces.

EVALUATING CORROSION EFFECTS ON MESH GASKETS

The most logical way to evaluate the effects of corrosion on a shielding gasket is to simulate a corrosive environment in which the gasket material may be used. However, it is not an easy task to duplicate all service conditions in the laboratory. Therefore, it is necessary to evaluate individual effects.

The test used to evaluate the corrosive effects on mesh gaskets was Federal Std. #151, Method 811.1 (5% salt spray solution for a period of 240 consecutive hours). Two hundred and forty consecutive hours is an extended period. However, it is necessary because corrosion rates usually vary with time, the rate being faster in the initial stages of exposure and leveling out with time because of corrosion product build-up.

Eight sample wire mesh materials (Al, Ag/Br, Sn/Cu/Fe, Cad/Steel, SS-304, SS-430, Sn(Cu-Cd)) were chosen and constructed in gasket form, then evaluated before and after salt spray tests with respect to weight, resistance, compression-deflection and shielding effectiveness. The gaskets were subjected to the corrosive environment in three states: (1) The free hanging state; (2) Between an aluminum plate with no plating and an aluminum plate with a chromate finish and; (3) A steel plate with a cadmium finish and a steel plate with a chromate/cadmium finish.

The weight of the gaskets did increase after being subjected to the salt spray atmosphere in amounts from 0.001 to 0.1 grams. This is one indication that a reaction took place. As the corrosive oxides were removed, the weight of the gaskets decreased to a value less than the original weight, presenting a decrease in gasket mass and material area. This decrease in mass and area results in poorer shielding characteristics, because the gasket presents a smaller surface area to reflect the interference wave, and a lesser mass to absorb it.

The contact resistance (Figure 10) increased after the gaskets were subjected to the contaminated atmosphere. This is due to an increase in non-conductive oxides and the formation of greater "holidays" and voids. However, in all cases resistance decreased with an increase in load, consequently shielding efficiency increased. This fact can be attributed to the mechanical breakdown of the non-conductive oxides, and the decrease in open surface area. In comparison, the surface resistance was greater in all cases after salt spray, and the shielding capabilities of the gaskets were decreased because of the discontinuities in conductivity which caused leaky areas.

The in-strength resistance also increased after the

gaskets were placed in the salt spray atmosphere. This is not surprising since the resistance of a wire varies inversely with the cross-sectional area and as the diameter decreases the resistance increases. Therefore, the resistance of a gasket which is made of wire specimens will increase as it corrodes in a salt solution.

The resiliency of all the gasket materials was reduced after being subjected to the corrosive atmosphere. This can be seen in the typical % deflection curve (Figure 11). For example, the monel gasket dropped from 28% to 26% at 20 psi; the aluminum gasket from 21% to 17% at 20 psi; the Sn/Cu/Fe gasket from 31% to 26%; and the Cad/Steel gasket from 34% to 10%. As a matter of fact, the Cad/Steel gasket was almost completely deteriorated. Therefore, the service life, with respect to shielding, of all gaskets in this type of atmosphere is appreciably reduced.

With respect to the above tests, all indications tend toward a decrease in shielding efficiency after a gasket has been subjected to a salt spray or corrosive environment. To verify this, a radiated characteristic shielding test was performed, before and after salt spray application, to measure the shielding attenuation characteristics of each gasket. In general, the shielding efficiency decreased 5 to 15 dB. However, this is with respect to the free hanging gasket materials themselves and, basically, did not consider galvanic corrosion (see photographs, pages 16 & 17). However, looking at the results in the photos of the gasket materials between plates (pages 20 & 21) and the typical attenuation characteristic curve (Figure 12) it is easily recognized that the addition of galvanic corrosion to the other types would present a severe corrosion and shielding leakage problem. Therefore, the decrease in shielding efficiency would be greater, at least 50 to 60 dB.

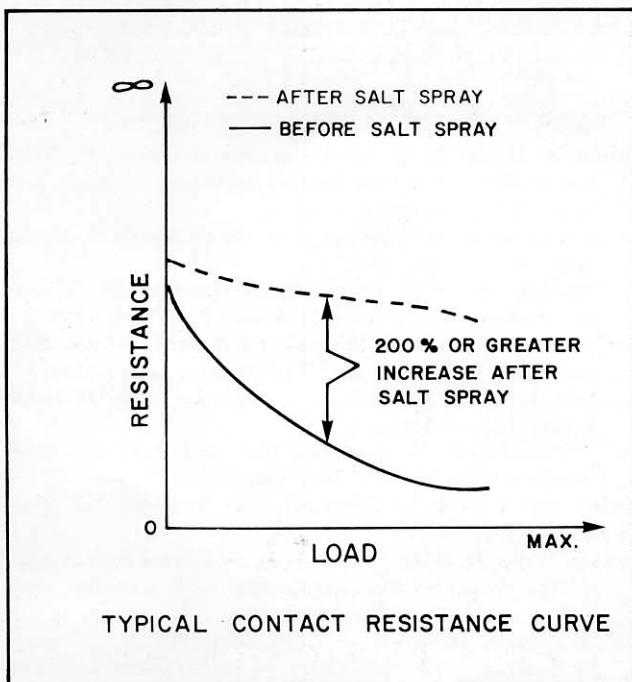


Figure 10.

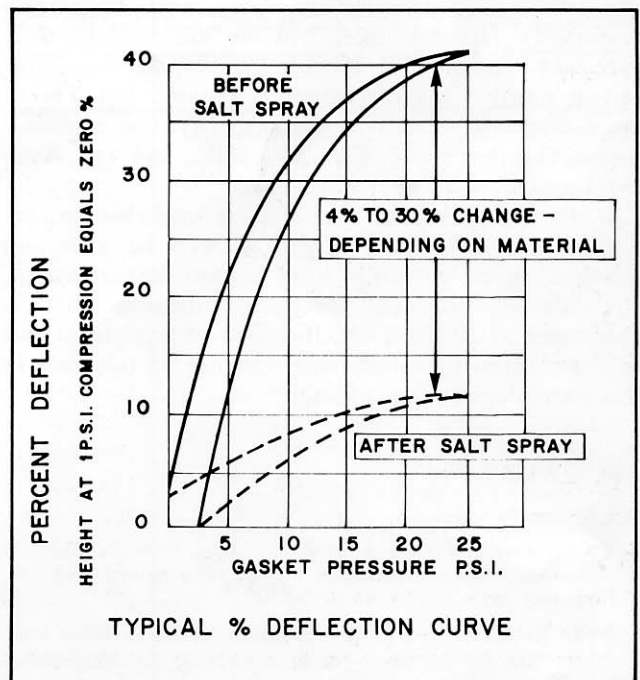


Figure 11.

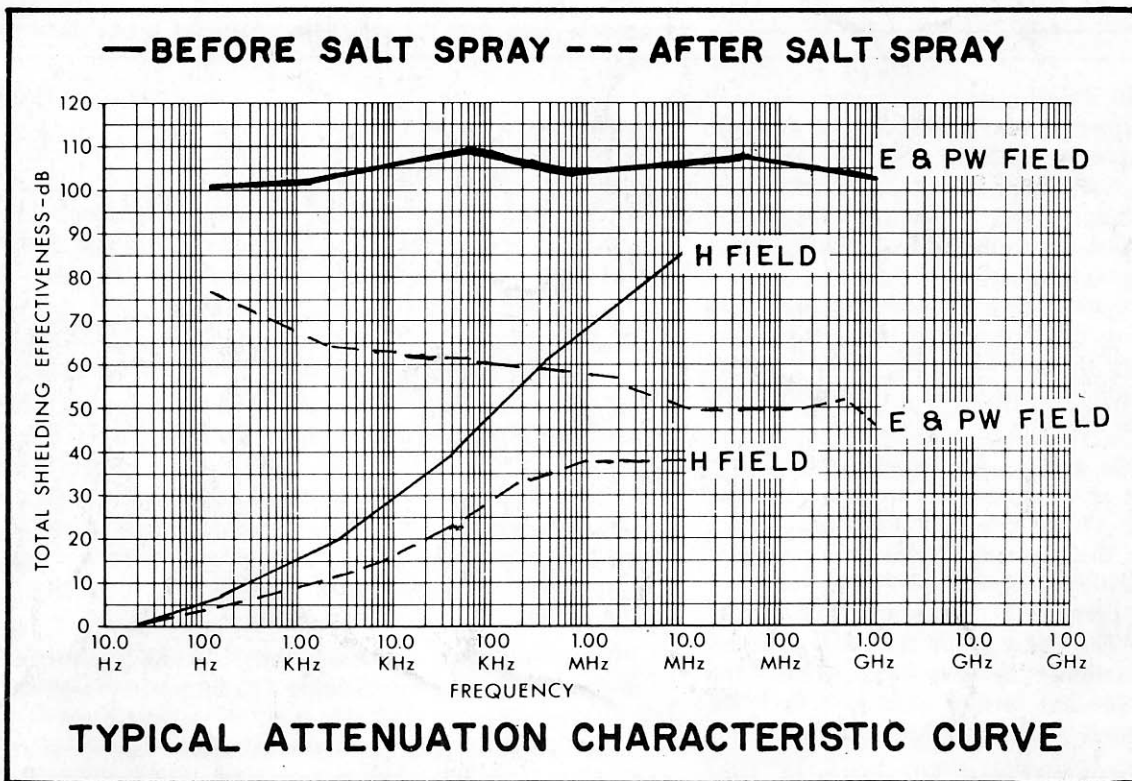


Figure 12.

CONCLUSION

Corrosion is like cancer; once the process begins, it continues to grow until the attenuation efficiency of the enclosure or wire mesh gasket is completely destroyed. Although there are many mysteries the engineering world has not yet solved with respect to corrosion, (for example; (1) The mechanism by which a metal atom leaves its lattice and becomes a hydrated ion in solution; (2) What determines the ability of a material to form an adherent protective film), corrosion must be stopped. It is imperative that the design engineer, especially in the EMI/RFI field, designs to protect against corrosion.

A step in this direction is to start with these basic rules: (1) Use the most suitable corrosion-resistant materials available; (2) Provide the best corrosion protection possible for the materials chosen; (3) Try to avoid dissimilar metals in contact; (4) Use combination environment and EMI/RFI seals; and (5) Keep moisture out of all electrical bonds.

If the possibility of corrosion is neglected in the design phase, shielding might as well be a second thought. Since shielding is of utmost importance in our crowded electronic spectrum, corrosion must be considered at all times. Malfunction of equipment due to electromagnetic interference can not be tolerated in this technological day and age.

ACKNOWLEDGMENT

Thanks Are Extended To:

- (1) International Testing Laboratories, Inc., Newark, N.J. for conducting salt spray tests in accordance with Fed. Std. 151, Method 811.1.
- (2) Mr. Robert Cuneo, Project Engineer, Technical Wire Products, Inc. for his assistance in conducting the compression-recovery experiments.

- (3) Mr. William Monroe, Laboratory Technician, Technical Wire Products, Inc. for his assistance in conducting the EMI/RFI shielding tests.

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