peters
Coating Innovations for Electronics

WP WHITE PAPER

How to Increase the Reliability of Electronics in Severe Corrosive Environments

The corrosive effect of environmentally-related gaseous influences on components and materials of electronic assemblies affects the reliability and life cycle of electro technical products.

Investigations concerning the resistance against noxious gases are carried out by simulating the influence on technical or electronic products, or on electronic assemblies, of atmospheres contaminated by noxious gases, i.e. the subaerial agents of the so-called “industrial atmosphere”. According to the test regulations, different types of tests are possible:

- Single gas tests,
- Single gas tests connected in series,
- Mixed flowing gas tests; the concentrations being similar to the actual conditions in the atmosphere.

A typical industrial atmosphere is composed of many different noxious gases. Table 1 lists up noxious substances and their content of pollutants.

Table 1: Typical pollutants in industrial atmospheres

Pollutant		Content in industrial atmospheres
Sulphur dioxide	SO_2	0.1–1 ppm
Hydrogen sulphide	H_2S	0.01–0.1 ppm
Nitrogen monoxide and nitrogen dioxide	$NO + NO_2$	0.01–0.1 ppm
Chlorine and hydrogen chloride	$Cl_2 + HCl$	0.01–0.1 ppm
Ozone	O_3	0.05–0.5 ppm
Ammonia	NH_3	0.01–0.05 ppm
Formaldehyde	HCHO	approx. 0.02 ppm
Carbon monoxide	CO	2–100 ppm
Dust		0.1 mg/m³

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In industrial atmospheres, typical noxious gases are the so-called nitrogen oxides or nitric oxides and sulphur oxides. The nitrogen oxides are abbreviated by NO_x as there are several nitrogen-oxygen compounds due to the many oxidation phases of nitrogen. With the exception of nitrous oxide, they react with water or humidity in the atmosphere to form various nitric acids. Due to this acid formation, they have an irritating and toxic effect on mucous membranes and attack materials. In case of the sulphur oxides, it is principally the sulphur dioxide (SO_2) and, to a lesser extent, the sulphur trioxide (SO_3) which are concerned. Both sulphur oxides form acids in aqueous solutions. Sulphurous acid (H_2SO_3) is formed out of sulphur dioxide whereas sulphuric acid (H_2SO_4) is produced from sulphur trioxide. Both acids contribute to the acidification of lakes and the forest dieback. Both sulphur oxides are also toxic in a gas state and attack materials as oxidants or acids.

Hydrogen sulphide is added to mixed flowing gases as especially corrosive for silver materials. Chlorine ions are introduced into the test atmosphere to emulate a coastal or maritime climate.

Background

Since electronics needs also to operate under harsh industrial or other conditions such as maritime or airborne conditions it is important to ensure that these devices withstand these conditions in the best case for a defined period of time. As already mentioned there are several different corrosive gas tests known for electronics. The Standard ISA-71.04-2013 provides the resistance of the industrial atmosphere via the corrosive reaction to copper and silver.

The following study from Peters describes the capacity of **ELPEGUARD®** conformal coatings to protect electronics in severe corrosive environments to improve the reliability of electronics and avoid field returns because of corrosion due to the exposition to corrosive gas. Different types of conformal coating as defined in IPC-CC-830C were chosen for the MFG test to prove which offers best protection in this regard (see also table 4).

Mixed Flowing Gas (MFG) and Moisture Insulation Resistance (MIR) Test

The following MFG and MIR testing was performed by the accredited test laboratory iST (Integrated Service Technology Inc., Taiwan, www.istgroup.com) based on the standards ISA-71.04-2013 and MIL-STD-202G.

Mixed Flowing Gas (MFG) Severity Simulation ISA-71.04 GX

The ISA-71.04-2013 standard has variants worldwide such as JEIDA-29-1990 (Japan) and the International Electrochemical Commission (IEC) Standard, IEC 60654-4 (1987-07). All of these standards characterize operating environments in terms of their overall corrosion potential.

According to the ISA-Standard, the corrosion potential of air pollutants on electronic assemblies can be divided into various levels of severity. In table 3, corrosion classes are listed describing the corrosiveness of an industrial atmosphere and its aggressive reaction to copper and silver.

Table 2: Composition of MFG acc. to ISA Standard 71.04-2013 at 25 °C and 75 % r. h.

	H_2S	SO_2	Cl_2	NO_2
Concentration [ppb]	50	300	10	1.250
Concentration [ppm]	0.05	0.3	0.01	1.25

The test substrates are tested under corrosive gas test conditions for a period of 30 days. The corrosion on the test substrates is measured and analysed via a coulometric reduction analysis. Depending on the result (measured in Angstroms [Å] per month), the environment is classified as G1 – Mild to GX – Severe.

Table 3: Corrosivity Classification acc. to ISA Standard 71.04-2013

Severity Level	Reactivity Level	Cu Corrosion Rate	Ag Corrosion Rate	Expected Downtime of Unprotected Electronics
G1	Mild	< 300 Å / month	< 200 Å / month	No failures to be expected through corrosion; a trouble-free operation of over 10 years is predicted.
G2	Moderate	< 1000 Å / month		Electronic components may show faults after 3-5 years, with risk of failure of components after 5-7 years; no disturbance if electrical components were coated.
G3	Harsh	< 2000 Å / month		Electronic components can only be operated with extra effort; malfunctions may occur after several months, with risk of failure after 3-5 years.
GX	Severe	> 2000 Å / month		Failure and downtime intervals may occur after a few months or weeks; without considerable effort, a trouble-free operation is impossible.

The corrosion thickness growth will be measured to determine the potential life cycle derived from an accelerated corrosion test on GX severity level within a 30 days simulation.

G1 Level: An environment where even unprotected electronic equipment would be expected to survive.

G2 Level: An environment where the effects of corrosion are measurable and may be a factor in determining equipment reliability. From this level upwards electronics protected by conformal coatings offer a clear advantage.

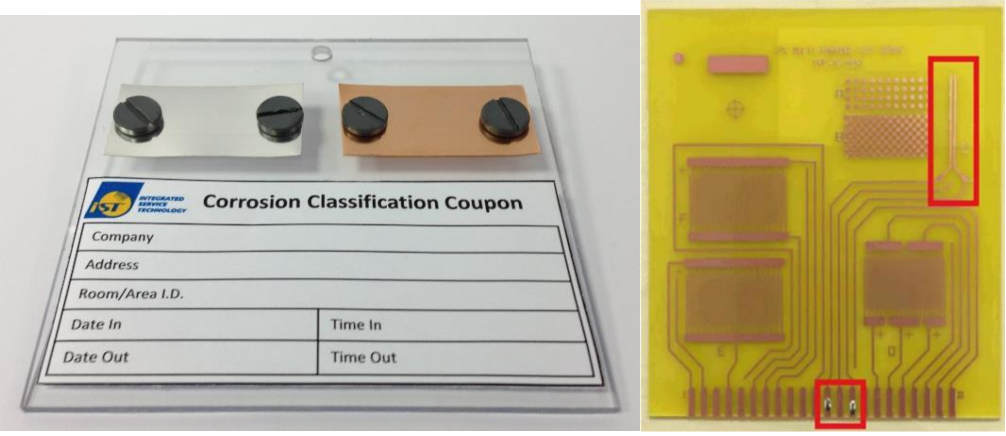
G3 Level: An environment where there is a high risk that corrosive attack will occur. These harsh levels should prompt further evaluation resulting in environmental controls or specially designed and packaged equipment.

GX Level: An environment where only specially designed and packaged equipment would be expected to survive.

Moisture Insulation Resistance (MIR) acc. to MIL-STD-202G

Additionally a Moisture and Insulation Resistance (MIR) was tested to measure the influence of the harsh corrosive test conditions on the electrical insulation of the conformal coatings.

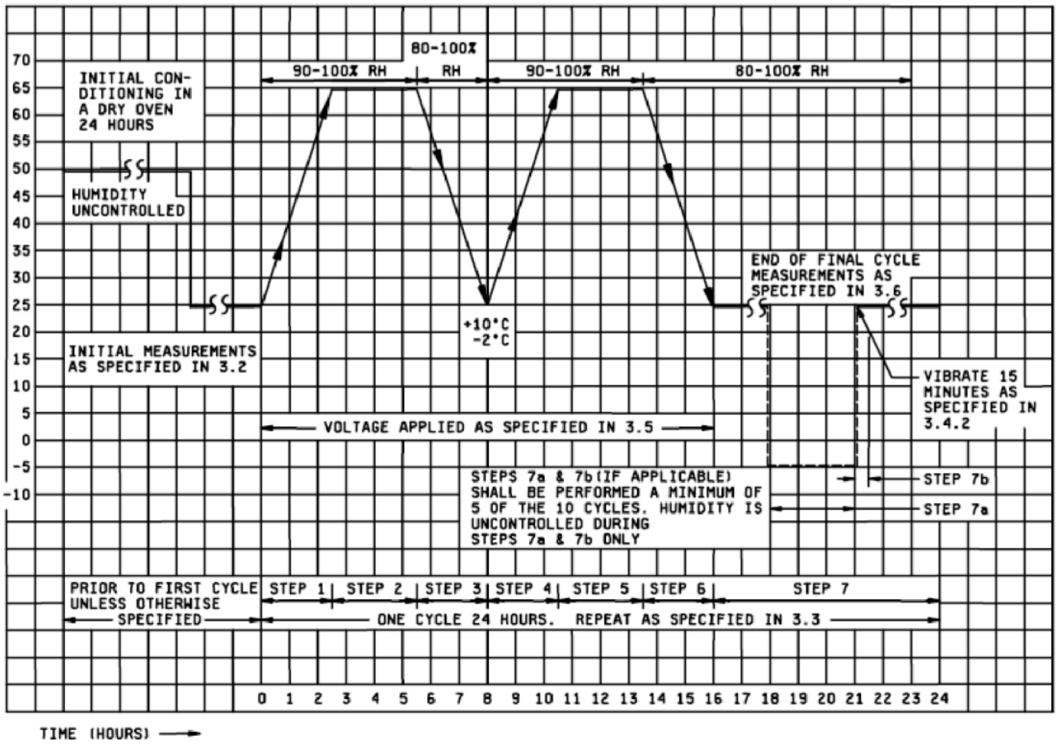
Coated MIR test substrates - IPC-B-25A boards - were also placed in the gas test chamber. They were removed every 2nd day from the gas test to undergo MIR testing. All Y combs (framed red in Picture 1) were tested for Moisture Resistance per MIL-I-46058C, MIL-STD-202G.



Metal Coupons for MFG Test **IPC-B-25A Board for MIR Test**

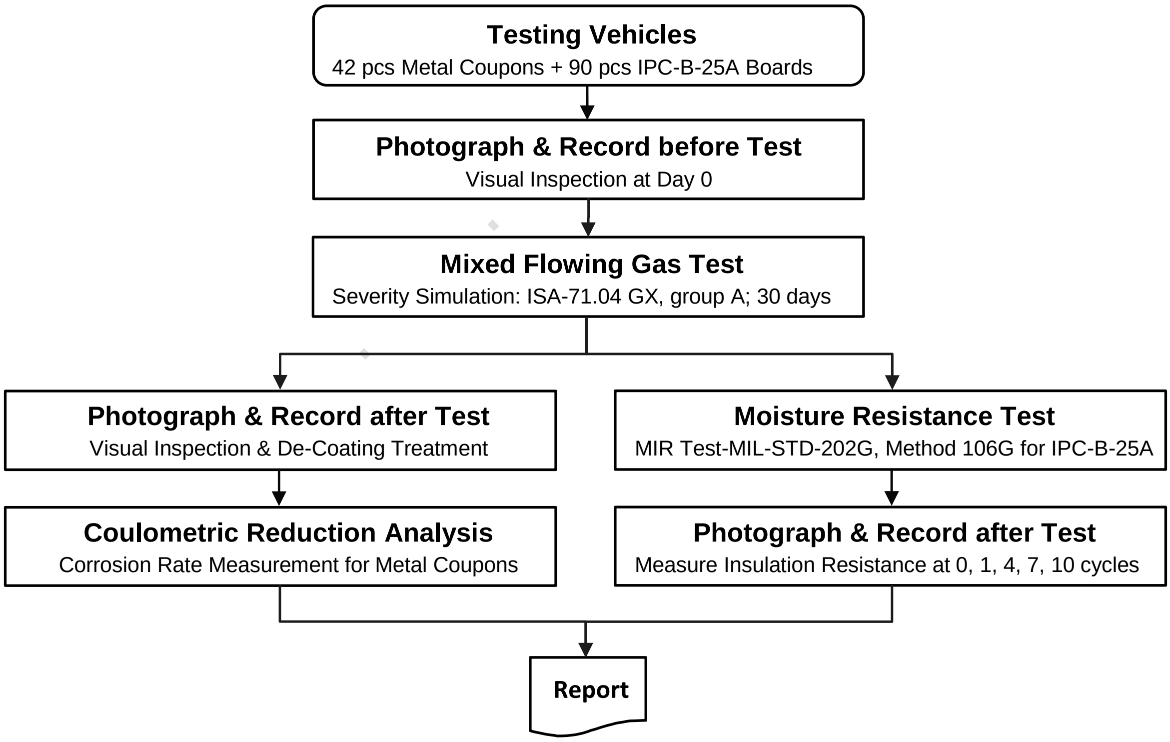
Picture 1: Test vehicles - metal coupon for Mixed Flowing Gas (MFG) test (left) and IPC-B-25A board for Moisture and Insulation Resistance (MIR) test (right)

The MIR test is based on MIL-STD-202G, Method 106G + Bias: DC 100 V (No Vibration).



Picture 2: Procedure of MIR test acc. to MIL-STD-202G, Method 106G

Description of Test Procedure at iST Lab

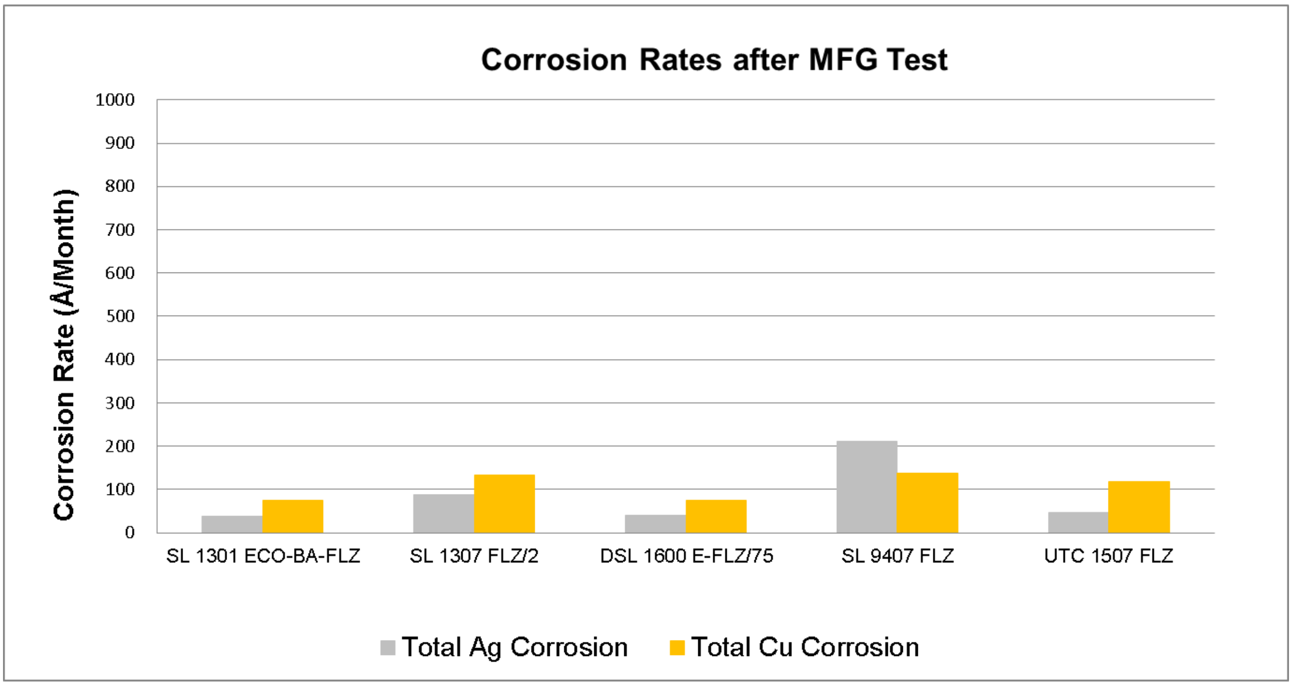


Results of MFG test

Severity level classification was ISA-71.04 GX for the conducted MFG test.

One test vehicle was pure metal foil without coating material (as control group) to verify whether the severity level can achieve ISA-71.04 GX level for this MFG test. The average total corrosion rate of the uncoated test vehicle was 8,767 Angstroms per-month for silver and 2,580 Angstroms per-month for copper. Corrosion rate measurements confirmed that the MFG test exposed the samples to an environment well above the minimum requirement (>2,000 Angstroms per-month) for an ISA-71.04 GX (Severe) rating.

Even in this severe environment all **ELPEGUARD**® conformal coatings tested showed an excellent protection against corrosive gases.



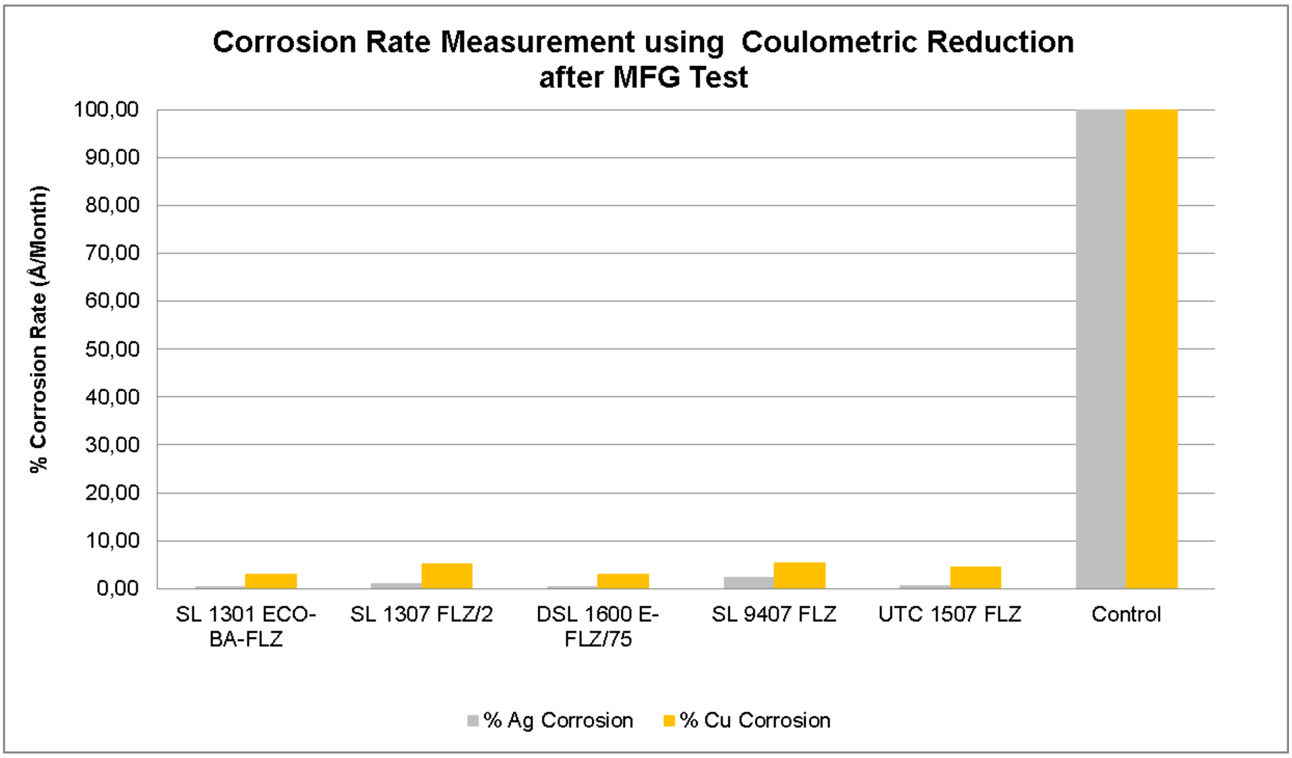
Picture 3: Corrosion Rate Measurement using Coulometric Reduction after MFG Test

Regarding the metal coupons with various coating material groups, a low corrosion rate means that coating material can provide the significant protection of metal against the corrosive gases at ISA-71.04 GX level exposure.

Table 4 shows the average values of the 3 respective test specimen as well as the percentage of the uncoated control group.

Table 4: Ag and Cu Corrosion Rates of ELPEGUARD® conformal coatings

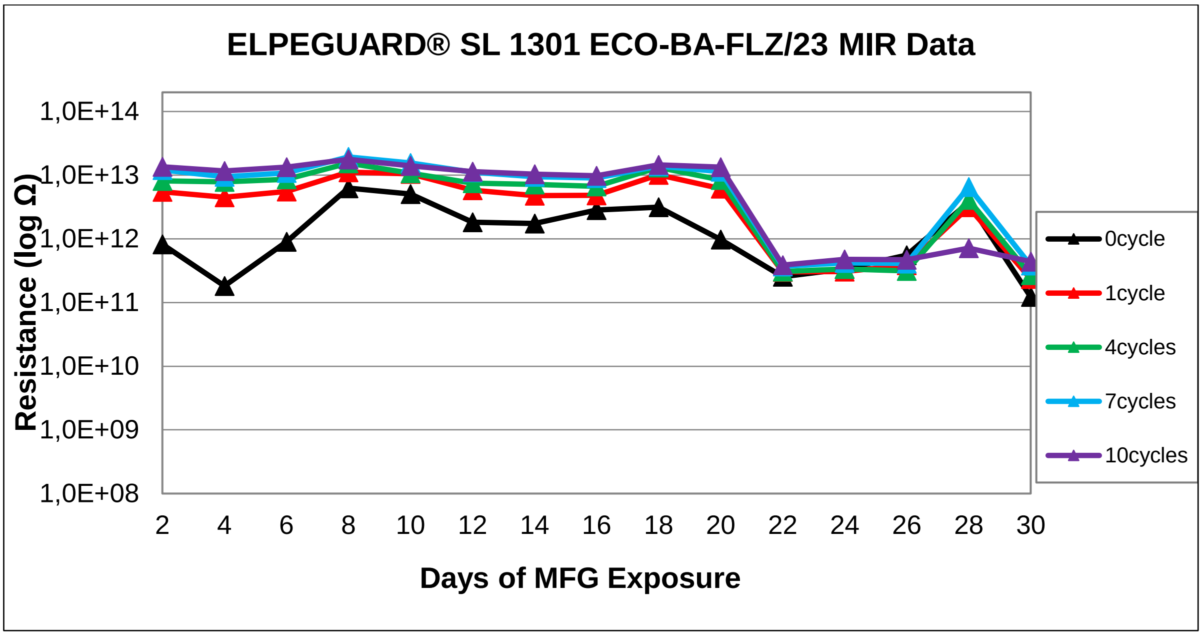
	Type acc. to IPC-CC-830C	Corrosive Reaction Rate (Å/Month)		Corrosive Reaction Rate (compared to Control)	
		Total Ag Corrosion	Total Cu Corrosion	% Ag Corrosion	% Cu Corrosion
SL 1301 ECO-BA-FLZ	UR	38	74	0,43	2,88
SL 1307 FLZ/2	AR	88	134	1,00	5,21
DSL 1600 E-FLZ/75	AR/UR	41	75	0,47	2,92
SL 9407 FLZ (2-pack)	UR	210	138	2,40	5,34
UTC 1507 FLZ	SC	47	119	0,53	4,60
Control		8,768	2,580	100.00	100.00

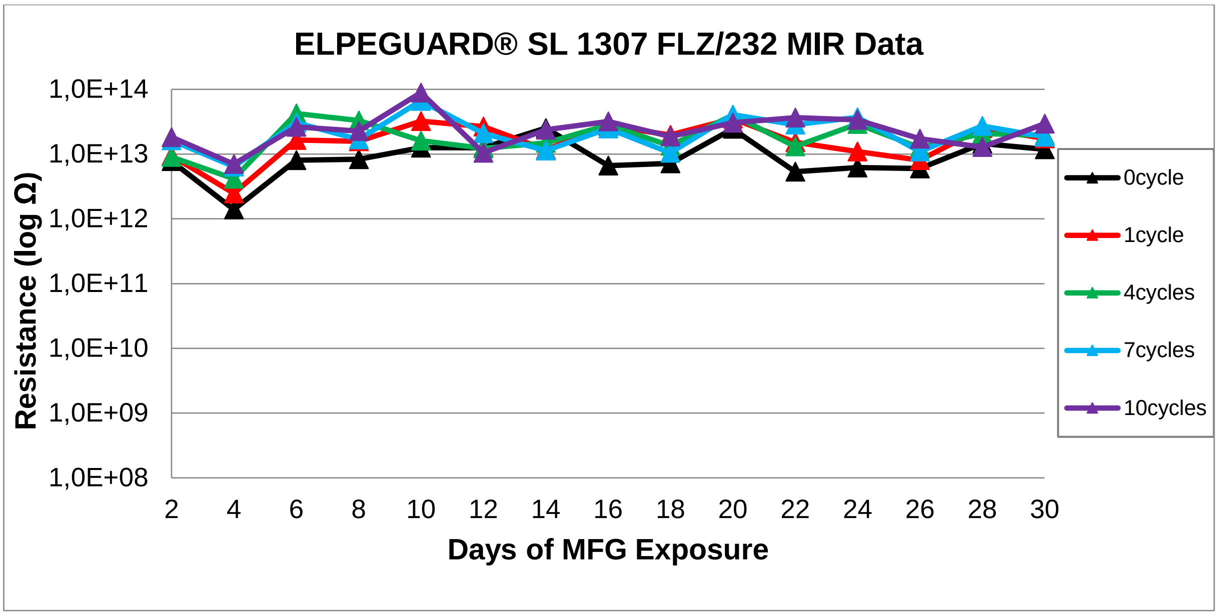


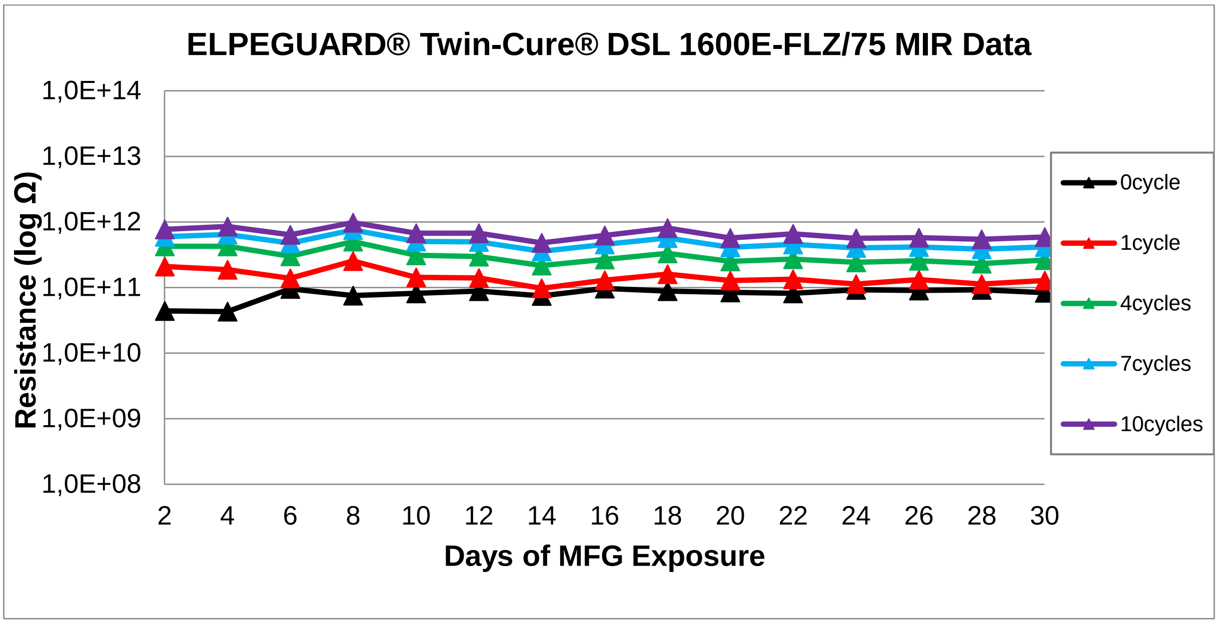
Picture 4: Chart on the corrosion rate in relation to the control group

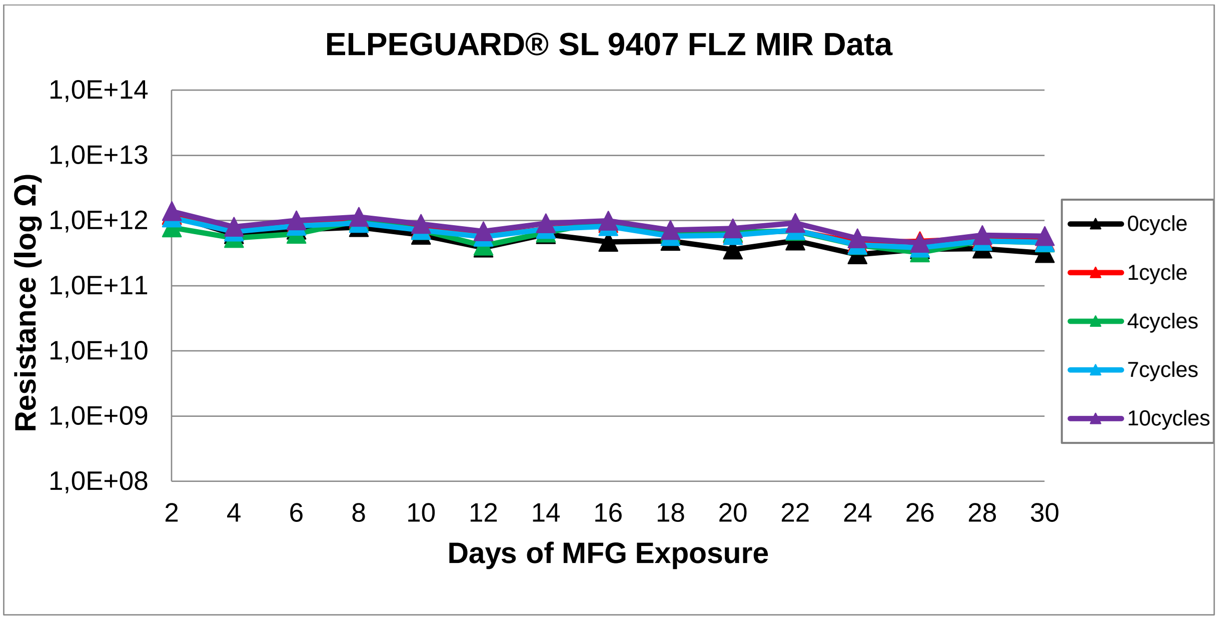
Results of MIR Test

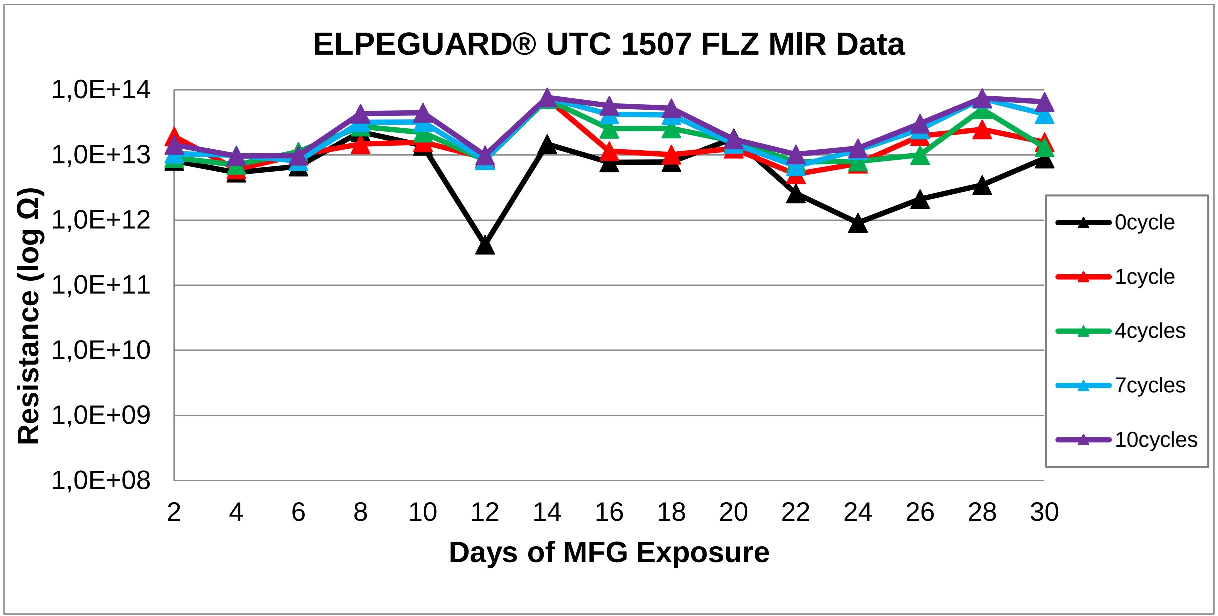
The insulation resistance level of **all coating materials passed the criteria of > 5 x10^9 Ω acc. to MIL standard.** It is important to note that all coating materials preserved the copper traces of the test coupon well enough to survive the 30-day exposure in ISA-71.04 GX level environment and 10 cycles of exposure in MIR test.




ELPEGUARD® SL 1307 FLZ/232 MIR Data
Resistance (log Ω)
1,0E+14
1,0E+13
1,0E+12
1,0E+11
1,0E+10
1,0E+09
1,0E+08
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Days of MFG Exposure
0cycle
1cycle
4cycles
7cycles
10cycles


ELPEGUARD® Twin-Cure® DSL 1600E-FLZ/75 MIR Data
Resistance (log Ω)
1,0E+14
1,0E+13
1,0E+12
1,0E+11
1,0E+10
1,0E+09
1,0E+08
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Days of MFG Exposure
0cycle
1cycle
4cycles
7cycles
10cycles


ELPEGUARD® SL 9407 FLZ MIR Data
Resistance (log Ω)
1,0E+14
1,0E+13
1,0E+12
1,0E+11
1,0E+10
1,0E+09
1,0E+08
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Days of MFG Exposure
0cycle
1cycle
4cycles
7cycles
10cycles



Summary

To investigate the performance of ELPEGUARD® conformal coatings to protect electronics in severe corrosive environments, the highest corrosive level exposure was chosen giving the following results:

Table 5: Results of ELPEGUARD® conformal coatings in MFG and MIR test

Coating material	Test	Result
ELPEGUARD® SL 1301 ECO-BA-FLZ/23	MFG Ag Corrosion MFG Cu Corrosion MIR	GX GX passed
ELPEGUARD® SL 1307 FLZ/232	MFG Test Ag Corrosion MFG Test Cu Corrosion MIR	GX GX passed
ELPEGUARD® Twin-Cure® DSL 1600 E-FLZ/75	MFG Test Ag Corrosion MFG Test Cu Corrosion MIR	GX GX passed
ELPEGUARD® SL 9407 FLZ	MFG Test Ag Corrosion MFG Test Cu Corrosion MIR	GX GX passed
ELPEGUARD® UTC 1507 FLZ	MFG Ag Corrosion MFG Cu Corrosion MIR	GX GX passed
Control Group (uncoated)	MFG Ag Corrosion MFG Cu Corrosion	Corrosion Corrosion

Conclusion

Finally, all **ELPEGUARD®** conformal coatings provided significant protection of metal against the corrosive gases and moisture, with **ELPEGUARD® Twin-Cure® DSL 1600 E-FLZ/75** and **ELPEGUARD® SL 1301 ECO-BA-FLZ/23** having the lowest tendency for corrosion.

Based on the downtime of unprotected electronics as described in table 3, the result GX means that a conformal coating provides the best protection of metal against corrosive gases and moisture, meaning no failures to be expected through corrosion; a trouble-free operation of over 10 years is predicted.

As the operating conditions for electronics become increasingly critical, the aspect of corrosion resistance of conformal coatings will continue to be an important issue to judge their reliability. Further tests on coming coating developments are already planned.

Literature

ANSI/ISA-71.04-2013 Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants, Instruments Society of America (ISA), 2013.

MIL-STD-202G, Department of Defense Test Method Standard: Electronic and Electrical Component Parts

Mixed Flowing Gas Test Report, Report No. HS1903140147A, June 5, 2019, iST (Integrated Service Technology Inc., Taiwan, www.istgroup.com)

Dr. Manfred Suppa, Conformal Coatings for Electronics Applications: Fields of Use – Requirement Profiles – Characteristics – Processing, 2012, ISBN 978-3-00-039856-8

Disclaimer

Any questions? We would be pleased to offer you advice and assistance in solving your problems. Samples and technical literature are available upon request.

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