Effect of Silicone Conformal Coating on Surface Insulation Resistance (SIR) For Printed Circuit Board Assemblies.

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ABSTRACT

Conformal coatings are considered a method of providing corrosion protection to electrical assemblies used in high-humidity or harsh environments. They are applied to PCBs for various reasons: to protect from moisture and contamination, to minimize dendritic growth, to provide stress relief, and for insulation resistance. These contribute to more durable handling, enhanced device reliability, and reduced warranty costs. Increased miniaturization of new circuit board designs requires flexible, low stress coating material to protect delicate components and fine-pitch leads. Silicone conformal coatings offer many advantages that address the general trend of ongoing PCBs designs, such as: high flexibility and low modulus to reduce stress on delicate or small components; high humidity resistance; wide operating temperature range that makes them suitable for extreme temperature cycling applications; excellent electrical properties; UV resistance; good chemical resistance, and adhesion to many common substrates used in electronics. Printed circuit board (PCB) coupons coated with three different silicone conformal coating formulations were exposed to temperature/humidity/bias conditions (85 °C / 85% RH/ 50 v) for 500 hours in order to evaluate the effects of conformal coating on surface insulation resistance (SIR). The goal of SIR testing is to identify possible failures in the functioning of printed circuit boards due to electro-chemical failure mechanisms, such as unacceptable electrical leakage under high humidity conditions, corrosion and metal migration, before they can occur on actual parts in the field. Results from this SIR testing are reviewed and discussed through this paper.

INTRODUCTION

Electronic components and modules are in a constant evolution. Major efforts and technologies are being implemented to reduce the size of the components and at the same time increase its power and efficiency. This trend has allowed the use of electronic components in environments and places never imagine, finding electronics components working in harsh environments and being exposed to severe conditions such as high humidity and ample temperature variations. The miniaturization of components and exposure to more severe environments has brought the need to work with materials that can withstand such conditions, protecting the electronics components and modules by forming barriers to isolate the electronic media from the surrounding environment. Protection of electronic circuits against these harsh environments has become a real challenge and it is often placing electronics designers in a dilemma to better select the material that will best suit their requirements.

For this new trend in the electronics industry, silicones have been widely accepted for several applications, including: adhesives and sealants, encapsulants, gels, protective coatings, thermal management materials, even device packaging materials and wafer-level coatings. Silicones have a combination of properties which contribute to provide a proven long term reliability and performance in harsh environments for several electronic applications. These features include: unmatched thermal stability with wide operating temperature range, flexibility, moisture resistance, excellent dielectric properties, UV resistance, good chemical resistance, adhesion to many common substrates used in electronics, low ionic impurity and compatibility with common processing techniques (easy to use). From all the different silicone products available for the electronics applications one material has been gaining great acceptance within the industry. These products are the silicone conformal coatings.

Silicone conformal coatings offer unique characteristics as protective materials that make them very suitable for a multitude of applications. It is the aim of this paper to provide information to better understand the nature of the silicone conformal coatings, properties and characteristics; and to review the performance of some of these products when they are exposed to high humidity environments as a way to provide valuable guidance in the proper selection of a protective material for an electronics application.

SILICONE CONFORMAL COATING

The term conformal, in the context of coatings, means nothing more than something that takes the shape of what it is applied to. In practice, it means a coating that wets out and sticks to just about any combination of surfaces it is applied to. Then, taking this into consideration, conformal coating can be defined as a thin layer of material that forms a barrier to isolate a surface providing environmental protection which when applied conforms its shape and coverage over the various topographical features and components on a circuit board.

Conformal coatings are widely used to protect electronics from dust, debris, moisture and a multitude of other environmental contaminants that could cause corrosion, electrical shorts and damage circuit boards. They are one of the least expensive means to do so, and therefore are a common choice when superior protection is required for a particular application.

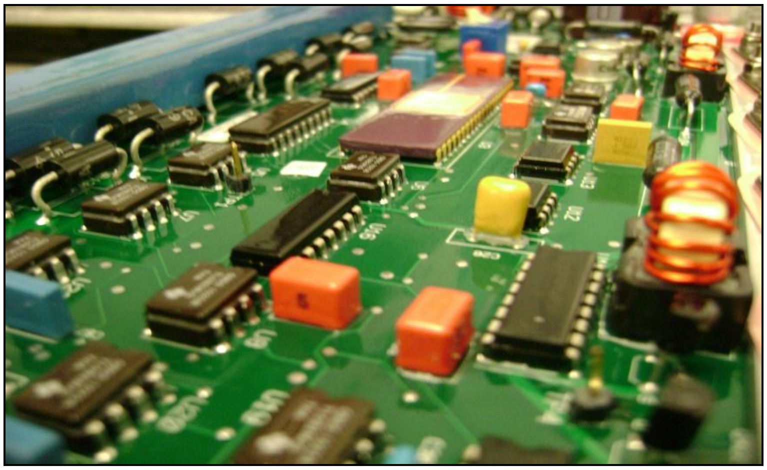

Fig. 1 Typical appearance of a cured conformal coating

Currently there are three different products that dominate the conformal coatings market: acrylics, urethanes and silicones. There are other materials used for coating electronic boards; however, these three are by far the most common. The scope of this paper is limited to the study of silicone conformal coatings only.

Silicones gather a series of properties that make them very attractive for conformal coating applications. Overall, silicone conformal coatings offer an extremely wide service temperature range. Silicone coatings can generally be used constantly at 150ºC for many years and up to 200ºC or even higher for shorter exposure times. Several studies have shown that some silicones can be exposed continuously to 150ºC for over 10 years and still perform well. In accelerated testing some of these conformal coatings have shown a predicted 10+ year life at up to 200ºC, and short exposures up to 250ºC or higher. Likewise, silicone coatings have a low modulus of elasticity compared to some other organic coatings, which can be translated into a high stress relieving capacity. This property is extremely important when protecting boards with very small components, fine pitch leads and/or sensitive solder joints that could be damaged during thermal cycling and thermal shock testing. Silicones exhibit very low surface tension and excellent wetting characteristics which helps creating a void free interface that prevents moisture from condensing. One key point here to remark is that silicone coatings exhibit high water vapor permeability, combined with excellent water repellency. In terms of protection, this is the ideal scenario, as on one hand silicones are assisting the easy elimination of surface moisture on the substrate after application. On the other hand they protect the surface from any liquid water ingress. Silicone coatings can also be used at very low temperatures. While the standard low temperature limit listed for most silicones is around -45ºC, many military applications use silicone coatings on parts which will see -65ºC or lower. Below about -45C a soft silicone hardens into a medium hard rubber. For some applications that may not represent a problem; however, it is important to verify this situation in case the circuit board is sensitive to changes in the hardness of the coating.

As early mentioned, silicone coatings are well known to provide exceptional protection to electronics even in very harsh environments. A variety of tests have been developed to provide accelerated aging and/or worst-case conditioning data to verify the performance of these products. Common industry standard tests include 1000 or more hours of dry oven ageing, 85 °C/85% RH ageing, thermal cycling from -40 to +150 °C and several varieties of salt water exposure and exposure to other chemicals. Today's densely populated electronic hardware configurations assembled in a very small areas demand more complex testing than the first generation of printed circuit boards or electronic modules. In the case of conformal coatings, surface insulation resistance (SIR) test is gaining acceptance to evaluate the performance of these products during environmental exposure, becoming a integral part in the material and process qualifications.

SURFACE INSULATION RESISTANCE (SIR)

Surface insulation resistance (SIR) is a test method for evaluating the reliability of materials used for board assembly. SIR testing evaluates and identifies possible failures in the functioning of printed circuit boards caused by shorts or current leakage due to metal migration between conductors. Metal migration or electromigration is best described as the transport of material caused by the gradual movement of ions in a conductor due to the momentum transfer between conducting electrons and diffusing metal atoms in the presence of ions, water and an electrical potential. In a certain period of time, this electromigration can move a significant number of atoms far from their original positions. A break or gap can then be developed in the conducting material, preventing the flow of electricity. Electromigration can also cause the atoms of a conductor to pile up and drift toward other nearby conductors, creating an unintended electrical connection known as whisker failure (short circuit). Both of these situations can lead to a malfunction of the electronic circuit.

SIR is a test that measures a change in current over time and is typically performed at elevated temperatures and humidity levels. Surface insulation resistance is defined as electrical resistance between two electrical conductors. Sheet resistance, bulk conductivity, and electrolytic contaminant leakage are all factors that affect the insulation resistance. For the electronics manufacturer or producer, surface insulation resistance can be thought of as a system's ability to resist surface shorting of leads or traces.

There are several industry standards developed by the IPC, Bellcore (Telecordia), and Japanese Industrial Standards (JIS) used to classify fluxes, residues, and conformal coatings. The standards used, test conditions, and layout of the SIR pattern is dependent upon the materials to be tested.

TEST CONDITIONS

There are two cure chemistries developed for silicone conformal coatings: addition cure (also known as platinum-cured) and condensation cure (or moisture-cured) materials. For this study, three different silicone conformal coating formulations were evaluated for surface insulation resistance at severe conditions that may accelerate reactions and encourage metal migration. The products selected for this test are listed in the table below:

Table 1 Silicone Conformal Coatings Evaluated for SIR

Product	**Cure Chemistry**	**Viscosity, cp**
Conformal Coating A	Moisture	110
Conformal Coating B	Moisture	360
Conformal Coating C	Addition	470

The three silicone conformal coating formulations evaluated are solvent-less products. These silicone coatings are 100% solids, being the main difference, beside cure chemistry, their viscosity, as indicated in table 1.

The test specimens for this study consisted on 17 X Q747 coupons with conductor line widths and spacing of 0.318 mm [0.01250 in] and 3 bare copper boards as control. The test conditions to evaluate surface insulation resistance were as follow: 85 °C and 85% RH with bias (50 V DC). Measurements of insulation resistance were taken in-situ every 20 minutes.

The performance of the conformal coatings for the test was evaluated according to: A material stack-up will be considered a "pass" if the log10 of the lower 95% confidence limit is > or = 8 ohm after 96 hours. Any dendrite that spans 50% or more of the original spacing between traces constitutes a failure. Discoloration of the comb patterns (green, blue-green, blue, or black discoloration of the conductors) shall be considered a failure.

RESULT CALCULATION

The resistivity readings shall be averaged over the 500 hours of the SIR test. The 95% lower confidence level (LCL) of the log mean is calculated for each sample group at each read point using the following formula:

$$LCL = \text{logmean} - t(\text{stddev}/\text{sqrt}(n))$$

Logmean" is the mean of the Log10 resistance values of the 7 - 10 values for a particular group at a particular read point. "t" is the student's value for n-1 degrees of freedom at the 95% level, 1-sided. "Stddev" is the standard deviation of the Log10 resistance values for the 7 - 10 values in the group. "n" is the sample size (usually 7 – 10 coupons or resistance readings).

An LCL value (for the 95% confidence of the mean) is calculated at each read point for each sample group. For each sample group, the LCL logmean values (from each read point) are averaged to arrive at the final LCL value for the sample group over the entire 500-hour test.

Where an assignable cause can be attributed to the SIR failure, which is properly attributed to the laminate, stack-up or the process used to produce the PCB, the failed laminate may be removed from the coupon set for the SIR calculation. Such assignable causes include:

- Contamination on the insulating surface of the coupon, such as lint or solder balls.
- Incomplete etch patterns that decrease the insulating space between conductors by more than the amount allowed in the appropriate design requirements dialog.
- Scratched, cracked, or obviously damaged insulation between conductors.

METHOD

It is well known in the electronics manufacturing industry that the cleanliness of a printed circuit board (PCB) is crucial to the performance and reliability of an assembly. Performance of SIR test samples are directly related to cleanliness. All boards used for this study were carefully cleaned before applying the conformal coating. Each board was cleaned rinsing with de-ionized water and scrubbing with a soft bristle brush for a minimum of 30 seconds. Boards were let dry at room temperature for 5 minutes. Afterwards, boards were rinsed with isopropyl alcohol (IPA) and let dry at room temperature for another 5 minutes. After the rinsing process, boards were dried in an oven at 90 °C for 15 minutes. Before applying the conformal coating, all connecting areas were masked using high temperature tape, this would prevent contaminating the area with the conformal coating when spraying the coating on the boards.

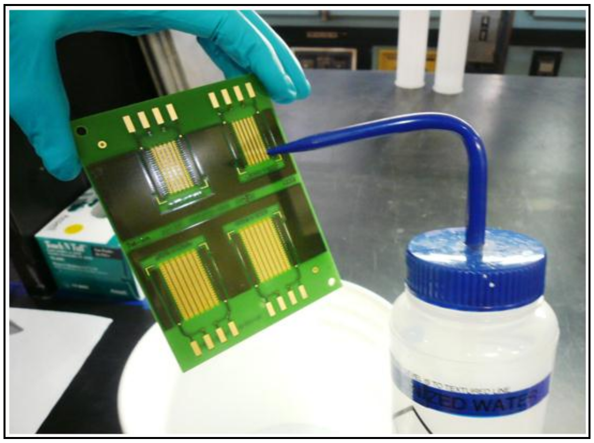

Fig. 2 Rinsing with de-ionized water

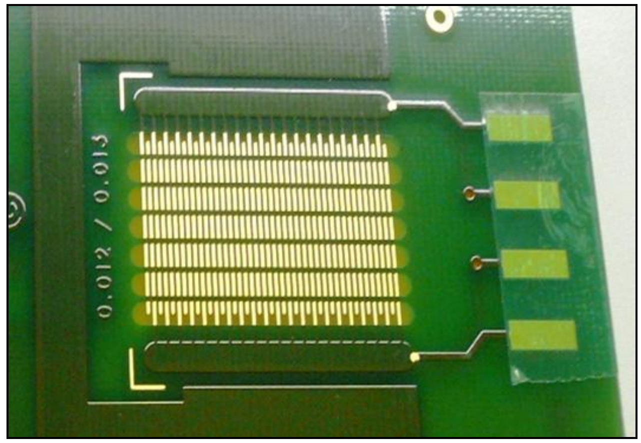

Fig. 3 Clean, dry and masked board

Conformal coating A, B and C were applied using an automated spray coater system as shown in figure 4. Curing conditions for Coating A and B were 24 hours at room temperature, and for coating C were 10 minutes at 100 °C. The average film thickness applied for each coating is listed below in table 2.

Table 2 Average Film Thickness of Conformal Coatings

Product	Average Thickness (mils)
Conformal Coating A	5.5
Conformal Coating B	6.0
Conformal Coating C	5.0

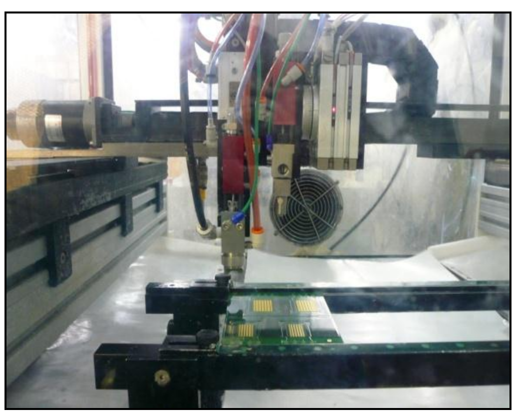

Fig. 4 Spraying Silicone Conformal Coating

All boards were visually inspected after curing the conformal coating. All boards showed a smooth dry uniform film, free of voids and wrinkles.

22 Gauge Teflon-coated wires were soldered to the test boards. All test patterns were shielded during soldering to avoid flux spitting. After all coupons were wired, the solder junctions were cleaned using isopropyl alcohol followed by a rinse in isopropyl alcohol. The test boards were placed in the temperature / humidity chamber. The chamber was set to 85°C. After allowing the chamber to stabilize for 3 hours at 85°C, the humidity was ramped up to 85% relative humidity. The coupons

were allowed to come to equilibrium for 1 hour at 85°C/85%RH before applying bias voltage and beginning the 20-minute test cycles. The insulation resistance was measured using 50 volts DC. Automated data collection was continued for 500 hours, taking an SIR measurement on each coupon at each read point every 20 minutes.

At the completion of the test, the 50V bias was turned off prior to ramping down the temperature and humidity. Likewise, all coupons were examined under a microscope using backlighting.

RESULTS

Surface insulation resistance data for conformal coating A (moisture cure low viscosity) are shown in figure 5. According to the requirements established for "pass" or "fail" coupon, exposed before, it was identified that all samples prepared with this coating met the requirement showing an average surface insulation resistance of 3.5X 10^{9} Ohm or 9.5 log Ohm.

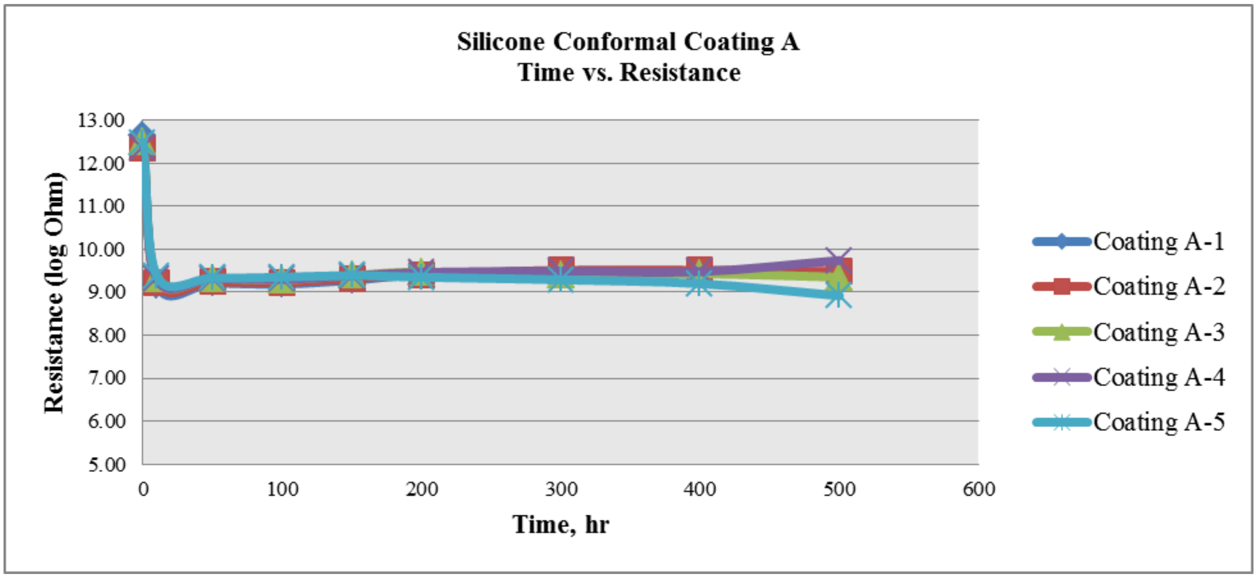

Fig. 5 Surface Insulation Resistance Data for Silicone Conformal Coating A

All coupons were inspected after the completion of the test. No anomalies on the surface of the board related to signs of corrosion, discoloration or dendritic growth were observed.

Similar results were observed for conformal coating B (moisture cure medium viscosity), figure 6. This is something expected as both conformal coatings, A and B, are similar in chemical composition with main difference being their viscosity. Once the coating is cured, the final composition for both products is equivalent. Likewise, there is no much difference in the average film thickness applied for both coatings. Therefore, both silicone coatings perform in a very similar way. The average value for surface insulation resistance observed for coating B is 4.5 X 10^{9} Ohm or 9.6 log Ohm. After the completion of the test, all samples were observed under the microscope, finding no signs of corrosion, discoloration or dendritic growth.

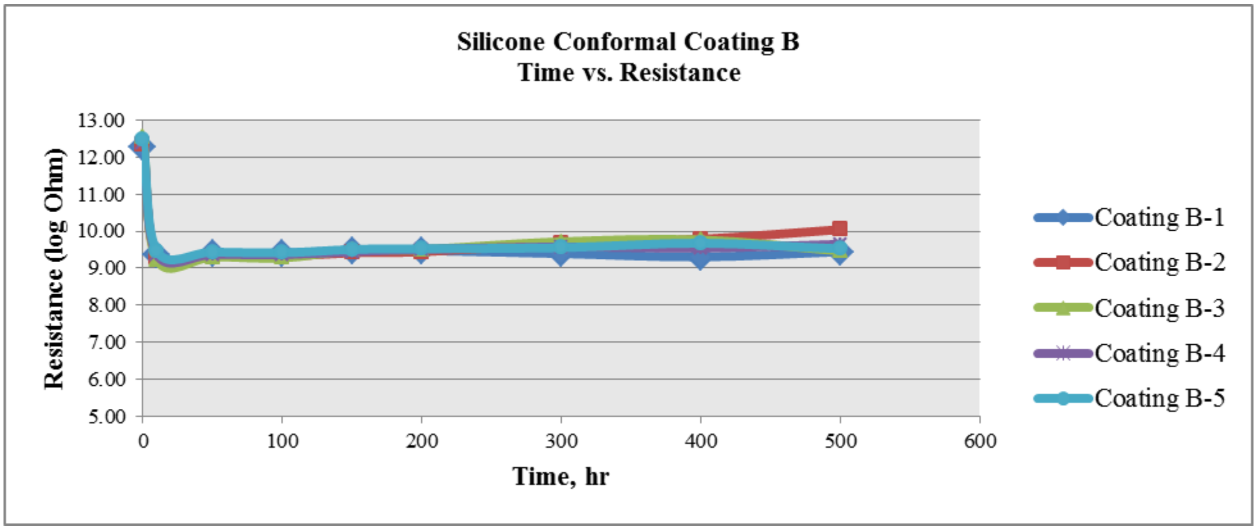

Fig. 6 Surface Insulation Resistance Data for Silicone Conformal Coating B

The surface insulation resistance for coating C was slightly lower for the first 100 hours of the test than the moisture cure coatings evaluated (A and B). After the 100^{th} hour, it was observed an increment in the surface insulation resistance, reaching similar values as the ones observed for the other two moisture cure coatings, figure 7. The behavior exhibited by this product can be explained by the effect temperature has on the cross-linking/adhesion reaction for this specific cure chemistry. When product is exposed to high temperature, additional bonds may be formed between coating and substrate, improving adhesion strength and surface protection. Therefore, an improvement on surface insulation resistance may be observed, reaching an average value close to 3.5×10^{9} Ohm or 9.5 log Ohm and even a slightly higher number at the end of the test. Further work is needed to understand reproducibility of these results and if there indeed might be actual significant improvement of surface insulation resistance with temperature for this cure chemistry.

It is essential to indicate that all parts prepared for this study were tested more than 10 days after conformal coating was applied on each board. This is significantly important for the moisture cure coating, as this product reacts with moisture from the air at room temperature; therefore, after 10 days at room temperature, coating can be expected to be fully cured and good adhesion strength developed. This may explain the low impact that high humidity and high temperature have on the surface insulation resistance the coating A and B exhibited during the test.

A drop in the surface insulation resistance for the three coatings evaluated is observed when comparing initial value and value reported after the first 20 minutes of the test. This behavior may be explained by the absorption of water into the silicone coating. Silicones have very low water solubility; however, water vapor has a high permeability through it. This high permeability allows water to reach a saturation point in the cured silicone readily fast. However, this amount of water is very small and the measured surface insulation resistance remains in an acceptable level, a value higher than 1×10^{8} Ohm. After reaching the saturation point, no more water can be absorbed into the cured silicone and the surface insulation resistance practically remains constant until the conclusion of the test.

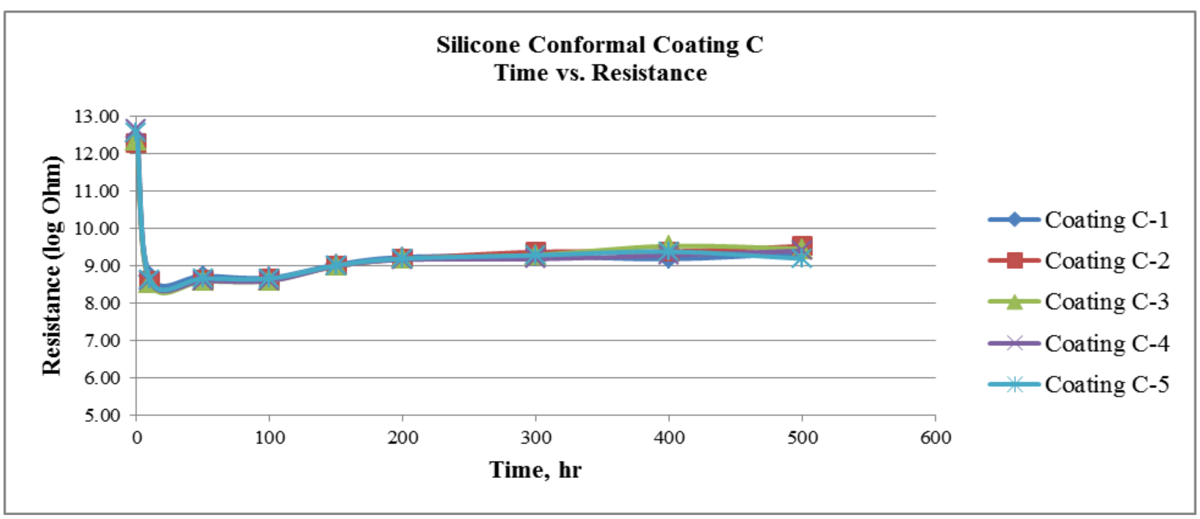

Fig. 7 Surface Insulation Resistance Data for Silicone Conformal Coating C

At the conclusion of the test, all parts coated with coating C were inspected under the microscope. No signs of corrosion, discoloration of dendritic growth were observed. Coating C met the requirements, initially marked, for surface insulation resistance.

CONCLUSION

According to results observed, it can be conclude that the silicone conformal coatings may improve reliability and reduce susceptibility to surface insulation resistance degradation of printed circuit boards. However, it is important to observe that surface insulation resistance is highly dependent on the level of contamination at the surface level of the circuit board; especially, if the contaminate is of ionic character (residue that contains molecules or atoms that are conductive when in solution). Silicone conformal coatings protect corrosion-sensitive surfaces by producing a seamless coating that totally excludes water from contacting the surface. While water vapor will transport through silicones very rapidly, liquid water is completely blocked. For corrosion to occur, liquid water and mobile ions must be in direct contact with a sensitive surface, even in microscopic amounts. Therefore, it is of paramount importance to verify the compatibility of silicone coating with the contaminants that could remain at the surface level of PCB or components to effectively form a protective barrier. Contaminants may promote the formation of voids or interfere with the silicone wet-out and/or adhesion creating areas where water can collect in and cause problems with ionic contaminants.

Due to the complexity and densely populated electronic hardware configurations assembled in new electronics designs, new and more sophisticated test methods are required to evaluate the proper function of the electronics assemblies. In the case of conformal coatings, surface insulation resistance (SIR) test is gaining acceptance to evaluate the performance of these products during environmental exposure, becoming an integral part of material and process qualifications. However, SIR test should not be used solely to evaluate the performance of an electronic module or PCB. Additional test are encouraged to verify proper function of protective coating.

It is important to remark that long-term accelerated life testing and surface insulation resistance analysis should be performed on the end product, assembled under factory conditions, conformally coated and de-masked. This will ensure there are no electrochemical compatibility issues between various assembly chemistries and materials, such as solder resist, flux, adhesives, cleaning agents, among others that could cause unexpected long-term product reliability problems. Corrosive contaminants left on a circuit from assembly and manufacturing processes may present reliability problems. The information presented in this paper is based on data and tests we believe to be accurate and intended for use by persons with adequate technical skill. Information and test results are relevant only to the items submitted for testing. Extensive testing and evaluation is encouraged to determine feasibility of use a silicone conformal coating for a particular application.

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Goals

- Provide information to better understand the nature of the silicone conformal coatings: properties and characteristics.
- Review the effect of silicone conformal coating on surface insulation resistance for PCB assemblies when exposed to 85 % RH/85 ° C conditions.

APEX EXPO IPC 2012

- Market Trend: Reduce the size of PCBs and at the same time increase its power and efficiency.
- This trend has allowed the use of electronic components in very harsh environments.
- Protection of electronic circuits against these harsh environments has become a real challenge.

Protective Materials

- Conformal coatings are widely used to protect electronics from dust, debris, moisture and a multitude of other environmental contaminants that could cause corrosion, electrical shorts and damage circuit boards.
- There are three primary materials types that dominate the conformal coatings market: acrylics, urethanes and silicones.

-- scope of this paper is limited to the study of silicone conformal coatings --

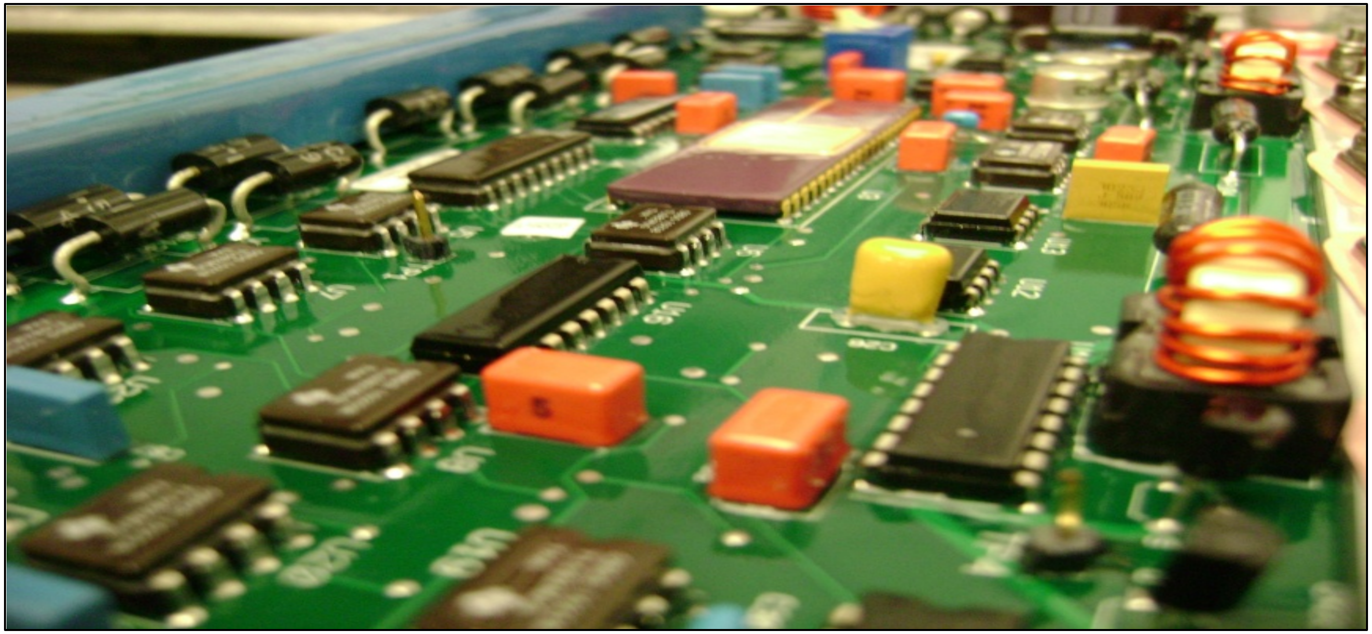
Silicones have properties which contribute to provide a long term reliability and performance in harsh environments:

- Good thermal stability
- Moisture resistance
- Low temperature flexibility
- Good adhesion to many substrates
- Excellent dielectric properties
- Good chemical resistance
- Low ionic impurity
- Compatibility with common processing techniques.

Tests to Verify Performance

- Dry oven aging (1000 hr or more)
- High Humidity / High Temperature (85/85)
- Thermal Cycling (-40 to 150 C)
- Salt water exposure
- Exposure to different chemicals

Today’s densely populated electronic hardware configurations assembled in very small areas demand more complex testing than the first generation of printed circuit boards or electronic modules.



Surface Insulation Resistance

- SIR testing evaluates and identifies possible failures in the functioning of printed circuit boards caused by shorts or current leakage due to metal migration between conductors.
- Metal migration: the transport of material caused by the gradual movement of ions in a conductor due to the momentum transfer between conducting electrons and diffusing metal atoms in the presence of ions, water and an electrical potential.
- A break or gap can be developed in the conducting material, preventing the flow of electricity.
- Metal migration can also cause the atoms of a conductor to pile up and drift toward other nearby conductors, creating an unintended electrical connection known as whisker failure

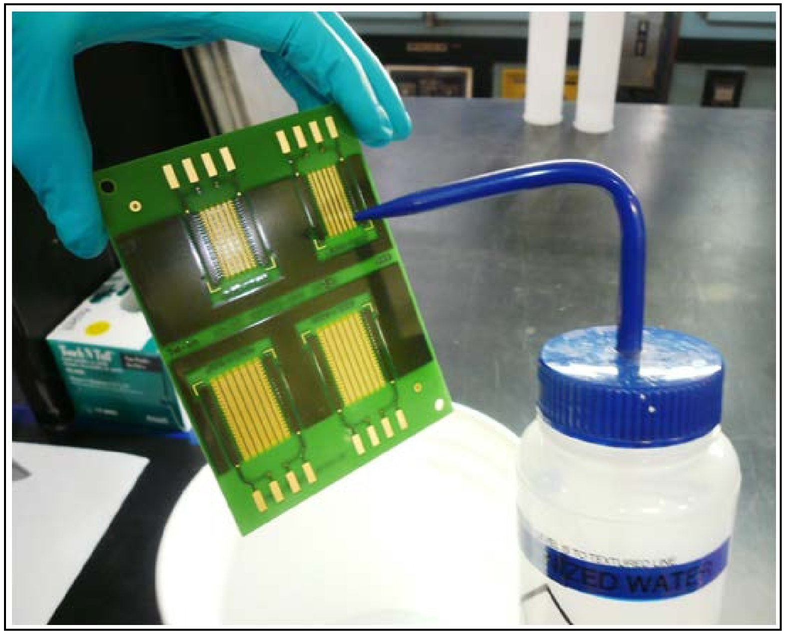
SIR Test

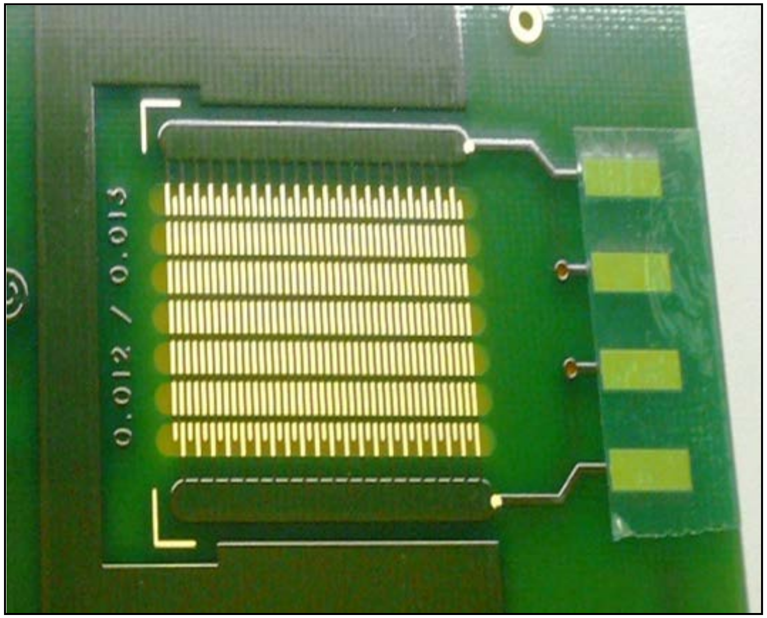
Product	Cure Chemistry	Viscosity, cp
Conformal Coating A	Moisture	124
Conformal Coating B	Moisture	352
Conformal Coating C	Addition	470

SIR Test

- Q747 coupons with conductor line widths and spacing of 0.318 mm [0.01250 in]
- Test conditions: 85 ° C and 85% RH with bias (50 V DC).
- Measurements of insulation resistance were taken in-situ every 20 minutes.

Cleaning the Boards

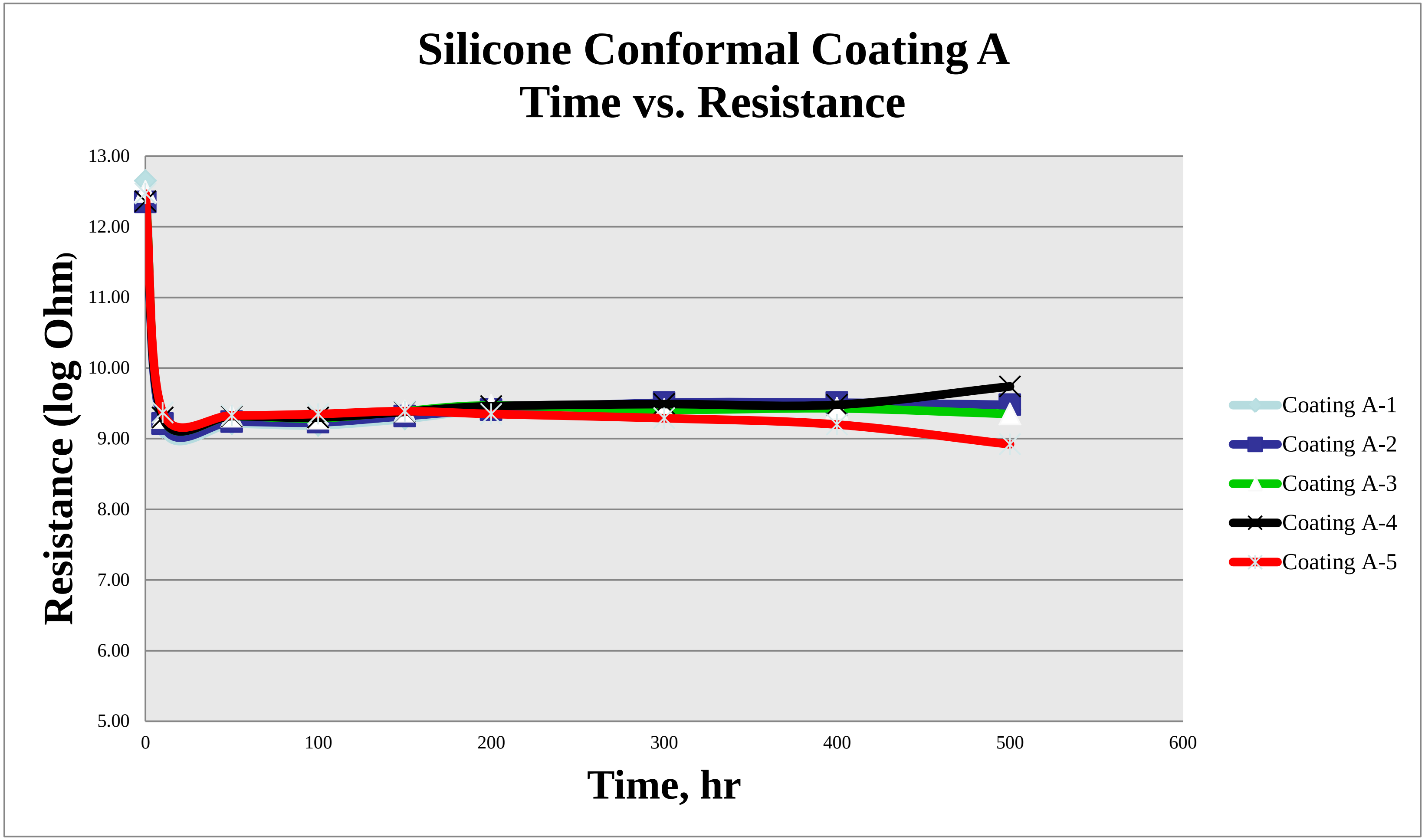




Average Film Thickness of Conformal Coatings

Product	Average Thickness (mils)
Conformal Coating A	5.5
Conformal Coating B	6.0
Conformal Coating C	5.0

Results


Silicone Conformal Coating A
Time vs. Resistance
Resistance (log Ohm)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
0
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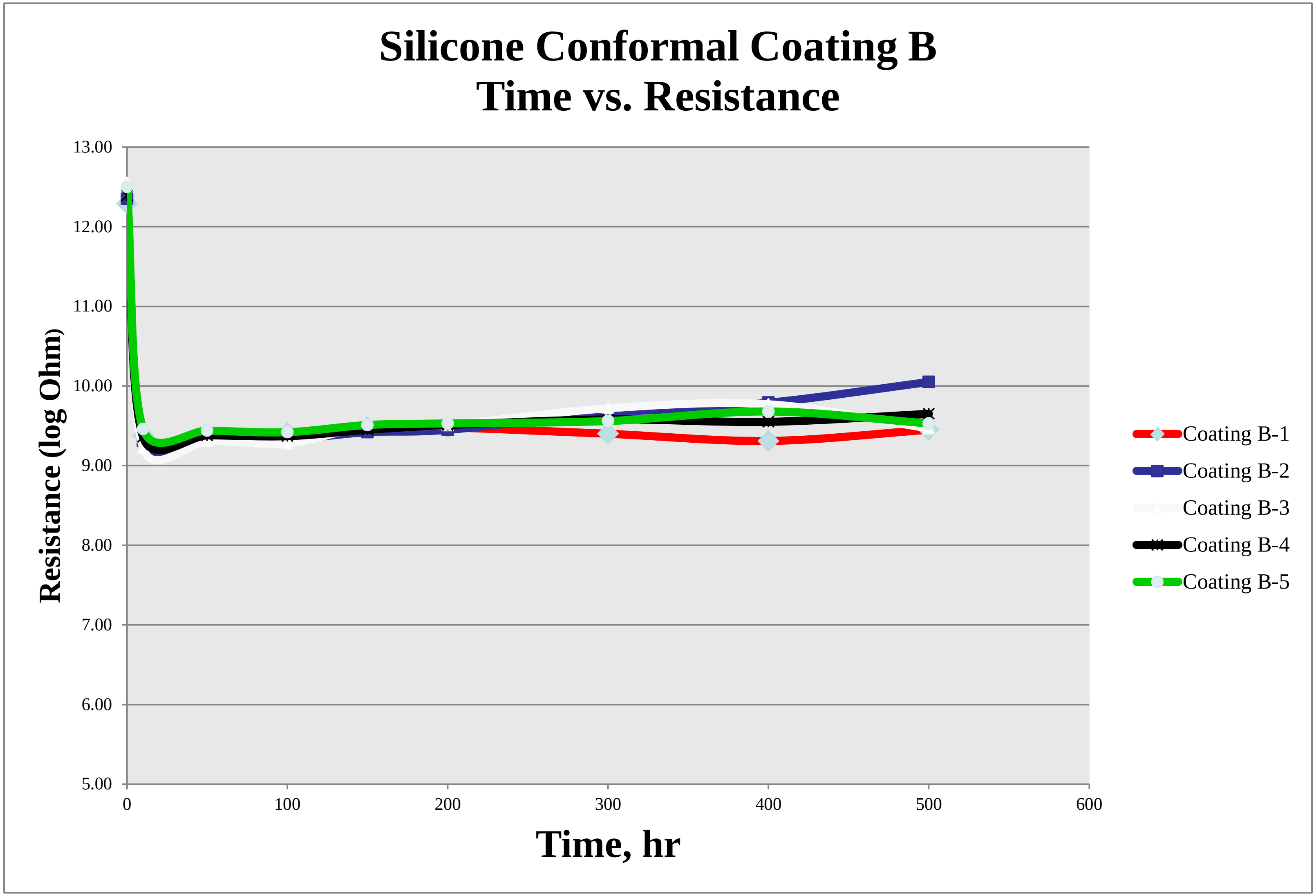
Time, hr
Coating A-1
Coating A-2
Coating A-3
Coating A-4
Coating A-5


Silicone Conformal Coating B
Time vs. Resistance
Resistance (log Ohm)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
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100
200
300
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Time, hr
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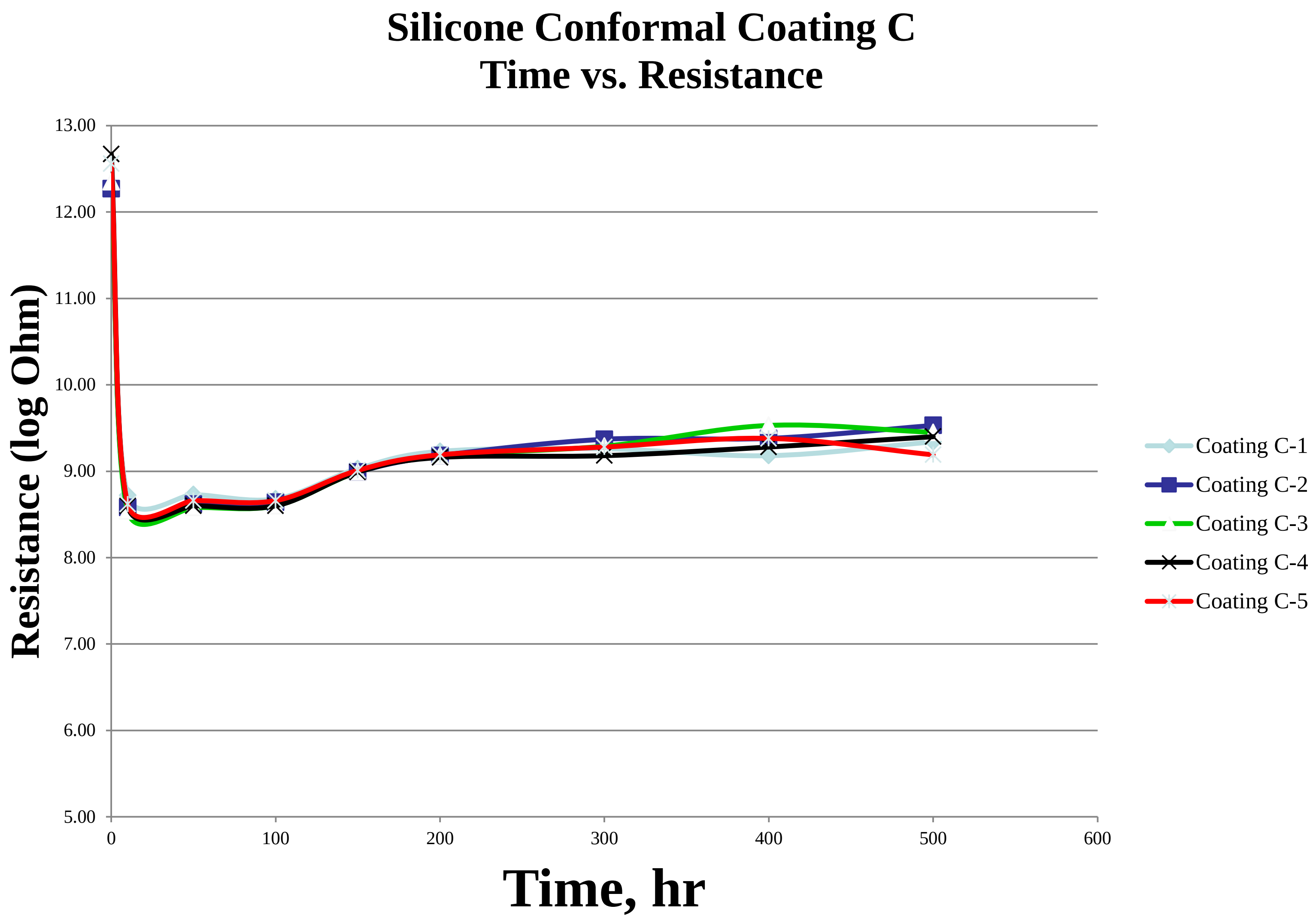
Coating B-2
Coating B-3
Coating B-4
Coating B-5


Silicone Conformal Coating C
Time vs. Resistance
Resistance (log Ohm)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
0
100
200
300
400
500
600
Time, hr
Coating C-1
Coating C-2
Coating C-3
Coating C-4
Coating C-5

Conclusions

- Silicone conformal coatings may improve reliability and reduce susceptibility to surface insulation resistance degradation of printed circuit boards.
- it is important to observe that SIR is highly dependent on the level of contamination at the surface level of the circuit board.
- Silicone conformal coatings protect corrosion-sensitive surfaces by producing a seamless coating that excludes water from contacting the surface
- Contaminants may promote the formation of voids or interfere with the silicone wet-out and/or adhesion

Conclusions

- SIR tests should not be used solely to evaluate the performance of an electronic module or PCB. Additional tests are encouraged to verify proper function of protective coating.
- Corrosive contaminants left on a circuit from assembly and manufacturing processes may present reliability problems.
- Long-term accelerated life testing and SIR should be performed on the end product, assembled under factory conditions, conformally coated and de-masked.

Thank You

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