CONFORMAL COATING OVER NO CLEAN FLUX RESIDUES PART II

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ABSTRACT
Building on the work completed in early 2013, AIM's Technical Team as advanced their understanding of the process through continued research and development.

AIM's earlier study focused on the overall feasibility of applying conformal coating over No Clean flux residues. We set out to establish what methods would be the best to characterize 'compatibility' and what materials would be best suited to perform the task. What was discovered was that, coating over no clean is feasible, 'compatibility' is a fuzzy term and the mission profile of the assembly determines the best material set for a specific application.

In this second phase of the testing we set out to better understand the variables that impact performance of the materials in combination and to assess the impact of advancements in both coating and flux technology.

We attempt to include all of the readily available coating technologies. The three major categories are acrylic, urethane and silicone. Subsets of these three categories are differentiated by the curing method; air dried, moisture cured and ultraviolet light (UV) cure with secondary moisture cure. To these ends we engaged all of the major coating manufacturers in North America and Europe. We focused on companies that have predominant market share both in terms of volume and market penetration. The effort had to be collaborative as AIM does not possess the equipment and expertise to ensure the coatings are applied in the best possible way. We are, after all, violating the first rule of the coating manufacturer:

Cleanliness of the substrate is extremely important to the successful application of a conformal coating. Surfaces should be free of moisture, dirt, wax, grease and all other contaminants. Otherwise, ionic or organic residues on the substrate could be trapped under the coating and cause problems with adhesion or electrical properties. The highest long term reliability for a coated printed circuit assembly will be when the conformal coating is applied over a clean, dry substrate.

Key words:
Conformal Coating, No Clean, Compatibility, SIR

COMPATIBILITY

"Is your flux compatible with our conformal coating?" "We've got a part we can't wash and need to apply coating" is often how the dialogue begins.

We had to determine what criteria need to be applied and how to apply them in order to answer this question. After interviewing a number of industry experts and materials specialists there are two criteria that are applied to establish the baseline for compatibility: 1) Adhesion and 2) Electrical Characteristics.

In our previous study we had determined that an IPC B-24 SIR Test Coupon was the best method for establishing gross compatibility. They are relatively inexpensive, we have vast experience in their preparation with solder and flux and they can be prepared en masse. Samples of each lot of B-24 coupons were tested with dyne pens post preparation, pre-flux application to minimize the potential for an adhesion issue with the coupon prior to the application of the flux/paste.

The first level of establishing compatibility is a simple visual inspection of the test sample after application of the coating. There were circumstances where a combination that was clearly incompatible and was evident while applying the coating. No clean liquid fluxes may contain surfactants to reduce the surface tension of the flux to improve wetting and flow characteristics during the fluxing process. These same surfactants can inhibit a coatings flow and wetting properties. These interactions would lead to an immediate and easily observed de-wetting, 'orange peeling' or measles of the coating. These samples were eliminated if this condition was observed.

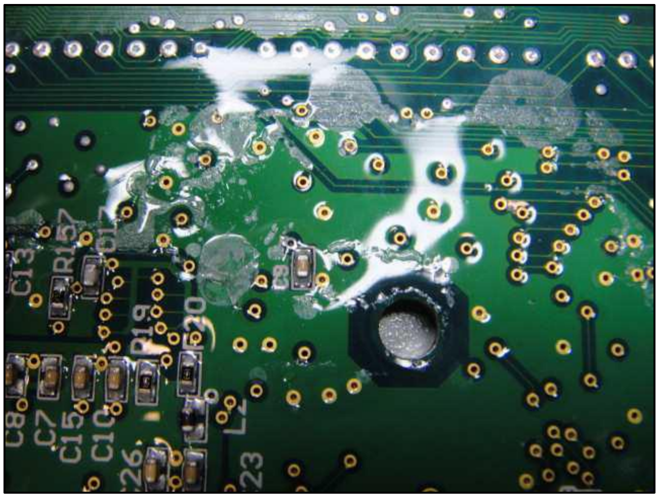


Figure 1. Blisters immediately appeared with this combination of flux and coating.

All coatings were applied via spray for controlled application with target thicknesses of 25-50um depending on coating type and manufacturers recommendations. Anecdotal data suggested that thickness had an impact on coating performance relative to thermal shock (T-Shock) testing. Thinner coatings generally outperformed thicker irrespective of coating type. In the interest of minimizing scope creep, we did not include this as part of the data collected.

If a material set passed the first test, the second portion of the visual test was to cure the material and inspect for any evidence of delamination of the coating from the fluxed area of the coupon. As we gained experience inspecting materials, it became possible to determine that a set would likely not pass post thermal shock tests. These coupons were subjected to tape adhesion testing per IPC-CC 830/IPC 650 2.4.28.1 and ASTM-3359 prior to T-Shock rather than post T-Shock.

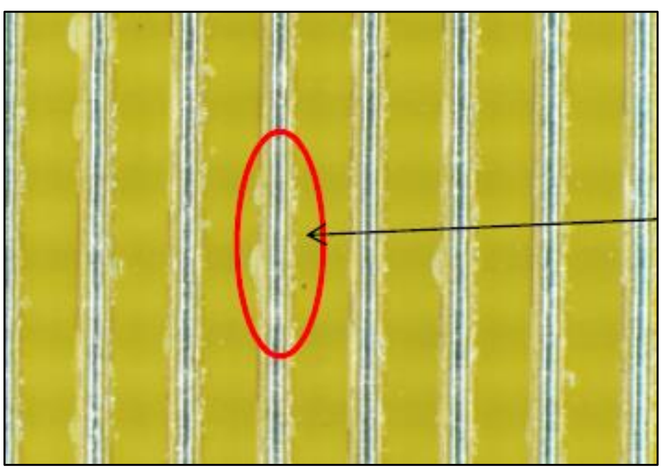


Figure 2. Post-cure example of imminent adhesion failure

Material sets that did not pass this portion of the testing were excluded from further testing. Once it was determined that a material set was fundamentally compatible, it advanced to the third tier of testing, thermal shock followed by the same adhesion test protocol.

All of the liquid flux samples that passed the second stage of testing also passed the -65C+125C testing and were advance to the final phase of this round of testing. This was attributed to the fact that so little residue is present with the low residue/no clean fluxes that were tested, that there wasn't enough material to cause a CTE mismatch and failure.

As observed in the previous study, solder paste residues had difficulty passing the thermal shock portion of the testing. None of the materials aside from silicone, passed -65+125C T-shock profile established by IPC-CC-830.

In an attempt to define the 'falling off' point of the materials four thermal shock profiles were investigated.

-10°C to + 125°C

-25°C to + 125°C

-35°C to + 125°C

-65°C to + 125°C

All profiles have a 20°C/min ROC and 15 min dwells at each temperature extreme with inspection performed after every 10 cycles ending at 50 or until delamination observed on all 3 test assemblies. Microscope inspection was performed at 25x magnification for evidence of delamination.

These tests corroborated earlier observations that the material sets tested were failing due to CTE stresses imposed during the cold portion of the thermal cycling experiment, with low modulus materials outperforming high modulus materials.

Below is an example of the failure mode. The coating remains a contiguous sheet, but adhesion has failed at the interface of the flux residue and the coating. Upon inspection, the flux residue is still adhered to both the board and the coating, but had suffered a cohesive failure and disintegrated, leading to a delamination condition. Fig.3-4

It was determined that virtually no combination of materials survived below -25C and that the majority of failures occurred at -10C and below.

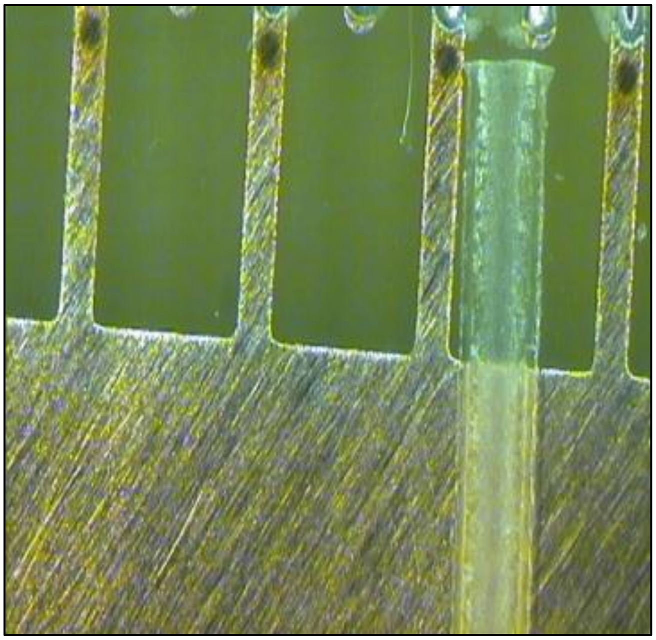


Figure 3. Coating with flux residue still adhered post T-Shock

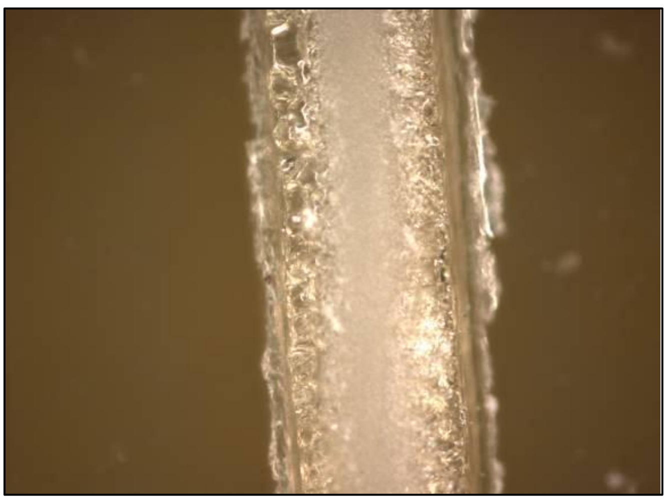


Figure 4. Close up of flux residue on conformal coating

To further prove the theory that modulus of the materials and CTE mismatches were the root cause of the failure, we delved in to the basic chemistry of the solder paste. No clean solder paste flux chemistry consists of 3 primary components, a suite of activators in a resin base combined with various stabilizers, solvents and rheological additives. AIM had developed a resin free no clean solder paste for a very specific customer requirement. With resin omitted from the formula, it would validate the assumption that the resin component of solder paste was leading to the hardening, fracture and disintegration of the solder paste under the conformal coating as the flux medium is roughly fifty percent resin prior to reflow. Samples were prepared and coated with a urethane acrylate UV cure coating and subjected to -65+125C T-Shock.

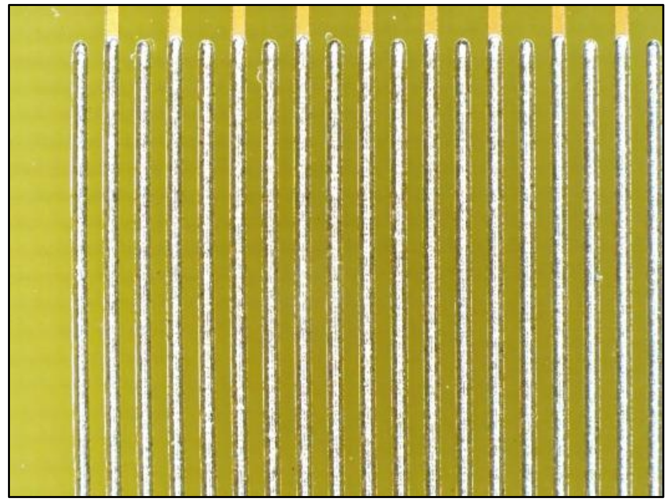


Figure 5. Resin-free paste + coating pre-T-Shock

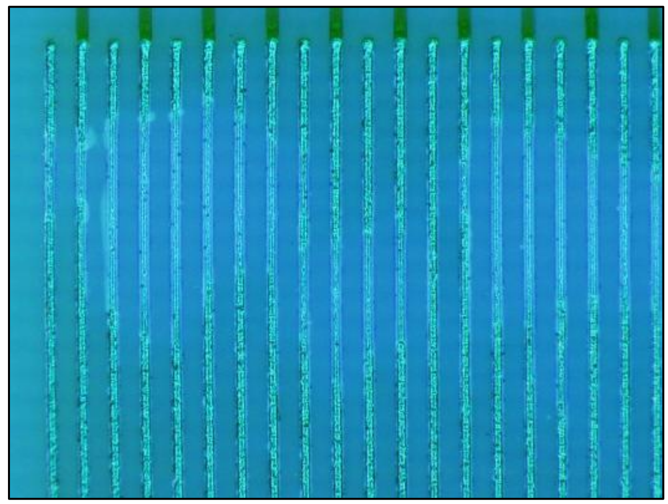


Figure 6. Resin-free paste + coating post-T-Shock

Careful examination of the fluxed area in Fig. 6 revealed some areas of concern as evidenced by the image under UV inspection. Re-inspection of coupons not subjected to T-Shock revealed the issue was evident, indicating a wetting issue with the coating over the flux residue and was not related to T-Shock. What was noteworthy was the fracturing condition was <u>not</u> observed, further implicating the resin component of the solder paste residue as cause for failure.

These conclusions lead the team to consider the options for addressing the thermal shock failures.

1) Use a lower modulus coating with the well-established and understood resin based solder paste
2) Modify the solder paste resin system to minimize CTE mismatch or to reduce the modulus.

There are considerations when contemplating these changes to the material which will be discussed when the subject of electrical resistivity and coating durability are reviewed later in the study.

As solder paste has to perform many functions during its application and processing, it was decided that approaching the problem by modifying the conformal coating, would require less re-engineering with theories on the failure mechanism proven more quickly.

The first step was to use the lowest modulus material that was readily available which was a silicone based coating. Silicone conformal coatings are extremely compliant, exhibit excellent adhesion and are available in both air-cure and UV-cure formats. Their limitations are low mechanical strength, vapor permeability. Also, there is a lingering perception that the presence of silicone in a facility where soldering is performed represents a concern. The curing of some types of silicone releases material that can redeposit on solderable surfaces rendering them permanently unsolderable. Modern formulations do not exhibit this characteristic, but the concern persists.

As seen in Fig.7, the silicone conformal coating alleviated the T-Shock failures associated with the harder acrylic and urethane materials.

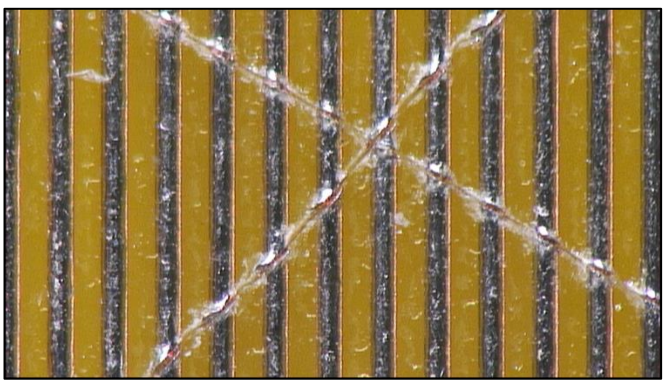


Figure 7. Moisture cure silicone post T-Shock passed adhesion testing

During the course of our investigation, coating manufacturers involved in the study recognized the need for a product that had the positive attributes of the urethane acrylates but a lower modulus to improve performance at low temperature. As a result, new materials became available that were included in the study to determine their characteristics in comparison to the materials already tested. We also consider this a final data point in determining the fact that the modulus of the coating in relation to the flux residue was the root cause of the adhesion failure.

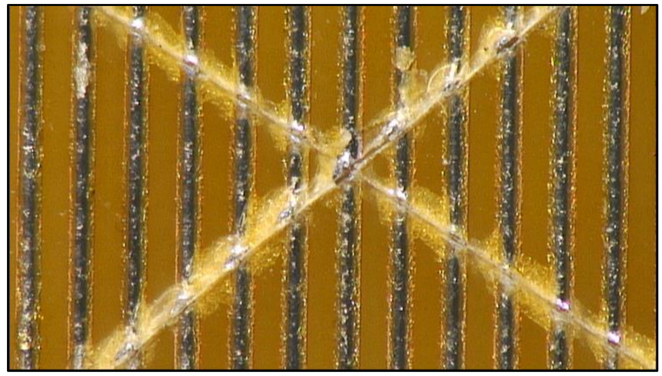


Figure 8. Low modulus, urethane acrylate based, UV cure post T-Shock – Passes adhesion testing

AIM is currently developing solder pastes that have constituent materials that have physical properties similar conformal coatings. Our goal is to determine if using more closely aligned materials in both the paste and coating will mitigate the T_g mismatch and alleviate the T-Shock failures. This development is ongoing, but preliminary data is encouraging.

To summarize the finding of the adhesion portion of the study, we can make the following statements with (adhesion only) a high degree of confidence:

1) Coating issues over properly processed no clean liquid flux are evident via visual inspection at the time the coating is applied. Fish-eyes, pin-holes, measles, blisters and other types of defects are easily noted and that material set can be deemed incompatible.
2) Solder paste residues coated over with silicone, acrylic and urethane coatings have considerations that require vetting for the ‘mission profile’ of the assembly. Defects that are observed during the application of the coating can be quickly deemed incompatible with the paste flux residue as with liquid flux. However, there were material sets that coated perfectly, but after curing exhibited a delamination condition even at room temperature.
3) Thermal stresses will cause most coating/paste residue combinations to fail -65+125C thermal shock aside from silicone. Different materials exhibited a wide range of tolerance. All failures observed were attributed to the cold side of the thermal shock testing.

It may be the case for many applications that thermal shock tolerance is not a concern. Many electronic devices are never exposed to temperatures below room temperature or are under continuous power and never experience temperatures below 0C. However, if a PCB manufacturer is bearing the added expense of ruggedizing the PCB assembly, it’s assumed this device will be exposed to harsh environments including temperature extremes.

ELECTRICAL CHARACTERISTICS OF CONFORMAL COATING/NO CLEAN FLUX

The second criteria for establishing the compatibility between coatings and residues is their impact on their performance on an electrical circuit.

In North America and most of Europe the Joint Industry Standards (J-Std) are the quality documents and test methods that are used to assess and classify the materials that are used for manufacturing of printed circuit boards. The subset of tests that apply to soldering fluxes and their properties is the -004B standard. This standard categorizes flux chemistry via the outcome of a battery of tests and classification procedures, providing guidance to a fluxes properties and how it should be used.

The term 'no clean' is a catchall phrase describing fluxes whose properties are such that they can be left on a PCB after soldering without becoming conductive or corrosive. In order for a flux to be assigned this classification the flux must pass several tests, the most significant being the Surface Insulation Resistance (SIR) test.

The SIR test consists of a test coupon (IPC B-24) with a pattern of traces with very precise spacing called a comb pattern. (Fig. 9) Samples of the flux are applied to the comb pattern per the J-Std. requirements and subjected to conditions (40°C 90%Rh 10V Bias) that encourage the growth of metallic dendrites and corrosion. Precise measurements of the electrical current that passes between the 'tines' of the comb at prescribed intervals and these measurements are recorded as Ohms (Ω). A failure is any reading that falls below $1x10^8\Omega$.

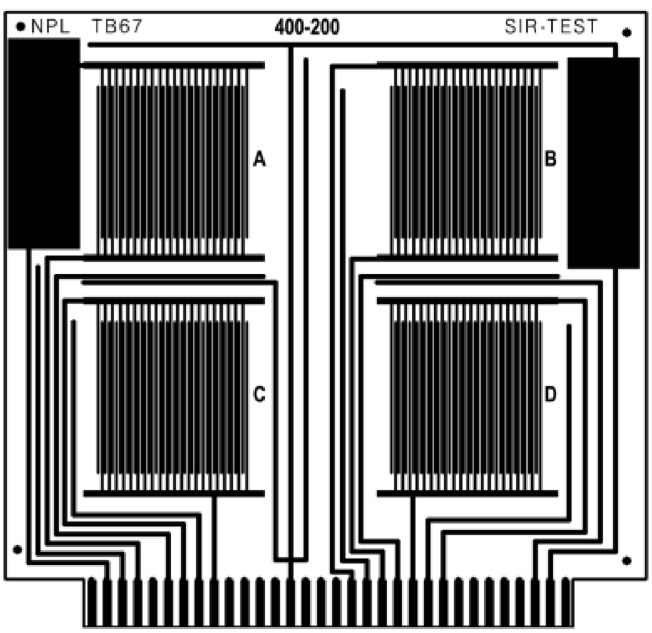


Figure 9. B24 SIR Test Coupon

A failure indicates that the materials on the comb pattern have the potential to produce unacceptable current leakage or shorts due to metal migration. The occurrence of metal migration is similar to electro-plating of the copper trace or solder alloy in the presence of ionic compounds, water and the application of an electrical potential.

Additionally, any change in color to the comb pattern to green, blue-green or black will also be considered a failure.

All of the fluxes and coatings that were included in this testing pass SIR testing individually. Otherwise, they could not be called 'no clean' fluxes and they could not be viable conformal coating materials. The SIR testing we have performed is with materials in combination. Our goal was to determine if applying coating over no clean flux residues impacted SIR values and if so, could we determine what coatings or class of coatings had the least impact. We also wanted to better understand failure mechanisms for coating and flux combinations.

Different coating technologies have vastly different properties. As mentioned earlier, the modulus of silicone is much lower than that of acrylic, but its vapor permeability is much higher. How do these differences effect electrical properties when in intimate contact with resin and weak organic acids found in flux residue? The results of this test matrix will provide insight to how coatings act in the presence of different flux residues.

The fluxes that were selected represent the most current formulations of no clean; all exceed the SIR requirements for the J-Std. 004B.

- AIM NC SAC305 Solder Paste (Fig.10)
- AIM NC IPA-Based Liquid Flux (Fig.11)
- AIM NC Water Based VOC-Free Liquid Flux (Fig.12)

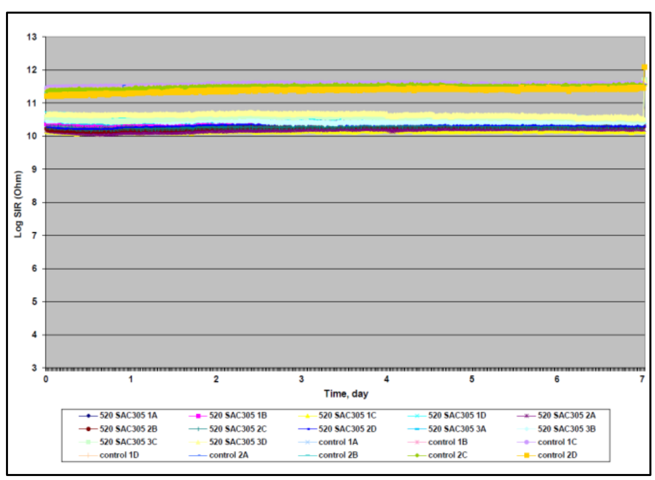


Figure 10. AIM NC Solder Paste SAC305 SIR Test Results

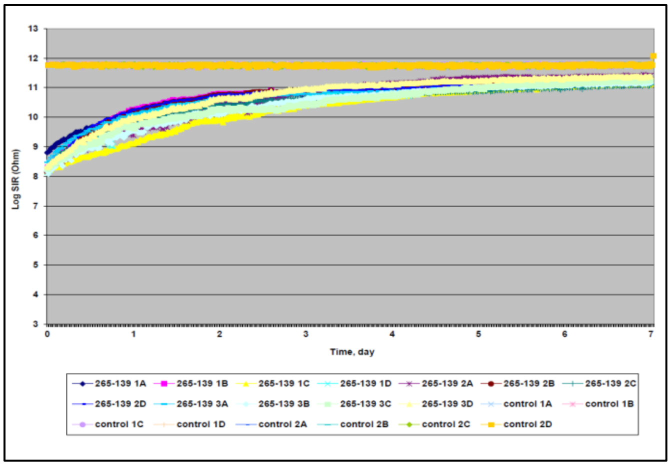


Figure 11. AIM IPA-Based NC Liquid Flux SIR Test Results

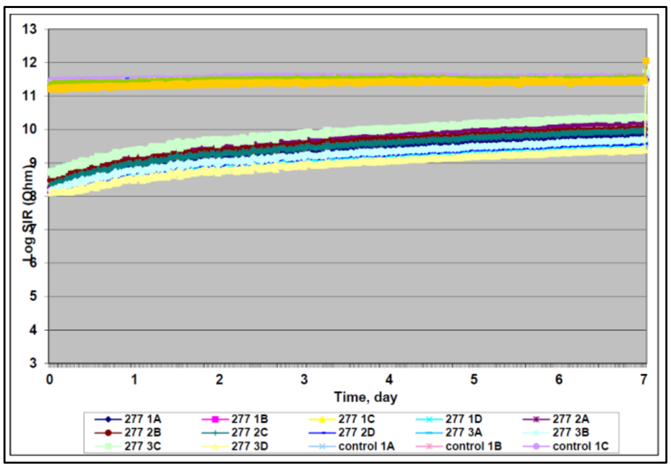


Figure 12. AIM Water Based VOC-Free NC Liquid Flux SIR Test Results

The keen observer will note that the SIR results of solder paste, opposed to liquid flux are considerably higher at the outset and remain so throughout the test. This is due to an inherent difference between the products. As mentioned previously, solder paste formulations consist of a significant amount of resin/rosin. These materials are used because when they are heated in the reflow process they become 'active' and aid in reducing the oxides and removing contamination from the solderable surfaces. When they cool, they become inert. They also serve to contain other activator components within their chemical matrix. Conversely, low solids liquid fluxes contain very little or no resin/rosin and rely on oxidation and decomposition of the flux activators during processing to render them inert. Without the resin/rosin component, they will exhibit lower initial SIR values which tend to rise (improve) as the flux oxidizes and decomposes in to more benign substances.

The coatings that were tested represent the most commonly used materials, acrylic, urethane and acrylate-urethane UV curable coatings. Below are examples of SIR data for these materials on cleaned samples with no flux residues.

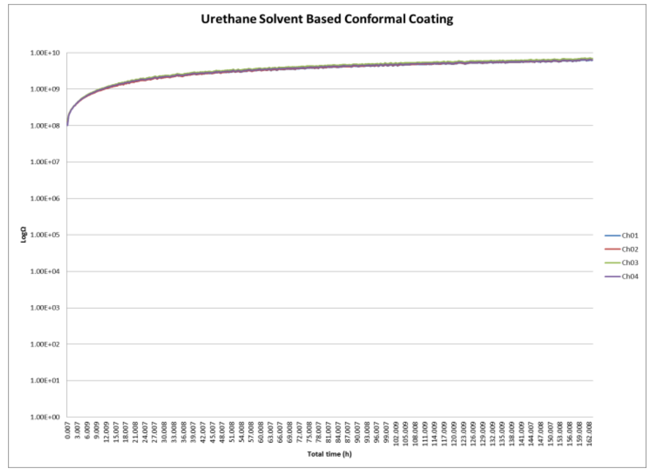


Figure 13. Urethane Solvent Based Conformal Coating SIR Test Results

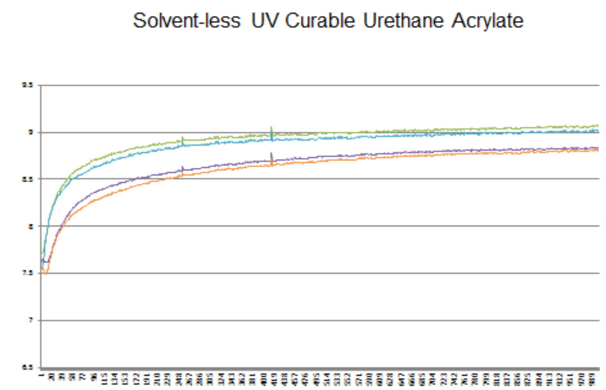
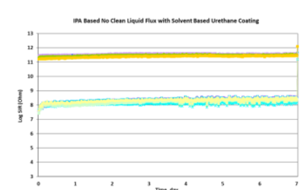
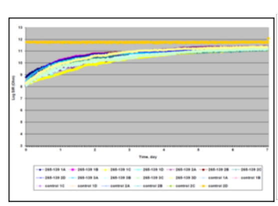
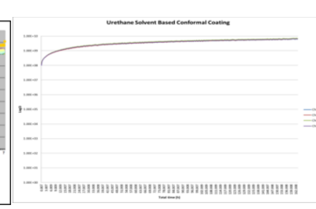


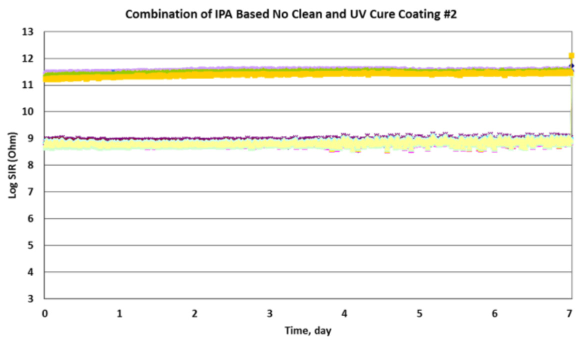
Figure 14. Solvent-less UV Curable Urethane Acrylate SIR Test Results

All of the material sets pass SIR testing individually. The results below indicate how resistivity is affected when the materials are tested in combination.

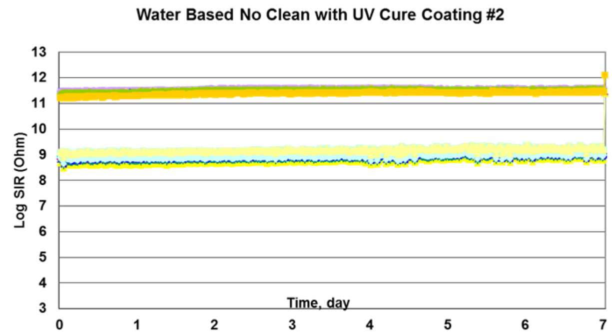




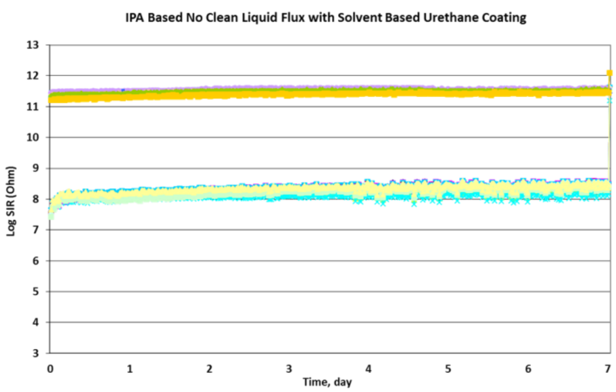




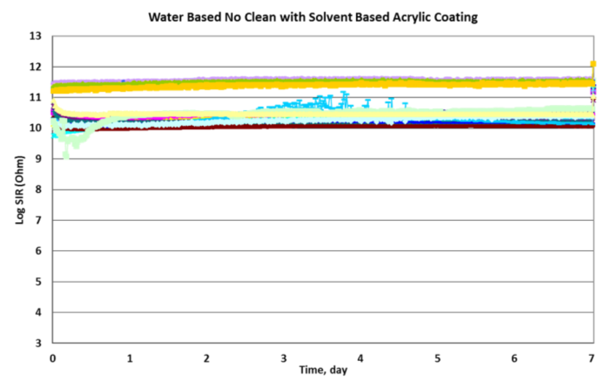
Combination of IPA Based No Clean and UV Cure Coating #2
Log SIR (Ohm)
Time, day



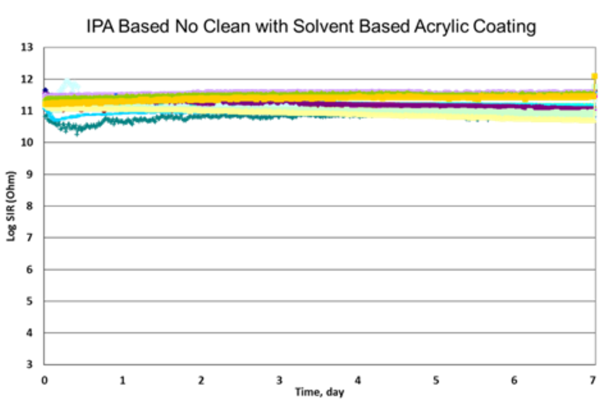
Water Based No Clean with UV Cure Coating #2
Log SIR (Ohm)
Time, day



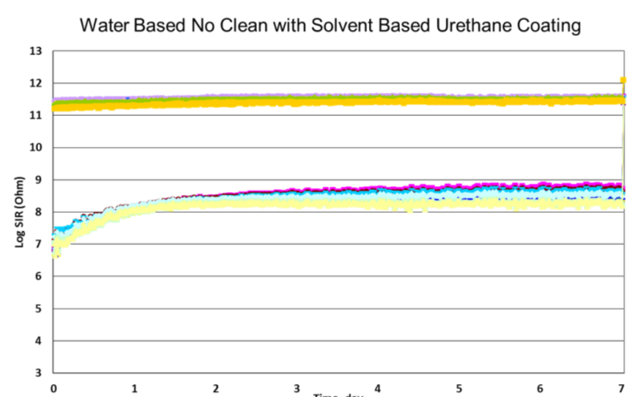
IPA Based No Clean Liquid Flux with Solvent Based Urethane Coating
Log SIR (Ohm)
Time, day



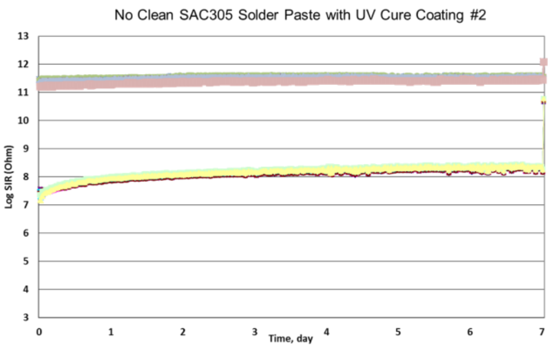
Water Based No Clean with Solvent Based Acrylic Coating
Log SIR (Ohm)
Time, day

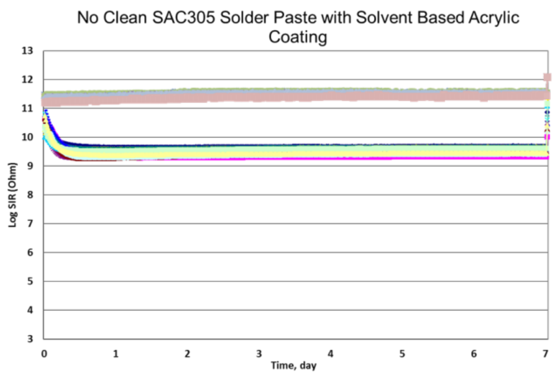


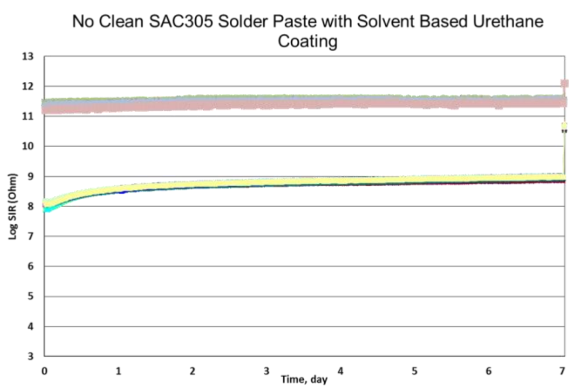
IPA Based No Clean with Solvent Based Acrylic Coating
Log SIR (Ohm)
Time, day



Water Based No Clean with Solvent Based Urethane Coating
Log SIR (Ohm)
Time, day







Conclusion: The study consisted of over 1000 samples of various combinations with the results being condensed in to the following general statements:

- All polymer coatings have a propensity to harden at colder temperatures increasing the CTE mismatches between the substrate, residue and coating which exacerbate delamination. This was observed with all coating manufactures materials.
- Lower modulus (softer) materials improved thermal shock performance but did not eliminate the delamination condition for all products. There is another, as yet undefined, variable that has an impact on cold-side performance. Testing indicates this is the adhesion to the flux residue and may be affected by the solvents used in the coating material.
- Low solids no clean liquid fluxes easily pass the most intense thermal shock requirements, regardless of coating type.
- Anecdotal evidence suggests coating thickness may have an impact on outcomes with thinner coating outperforming thicker in thermal shock, but may provide less environmental protection.
- Low Solid No Clean Liquid flux SIR performance was most affected by the type of coating used.
- Solvent based acrylic coatings consistently gave higher SIR values than all other coating types.

This study is ongoing and more data points are being developed to further identify trends that can provide end users with information that will reduce the time and research needed to make material choices for their application requirements.

Future Work:

The use of a B-24 Test Coupon was a useful, cost effective choice in identifying material set characteristics. However, it is not representative of the use of conformal coating in the production environment.

The third and final phase of this study will incorporate a test vehicle that will include a fully assembled PCB with modern components as well as SIR test capabilities. The goal is to ascertain the impact of the presence of components and the assembly process as it relates to previous data and how combining residue and coating to overall coating performance on a completed assembly.