Corrosion and EMI Evaluation of Gasketed Systems After Sulfur Dioxide Salt Fog Exposure

ROBERT FOSTER, DAVID INMAN and PHILIP LESSNER
Chomerics, Inc., Woburn, MA*

INTRODUCTION

EMI shielding requirements for electronic systems are becoming increasingly stringent in military and commercial aerospace systems. This has led to increased use of conductive gaskets, sealants, and coatings. Such materials are used to provide a low impedance interface between mating joints in electronic enclosures and to enhance the shielding effectiveness of aircraft structures. The conductive materials usually incorporate silver, silver-plated metals, copper, nickel, Monel, or other metals. The electronic enclosures and structural components are typically made from aluminum alloys. When exposed to corrosive environments, a galvanic couple will occur between the gasket and the aluminum. This can result in corrosion of the aluminum because it is less noble than the conductive interface material. Depending on the type of gasket material, it too may deteriorate in a corrosive environment. Shielding effectiveness can degrade as a result of conductivity loss due to the buildup of nonconductive corrosive material between the seal and the aluminum flange.

This deterioration was evident in the electronic enclosure of a mobile missile launcher system. The enclosure was found to have a buildup of corrosion products and pitted aluminum after exposure to a marine environment. The manufacturer of this system wanted to replace the shielding gasket and conductive coating with materials that would be less corrosive when used in conjunction with the aluminum enclosure, but that would still provide the required 60 dB level of shielding effectiveness up to 10 GHz after long-term exposure to the marine environment. This required a test to evaluate the shielding effectiveness before and after environmental exposure and corrosion.

Gasketed systems exposed to harsh environments must be specially treated to maintain shielding effectiveness.

Three tests were considered for predicting the ability of the system to shield before and after environmental exposure: dc electrical resistance, transfer impedance, and radiated shielding effectiveness measurements.

The dc resistance test method measures the surface resistance of conductive gaskets, conductive flange coatings, and sometimes of the complete gasketing systems. This method requires a minimum amount of test equipment and is very easy to perform. Using only a digital voltmeter (DVM), one can easily obtain repeatable measurements. However, dc resistance measurements cannot predict EMI leakage at radio and microwave frequencies.

The transfer impedance method measures electrical impedance as a function of frequency across a joint or flange. This method requires a specialized test fixture and test equipment and is only feasible up to 1 GHz. To perform a system test, a custom test fixture must be built. Performing the test correctly can be complicated, but produces repeatable data. However, this test may be misleading when trying to relate results to an actual shielding effectiveness value. This method, although commonly cited, only gives a small part of the total shielding picture of a gasketing system.

The radiated shielding method measures the attenuation of a radiated electric field and plane waves across a gasket/flange system. This method is complicated and requires an array of test equipment and a shielded enclosure. The data can be misinterpreted if the test is not performed correctly. However, this method is excellent for testing a gasket/flange system for electric field and plane wave attenuation. When the test is performed carefully, the test can be considered a useful engineering tool.

This radiated electric field attenuation test was used in this study because of its overall ability to test a gasket system and provide reliable engineering data.

Two marine environments were considered for corrosion testing of the systems. The environment at an unpolluted seacoast location or on a naval vessel burning clean fuel (e.g., nuclear) can be simulated by running a neutral salt fog test using the procedure found in ASTM Standard B117 or MIL-STD-810, Method 509.2. However, some time ago the U.S. Navy recognized that this test was not severe enough to simulate the environment on an aircraft carrier that burns sulfur-containing fuel. The Navy subsequently developed an acidic salt fog test to better simulate this corrosive environment; this test has become standardized as ASTM Standard G85, Annex A4. The effect of burning sulfur-containing fuel is simulated by periodically introducing sulfur dioxide gas into the salt fog. This test has shown good correlation with test panels exposed on an aircraft carrier. It can also be used to simulate the environment at a polluted seacoast location. The manufacturer of the missile launcher felt that the sulfur dioxide salt fog test would provide the most extreme and most realistic environmental exposure.

This article reports on shielding effectiveness measurements of conductive gasket-conductive flange coating systems before and after exposure to sulfur dioxide salt fog. Based on the factors discussed above, a radiated method of determining shielding effectiveness was used. The shielding effectiveness measurements were supplemented by dc electrical resistance measurements on the coated flanges and gaskets. The gaskets, coatings, and aluminum flange materials were also examined for evidence of corrosion and physical deterioration after exposure.

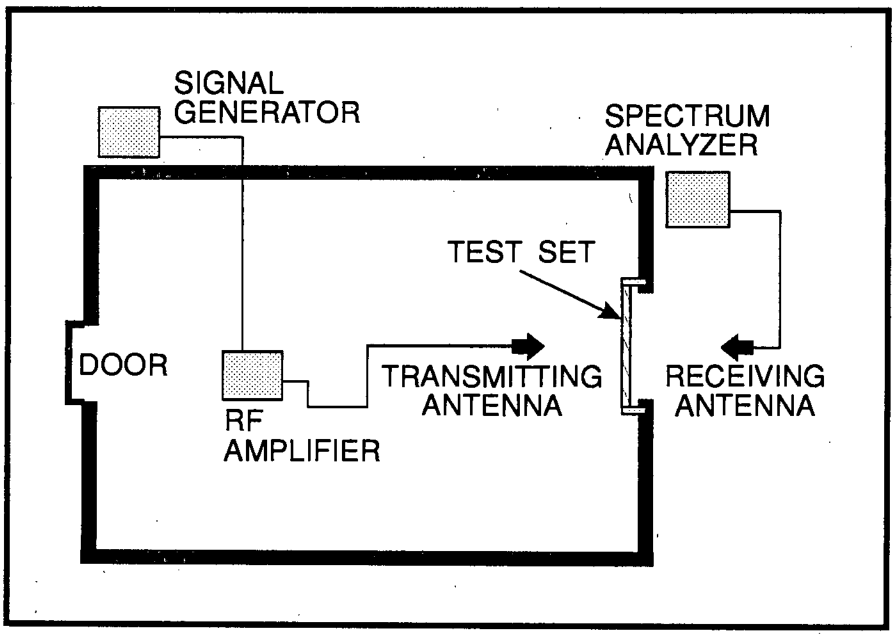

***FIGURE 1.** Shielding Effectiveness Measurement Layout.*

EXPERIMENTAL METHODS

TEST METHODS

Radiated Electric Field Shielding Tests

Attenuation tests for radiated electric fields and plane waves were performed in accordance with Paragraphs 4.1.2 and 4.1.3 of MIL-STD-285. The only exceptions to the MIL-STD-285 method were that the receiving equipment was placed outside the shielded enclosure and an extended set of frequencies were selected for the test.

This shielding effectiveness test configuration is shown in Figure 1. The test set, representing a simulation of the actual electronic enclosure, was bolted over an opening in the wall of a shielded enclosure. The transmitting antennas and RF amplifiers were placed inside the shielded enclosure. The receiving antennas, signal generators, and spectrum analyzers were placed outside the shielded enclosure. In accordance with MIL-STD-285, the transmitting and receiving antennas were placed two feet apart plus the width of the test panel. To achieve isolation between the transmitting and receiving test equipment, the spectrum analyzers and signal generators were placed 15 feet away from each other.

An open reference was taken in free space outside the shielded enclosure. A closed reference was taken with the test set in place. Shielding effectiveness was calculated by subtracting the power level measured during the open reference from the power level recorded with the test set in place. Shielding effectiveness measurements were taken on the test sets before and after sulfur dioxide salt fog exposure.

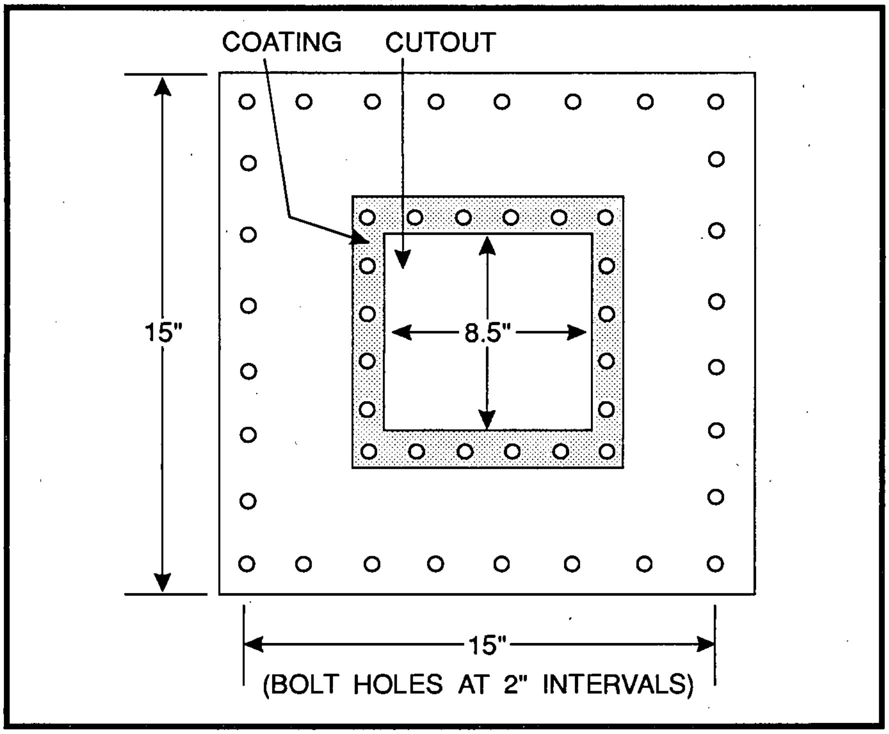

FIGURE 2. *Adapter Test Plate.*

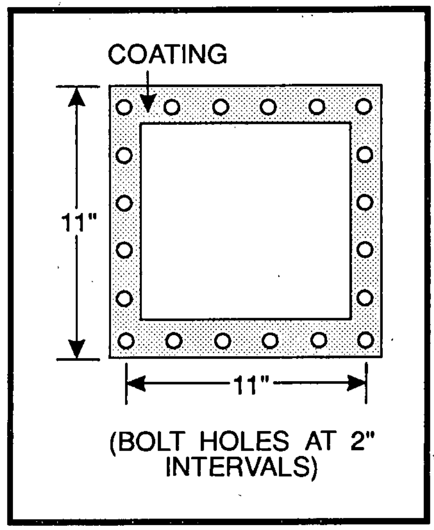

FIGURE 3. *Cover Test Plate.*

Test System Configuration

This study was performed to evaluate the EMI integrity of an existing mobile missile launcher's electronic enclosure before and after exposure to 192 hours of SO_2 salt fog. Therefore, test plates were fabricated with bolt spacing, compression stops and gasket configuration designed to represent the existing electronic enclosure and to fit inside the salt fog chamber. The test plates and compression stops were fabricated from an aluminum alloy, and all surfaces were chromate conversion coated to MIL-C-5541, Class 3. The gaskets used were a "P" cross-section conductive elastomer with a bulb diameter of 0.200 inch.

The adapter plate, Figure 2, comprises one half of the test plate set. Its outer bolt pattern matches the inner bolt pattern on the wall of the shielding enclosure. Its inner bolt pattern accepts the bolts from a cover plate. The adapter test plate is 0.125 inch thick. The aperture opening in the adapter plate is 8.5 inch^2.

The cover plate, Figure 3, is the other half of the test plate set. Its bolt pattern matches the inner bolt pattern on the adapter plate. The cover plate is 0.250-inch thick.

A conductive coating was applied to the gasket and compression stop mating area on the adapter test plate and cover test plate. The area coated is illustrated in Figures 2 and 3. The conductive coating was a two-part urethane containing a stabilized copper filler, copper corrosion inhibitors, an aluminum corrosion inhibitor, and an inorganic pigment. The function of these components in the makeup of a corrosion resistant conductive coating has been discussed in a previous paper.[1]

The compression stops were 0.122-inch thick strips of aluminum. This thickness was selected so that the nominal deflection of the gasket would be 39 percent. The system was assembled as shown (schematically) in Figure 4.

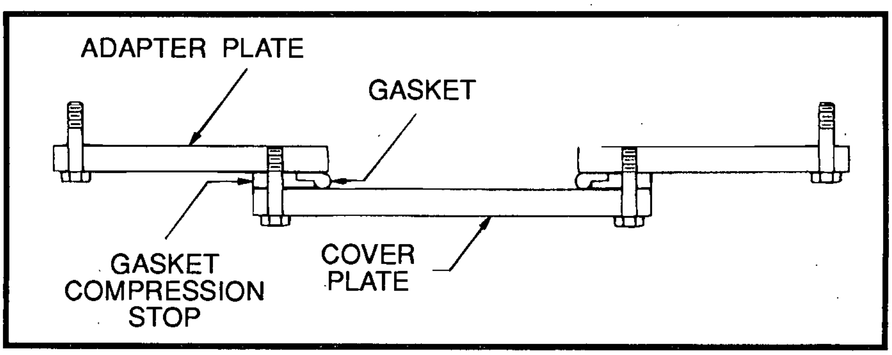

FIGURE 4. *Assembled System.*

The two systems tested were a silver-plated copper-filled silicone gasket (Ag-Cu gasket)

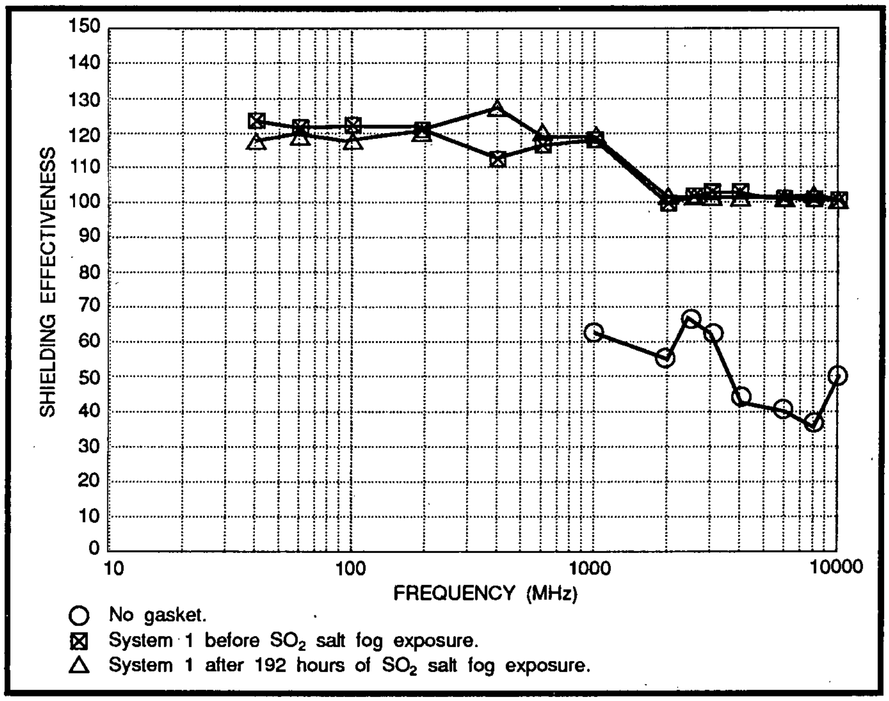

***FIGURE 5.** Shielding Effectiveness Versus Frequency.*

against the stabilized copper coated flanges (System 1) and a silver-plated aluminum-filled silicone gasket (Ag-Al gasket) against the stabilized copper coated flanges (System 2).

Salt Fog Tests

The test sets described above were exposed to 192 hours (8 days) of sulfur dioxide salt fog. The salt fog conditions were as described in ASTM Standard G85, Annex A4. The cycle defined in Paragraph A4.4.4.1 of this standard was used: constant 5-percent salt fog with introduction of sulfur dioxide for 1 hour, 4 times a day (every 6 hours).

CORROSION EVALUATION

After the final shielding tests, the test sets were disassembled. The coatings were examined for any evidence of discoloration, blistering, or loss of adhesion. Particular attention was paid to the coating deterioration in the areas under the gasket footprint and under the compression stops. This would indicate incompatibility of the coating with the gasket or aluminum. To make an electrical check for any coating deterioration, the dc resistivity of the coated plates was measured with the surface probe described in MIL-G-83528A.

After visual examination of the coated plates, the coating was stripped off using an organic solvent. The aluminum plates were then examined for evidence of pitting and corrosion at the gasket-flange interface, under the gasket footprint, and under the compression stops. The compression stops themselves were also examined for corrosion.

The gaskets were also examined to determine how they withstood the sulfur dioxide salt fog environment. The percent recovery of the gasket's initial height and the gasket's volume resistivity were measured.

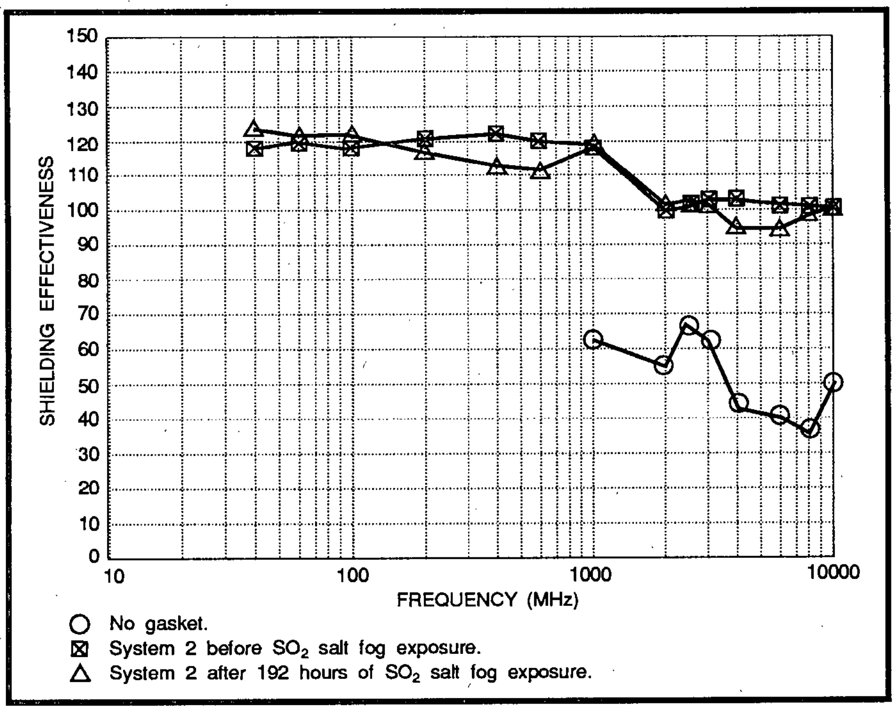

***FIGURE 6.** Shielding Effectiveness Versus Frequency.*

RESULTS AND DISCUSSION

SHIELDING EFFECTIVENESS

The shielding effectiveness without any gasket and with the cover and adaptor plate separated by nonconductive compression stops is shown in Figure 5. Shielding effectiveness ranges from 62 to 26 dB over the frequency range of 1 to 10 GHz. This test was performed to evaluate the test setup for shielding effectiveness without a gasket system in place.

The shielding effectiveness of the Ag-Cu gasket against the stabilized copper coating (System 1) ranged from 121 dB to 99 dB from 40 MHz to 10 GHz before sulfur dioxide salt fog exposure (Figure 5). The shielding effectiveness of System 1 after sulfur dioxide salt fog exposure ranged from 123 to 97 dB. From the overall trend of the data, the shielding effectiveness of System 1 did not degrade after 192 hours of sulfur dioxide salt fog exposure. Rather, System 1 demonstrated up to 71 dB improvement in shielding effectiveness exposure when compared to the control test.

Figure 6 shows a similar plot for the Ag-Al gasket against the stabilized copper coating (System 2). Shielding effectiveness ranged from 123 to 99 dB before sulfur dioxide salt fog exposure. After sulfur dioxide salt fog exposure, shielding effectiveness ranged from 122 to 95 dB. From the overall trend of the data, the shielding effectiveness of System 2 did not degrade with 192 hours of sulfur dioxide salt fog exposure. After the exposure, System 2 demonstrated up to 73 dB improvement in shielding effectiveness when compared to the control test.

CORROSION EVALUATION

Figure 7a shows the cover plate of the Ag-Cu gasket and stabilized copper coating system (System 1) after 192 hours of sulfur dioxide salt fog exposure. The

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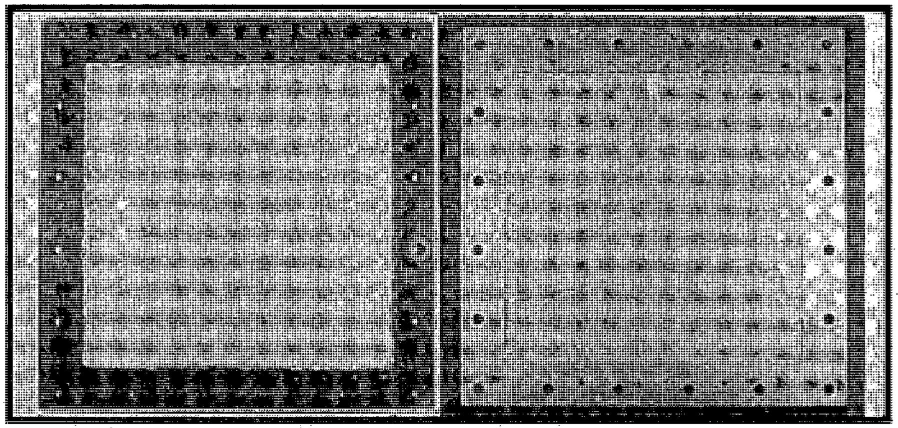

FIGURE 7. *Cover Plate of System 1 After 192 Hours of SO_2 Salt Fog Exposure. 7a: Flange Coating Intact. 7b: Flange Coating Removed.*

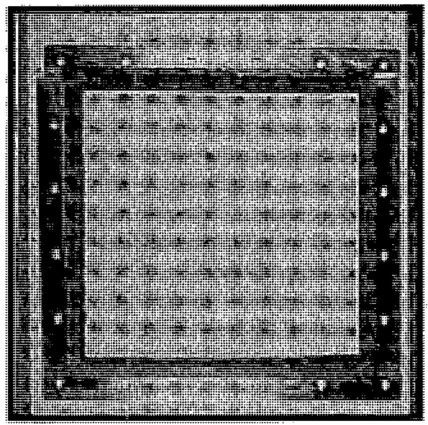

FIGURE 8. *System 1 Compression Stops and Gasket After 192 Hours of SO_2 Salt Fog Exposure.*

coating remained adherent under the gasket footprint and under the compression stops. Some lifting of the coating is noticeable at the gasket-flange interface. Resistivity readings on the coated plate ranged from 0.09 to 0.2 ohm/square after exposure. Typical readings before exposure are from 0.05 to 0.1 ohm/square. Thus, the coating remained highly conductive.

Figure 7b shows the same cover plate after the coating has been stripped off. The uncoated area at the gasket-flange interface is severely pitted in several spots. In contrast, the areas under the gasket footprint and under the compression stops (which were coated) show almost no pits except for some slight penetration under the lifted edge of the coating.

Figure 8 shows the condition of the Ag-Cu gasket and the compression stops after exposure. The compression stops are corroded. The gasket is darkened at the outer edge and under parts of the footprint. There is evidence of copper corrosion on the gasket. The outer edge appears to be partially torn. Figure 9 shows how the original cross-section of the gasket compares to the cross-section after sulfur dioxide salt fog exposure. The cross-section of the Ag-Al gasket is considerably less distorted than the cross-section of the Ag-Cu gasket. The Ag-Al gasket recovered over 90 percent of its original height after exposure. The Ag-Al gasket also remained highly conductive after exposure, undergoing a resistivity increase of about 2.3 times. The Ag-Cu gasket recovered only 71 percent of its original height. The volume resistivity only increases from 0.004 ohm-cm to 0.011 ohm-cm.

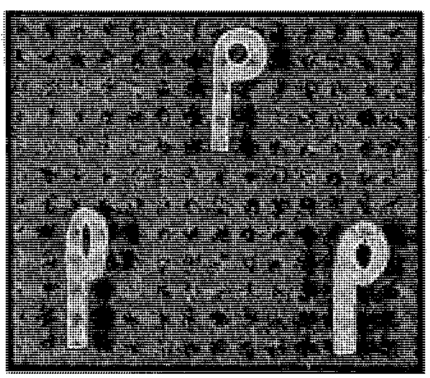

FIGURE 9. *Cross-section of Gaskets. Top: Original Cross-section; Bottom: After 192 Hours of SO_2 Salt Fog Exposure; Left: Ag/Cu Gasket; Right: Ag/Al Gasket.*

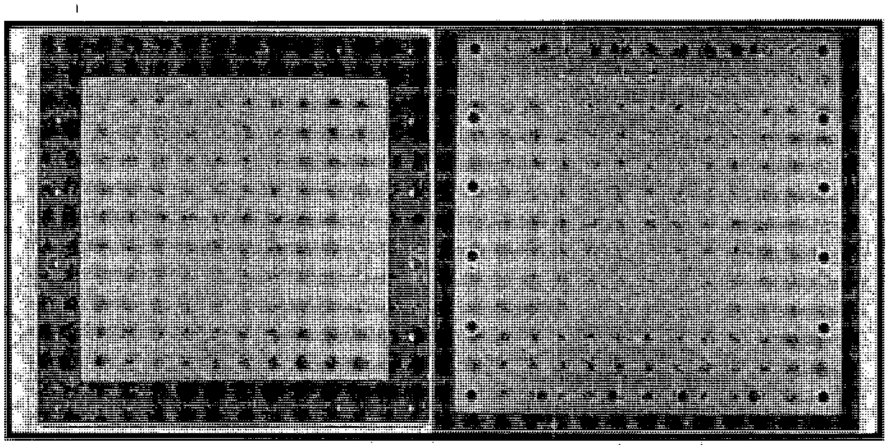

FIGURE 10. *Cover Plate of System 2 After 192 Hours of SO_2 Salt Fog Exposure. 10a: Flange Coating Intact. 10b: Flange Coating Removed.*

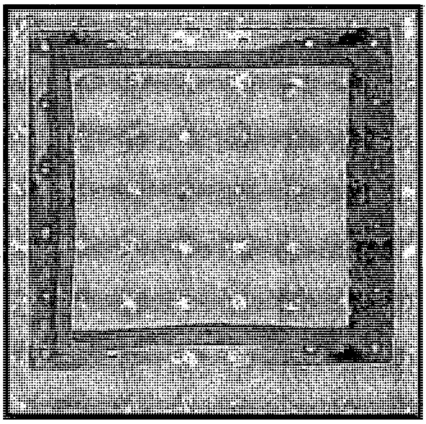

FIGURE 11. System 2 Compression Stops and Gasket After 192 Hours of SO_2 Salt Fog Exposure.

Figure 10a shows the cover plate of the Ag-Al gasket and stabilized copper coating system (System 2). The coating remained adherent except for some lifting at the edge. Resistivity of the coated plate was from 0.08 to 0.15 ohm/square after exposure. This was similar to System 1.

Figure 10b shows the same cover plate after the coating has been stripped off. The uncoated area at the gasket-flange interface is much less severely attacked than was System 1. There is some minor corrosion (lower left corner of figure) where the salt fog penetrated under the edge of the coating.

Figure 11 shows the condition of the gasket and compression stops after exposure. The compression stops were severely attacked by sulfur dioxide salt fog. The gasket shows darkening at the outer edge.

CONCLUSIONS AND RECOMMENDATIONS

It is apparent from the shielding effectiveness measurements that both systems were more than able to retain the required 60 dB of shielding effectiveness after 192 hours of sulfur dioxide salt fog exposure. This conclusion was supported by dc resistivity measurements, which showed that both the gaskets and the stabilized copper coating remained highly conductive after exposure.

The corrosion behavior and physical condition of the gaskets were quite different for Systems 1 and 2. The Ag-Cu gasket underwent a severe compression set while the Ag-Al gasket recovered most of its original height. The stabilized copper coating was able to protect the flange against corrosion by both gaskets; however, exposed aluminum surfaces were more severely corroded by the Ag-Cu gasket.

The additional protection afforded by the stabilized copper coating in the aggressive sulfur dioxide salt fog environment is most clearly illustrated by the condition of the flange area protected by the conductive coating compared to the uncoated compression stops. The compression stops were severely corroded while the coated flanges were not. The slight undercutting of the edge of the conductive coating by corrosion could be eliminated by edge sealing the conductive coating with a nonconductive paint.

ACKNOWLEDGEMENTS

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REFERENCES

1. P. Lessner, "Corrosion Resistant Materials For EMI Applications," CORROSION/91, Paper No. 336, National Association of Corrosion Engineers, Cincinnati, OH, March 1991.

***ROBERT FOSTER** is currently employed as an EMI Engineer with Chomerics Radiation Test Services. Mr. Foster has worked for Chomerics for seven years in the evaluation and testing of EMI materials and designs for military and commercial applications. He also is responsible for testing and evaluating electronic equipment for military commercial equipment test specifications including MIL-STD-461, TEMPEST, FCC, and CISPR. Mr. Foster received his Electrical Engineering Degree from Northeastern University. (617) 935-4850.*

*As Manager of TEMPEST related activities at Chomerics Radiation Test Services, **DAVID C. INMAN** is responsible for supervising Chomerics testing efforts in the area of MIL-STD-461, TEMPEST, FCC, VDE, CISPR and other commercial and military test activities. He has nine years experience in the analysis, design, development, implementation and evaluation of electrical and electromechanical equipment to meet EMI requirements. Mr. Inman received his Bachelor of Electrical Engineering Technology degree from Roger Williams College. He is a certified TEMPEST Engineer and a NARTE certified Electromagnetic Compatibility Engineer. Mr. Inman is a member of the Armed Forces Communication Electronic Association (AFCEA). (617) 935-4850.*

***PHILIP LESSNER** is a Senior Research Scientist at Chomerics, Inc. Dr. Lessner is responsible for all aspects of corrosion evaluation of conductive elastomers and coatings. He is a member of the National Association of Corrosion Engineers Committee on Corrosion of Electronic Equipment and is helping to coordinate a revision of an SAE document on corrosion of electronic enclosures. (617) 935-4850.*