Conformal Coating over No Clean Flux

Karl Seelig & Timothy O'Neill
AIM
Cranston, Rhode Island. USA.
kseelig@aimsolder.com & toneill@aimsolder.com

Introduction

As the proliferation of modern day electronics continues to drive miniaturization and functionality, electronic designers/assemblers face the issue of environmental exposure and uncommon applications never previously contemplated.

This reality, coupled with the goal of reducing the environmental and health implications of the production and disposal of these devices, has forced manufacturers to reconsider the materials used in production.

Furthermore, the need to increase package density and reduce costs has led to the rapid deployment of leadless packages such as QFN, POP, LGA, and Micro-BGA. In many cases, the manufacturers of these devices will recommend the use of no clean fluxes due to concerns over the ability to consistently remove flux residues from under and around these devices.

These concerns, along with the need to implement a tin whisker mitigation strategy and/or increase environmental tolerance, have led to the conundrum of applying conformal coating over no clean residues.

The AIM Research & Development team has united with OEM electronics and conformal coating manufacturers in an attempt to characterize the different coating technologies currently available. In this study, various coating materials were tested with different chemistries of no clean fluxes. Results demonstrate possible combinations meeting the mission profile of the assembly with consideration for the assemblers' capabilities and cost objectives.

Conformal coating of PCB has garnered serious attention in all phases of PCB design and manufacturing. Manufacturers and Engineers industry wide are exploring the capabilities, costs, and limitations of this technique. The driving factor being the deployment of electronics into more diverse and harsh environments as the demand for functionality and interoperability grows. These systems are being introduced to conditions that would have been considered unsuitable for electronics a short time ago, including condensing environments and dust environments. Some of the known benefits of coating include;

- Reducing entrapped surface contamination to contact power or ground areas
- Tin whisker mitigation

Having engaged multiple conformal coating manufacturers, there is a common recommendation for the application of conformal coating; that is that the substrate be cleaned prior to application, regardless of the type of coating to be applied. These same manufacturers will also admit that many of their customers are coating over no clean flux residues for a variety of reasons. The most common being;

- Cost of cleaning
- Through-put requirements
- Incomplete removal of ionic contamination under and around low-standoff devices
- Tin whisker mitigation

Analyzing final working environment is crucial to a successful outcome and should be the first consideration in determining the appropriate assembly process. One should determine if applying coating will a) achieve the desired outcome b) be practical given the nature of the assembly and the assemblers capabilities. Assuming coating is appropriate the materials to be used needs to be vetted.

In this study, we will address the findings of an in-depth analysis of various types of conformal coatings and how they perform in combination with a variety of no clean flux residues.

The following industry test standards were applied:

- IPC J-Std-004 SIR Testing
- IPC CC-830 - Qualification and Performance of Electrical Insulating Compound for Printed Wiring Assemblies
- ASTM – D3359 - Standard Test Methods for Measuring Adhesion by Tape Test

The three standards applied to this study will determine the SIR values and adhesion properties of each material in combination. These figures were compared with supplier provided data on the individual materials to determine if characteristics were measurably enhanced or degraded when combined. The classes of conformal coating materials tested are outlined below.

Acrylics

Thermoplastics dissolved in solvents – no cross-linking

Strengths	Weaknesses
Air Dry	VOC Bearing Solvents
Easy Solvent Rework	Poor Solvent Resistance
Good Moisture Barrier	Flammable
Ease of Use	Soften in High Temp

Urethanes

Cure through cross-linking

Strengths	Weaknesses
Solvent Resistant	Some contain VOC's
Humidity Resistant	Rework
Abrasion Resistant	Cure rate environmentally dependent
Dielectric Properties	Worker health risks

Silicones

Cure through moisture cross-linking

Strengths	Weaknesses
Humidity Resistant	Abrasion
Moisture Resistant	Workplace contamination
Flexibility	
Temperature Tolerant	

Epoxies

Usually two-part systems

Strengths	Weaknesses
Humidity Resistant	Two-Part
Moisture Resistant	Rework
Abrasion Resistant	Pot life
Dielectric Properties	

Acrylated Urethane

UV Curable Urethane

Strengths	Weaknesses
Protective Properties	Capital Investment
Through Put	Rework
Environment Impact	Shadowing
UV Inspection	

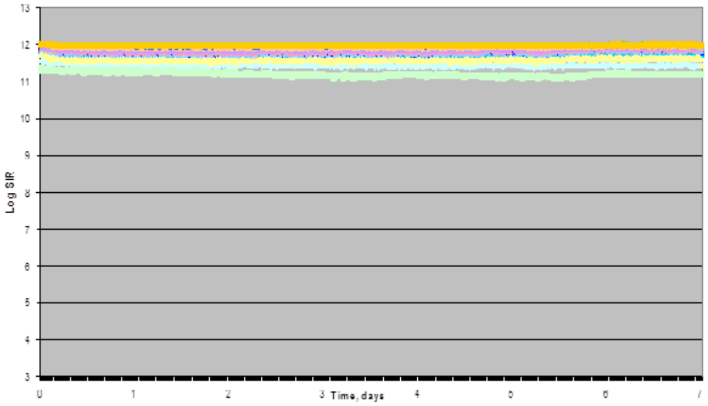
All of the samples tested passed IPC SIR testing without issue. An example of the data generated found below:

PASS-FAIL CRITERIA
IPC J-STD-004B §3.4.1.4.1
All measurements on all test patterns shall be exceed the 100 MΩ
No evidence electrochemical migration that reduces conductor spacing by more than 20%.
No corrosion of the conductors.

TEST RESULTS
1. Test data, chart attached, pass
2. Presence of dendrites: No
3. Maximum percent reduction of spacing: 0%.
4. Presence of discoloration between conductors: No
5. Presence of water spots. No
6. Presence of subsurface metal migration. No
Original test data available upon request.

Result Charts (1-3)

Chart 1. “L” UV Cure Coated, “Paste 54” (Sn-Pb), “Control”

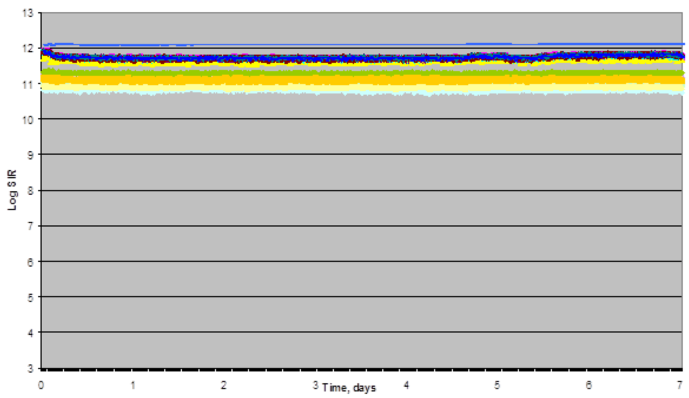


--Control D1--Control C1 --Control C1 --Control A1
--Control D2--Control C2 --Control B2 --Control A2

--Paste 54/L UV D1 --Paste 54/L UV C1 --Paste 54/L UV B1 --Paste 54/ L UV A1

--Paste 54/L UV D2 --Paste 54/L UV C2 --Paste 54/L UV B2 --Paste 54/ L UV A2
--Paste 54/L UV D3 --Paste 54/L UV C3 --Paste 54/L UV B3 --Paste 54/ L UV A3

Chart 2. “H” UV Cure Coated, “Paste 54” (SAC305), Control



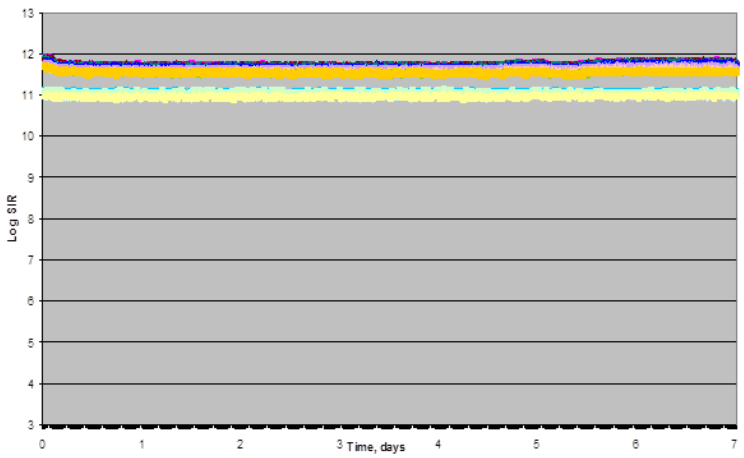
--Control D1 --Control C1 --Control C1 --Control A1
--Control D2 --Control C2 --Control B2 --Control A2

--Paste 54/H UV/ D1 --Paste 54/H UV/ C1

--Paste 54/H UV/ B1 --Paste 54/H UV/A1 --Paste 54/H UV/D2 --Paste 54/H UV/C2 --Paste 54/H UV/B2

--Paste 43/H UV/A2 --Paste 54/H UV/D3 --Paste 54/H UV/C3 --Paste 54/H UV/B3 --Paste54/H UV/A3

Chart 3. “H” UV Cure Coated, “Paste 54” (Sn-Pb), Control



--Control D1 --Control C1 --Control C1 --Control A1
--Control D2--Control C2 --Control B2 --Control A2

--Paste 54/H UV/ D1 --Paste 54/H UV/ C1

--Paste 54/H UV/ B1 --Paste 54/H UV/A1 --Paste 54/H UV/D2 --Paste 54/H UV/C2 --Paste 54/H UV/B2

--Paste 43/H UV/A2 --Paste 54/H UV/D3 --Paste 54/H UV/C3 --Paste 54/H UV/B3 --Paste54/H UV/A3

Adhesion testing/thermal shock testing was originally conducted on Practical Component SABER Test Assemblies; however after multiple tests it was determined that the required data could be collected using standard B-24 test coupons. In addition to a considerable cost savings, it eliminated variables that could have clouded the results including the presence of ionics, mold release agents and coating thickness variability.

The findings of the adhesion testing yielded some favorable and some unexpected results. The balance of this work focuses on solder paste. We did not test wire solder residues and all liquid fluxes where the conformal coating wet and adhered to the substrate at the time of coating/curing passed all subsequent tests.

Initial testing of thermal shock at -60°C +125°C showed gross delamination. Initially, it was thought the failure was due to movement of the flux residue having softened at 125°C. Further examination revealed that there was a cohesive failure of the flux residue, wherein the flux remained firmly adhered to the PCB substrate and to the coating, but failed internally (photo 3). This phenomenon was present on all coatings in varying degrees (other than silicone). In general, UV materials performed the worst, with solvent-based acrylics better and silicones the best, with no delamination. A failure was considered any evidence of delamination. It was not determined if delaminated coating that remained contiguous was still effective in protecting the underlying substrate.

Ultimately, we found the modulus of the coating is directly correlated to cold temperature failure. The CTE mismatch of the residue and a high modulus coating were enough to fracture the cold hardened flux residue. Flux medium used in solder paste is typically a resin-based material and after reflow, the residue is hard. The colder the environment is, the harder the residue. To test this theory, we varied the residue and the coatings using harder and softer materials. UV curable silicone having the lowest modulus of the materials tested and UV cure urethane the highest. We also tested a paste that is not resin based with residue that is waxy, rather than hard. As depicted below, reducing the modulus of either the coating or the residue eliminated the delamination failure.

We also noted that solvent-based acrylic coatings out performed UV cured urethane materials although it was product specific. It is believed that the solvent would facilitate a more intimate bond between the residue and the coating lessening the adverse effect of the CTE.

We went a step further to determine what the lowest temperature a resin based no clean paste and acrylic or acrylate/urethane coating can withstand before suffering delamination. The results of these tests were scattered, but none of the material sets were capable of withstanding more than -35°C for more than 10 cycles.

With this information, it would seem the simple solution to this problem would be to incorporate a softer residue solder paste to remedy the delamination issue. Unfortunately, there is a significant impact to the SIR characteristics as detailed below in Figure 1.

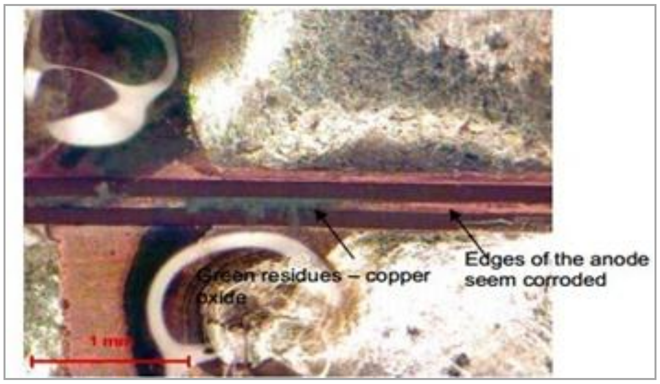


Figure 1. Moisture Absorption after Conformal Coat

UV Curable Urethane Hybrids	TG	Paste A	Paste B	Paste C	Comment
A	40	1	1	1	Complete delamination, combination with Paste C was the worst
B	25	3	1	4	Delamination but not global
C	3	4	3	4	Wetting issues, slight delamination
D	-60	5	5	5	Perfect, no delamination

Figure 2. Results: 1 to 5 (worst to best)

The results indicated that the silicon did not delaminate. Delamination is easy to see in the test as shown below. The following profile was used.

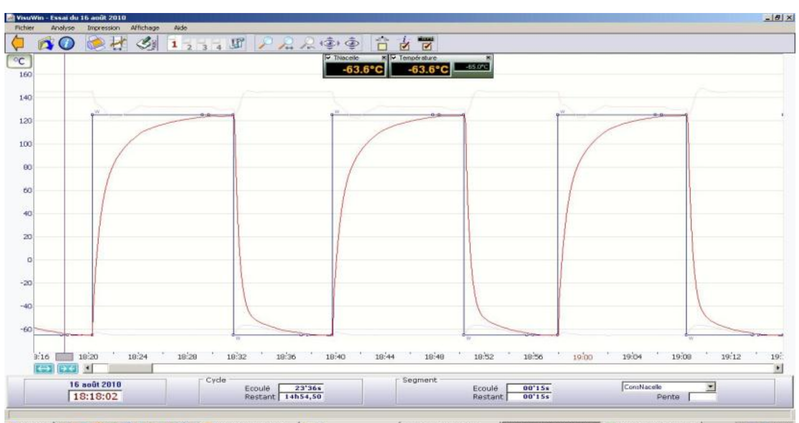


Figure 3. Profile

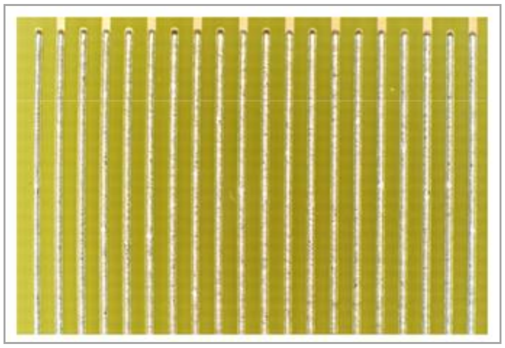


Figure 4. Pre Shock

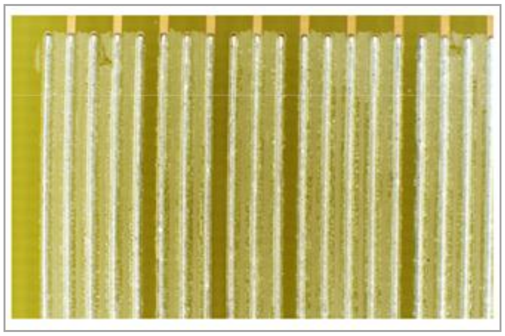


Figure 5. Paste 55 Post T Shock Delamination

However if the solder paste is a low/no residue nitrogen reflow solder paste delamination does not occur.

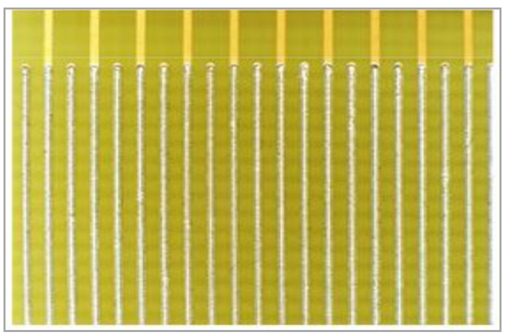


Figure 6. Paste 16 (low/no residue) Pre T Shock

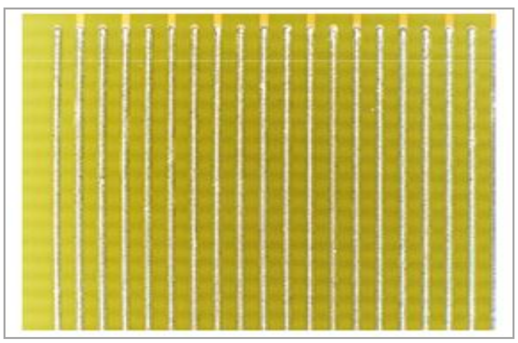


Figure 7. Paste 16 Post T Shock/No defects

The following are a series of photographs that identify the hard flux issue with delamination of a harder urethane coating.

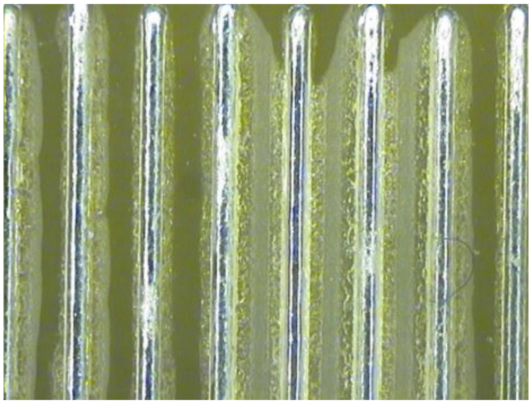


Photo 1
Delaminated after thermal shock testing

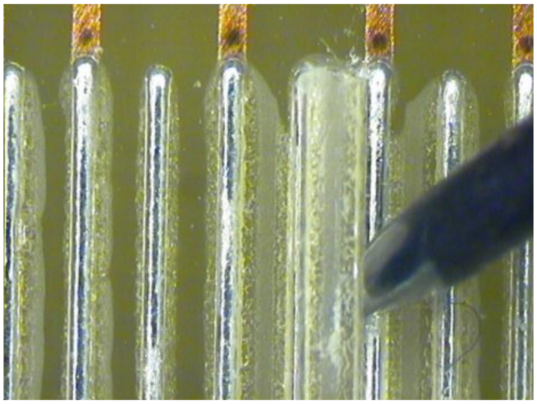


Photo 2
Delamination lifting off board

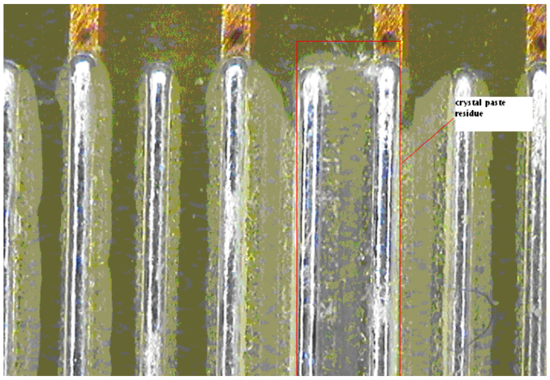


Photo 3
The crystal flux residue left on the board

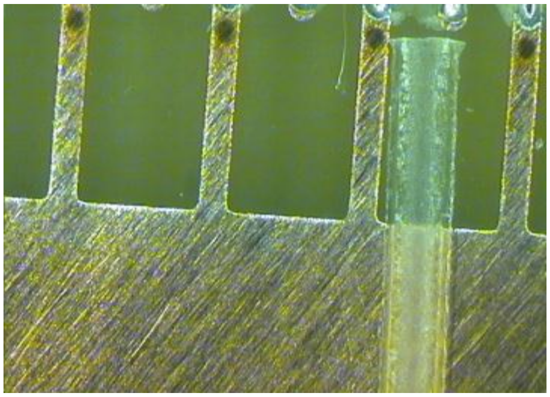


Photo 4
Crystal flux residue stuck to the coating

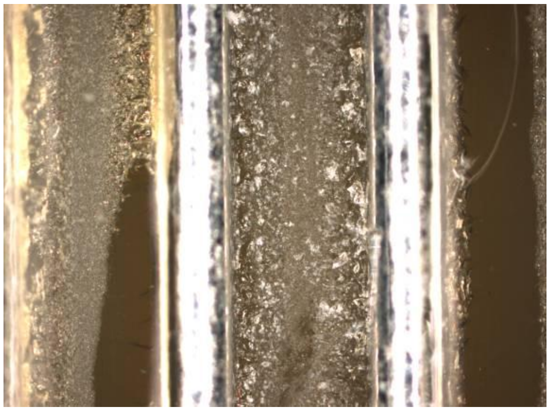


Photo 5
Close up of the above

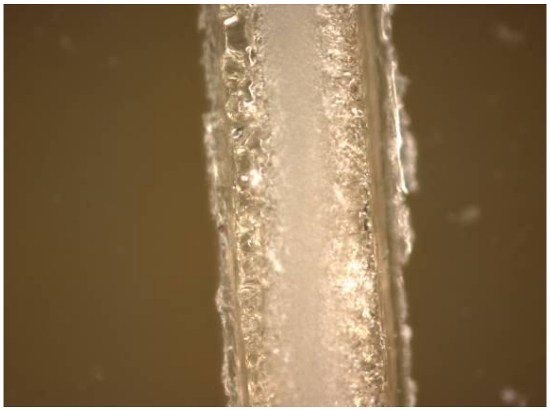


Photo 6
Close up of the above

Conformal coatings are not hermetic with all the materials tested having varying degrees of moisture vapor transmission. In this case, whereas moisture enters the coating, the softer residue solder paste absorbs the moisture and creates a “pressure cooker” of corrosion and electrical failures (shown in figure. 9).

Pictured below in figure 8 are SIR test results showing the beginnings of dendrites. These were run in 85°C/85Rh. SIR testing was also run at 40°C and 90 Rh. This test showed less failures compared to the 85°C/ 85Rh.

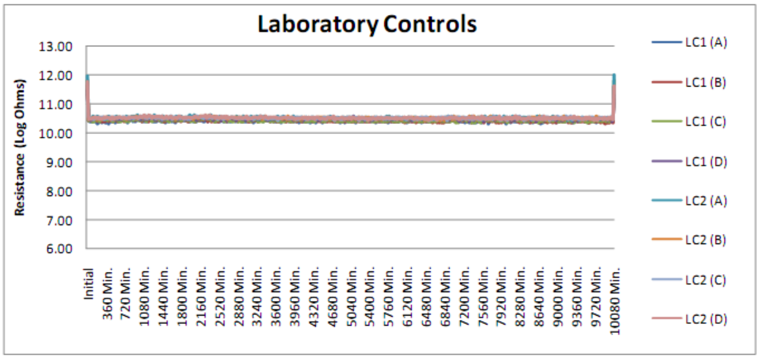


Figure 8. IPC 2.6.3.7 SIR Test (paste material coated with conformal coating).

The below picture is of a comb pattern that was run at 85°C/85Rh. The dendrites are starting to grow.

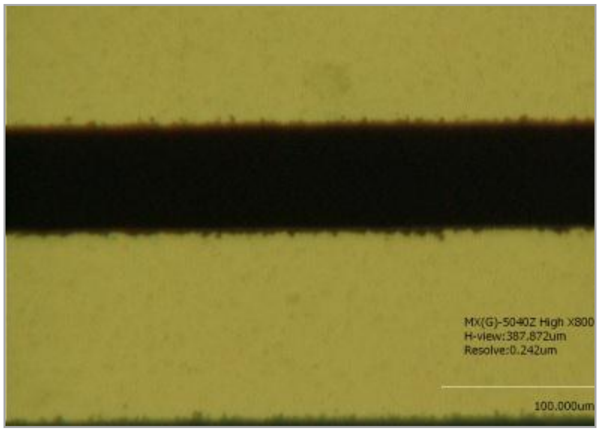


Figure 9. Comb Pattern w/ Dendrites

Adhesion to board and flux residues can also be determined by using a crosshatch cut and applying tape to check adhesion as shown in figure (s) 10 & 11.

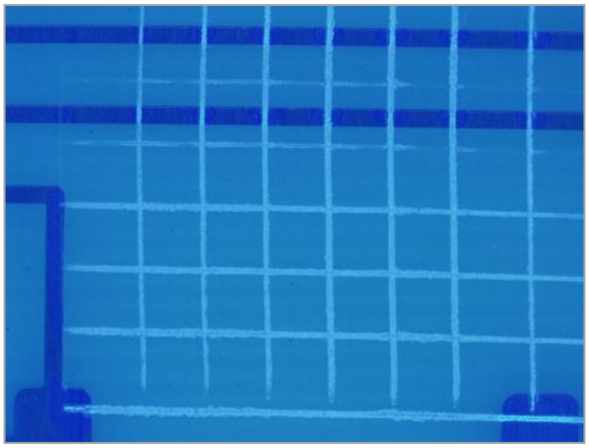


Figure 10. Black Light/Good Adhesion

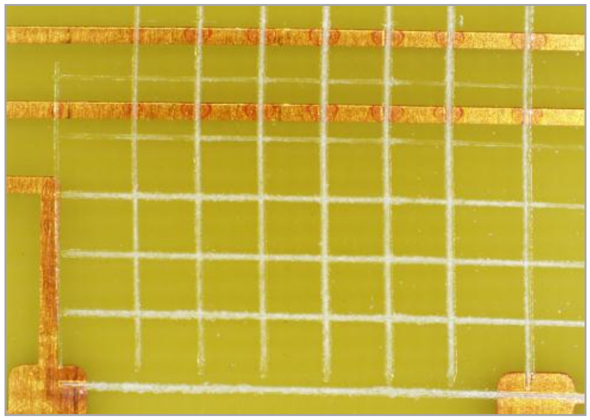


Figure 11. White Light/Good Adhesion

Conclusion

This writing is a consolidation of hundreds of tests and material combinations. The matrix of residues and available coatings would be too large to contemplate. The data has been edited to present key findings of collected information and provide practical guidance for engineers considering deploying this technique for their assemblies.

Based on our findings, we have concluded that conformal coatings can safely be used over no clean flux chemistry for many types of assemblies. It is imperative that compatibility testing be performed to ensure the coating provides the intended protection and meets the mission profile of the assembly.

The incorporation of low standoff devices and the ability to completely remove water soluble organic residues is driving more assemblers to consider a no clean process. The risk assessment of water soluble versus no clean in these applications consistently favors no clean. The cost savings in decommissioning the wash process and equipment is another major reason for migrating to no clean chemistries.

Finally, as conformal coating continues to be the only accepted practice for tin whisker mitigation, along with the looming expiration of the RoHS exemption, we predict no clean chemistries and the subsequent coating of the resulting residues will become increasingly prevalent over time.

Conformal Coating Over No Clean Flux Residues: A Case Study

Karl Seelig & Timothy O'Neill
AIM

New Age Electronics

Example of the proliferation of electronics throughout our lives

Chat on this water-resistant phone while you shower

New Age Electronics

Product technical specifications & material, components & processes

Specs

- Length : 7.87 inches // 200 mm
- Width : 1 inch // 24.5 mm
- Height : 2/3 inches // 15.70 mm
- Weight : 0.14 pound // 65 gr

Electronic Key

- Micro USB connector
- Batterie Lithium Polymere + 3.7 V
- Microchip Cortex M3 ST Micro electronic
- Capacitive detection
- Return to user : 1 vibrator + 2 leds
- 2 component plastic shells

Handle Fork

- Fits both electronically and mechanically with the electronic key

Patents : The technology is covered by four patents

1. Measure of the hand to mouth
2. Capacitive detection
3. Specific mechanical cooperation in between electronic and fork
4. Special cooperation between apps and data platform

Definition

HAPIfork is a connected fork which looks for a healthy eating behavior.

- Eat at the right time
- Eat at the right pace : not too fast
- Share with your coach : download his feedback alarm.
- Share with the community

Why Conformal Coat?

Long Term Reliability Benefits

- Reduces contamination on the PCB surface in use; preventing corrosion and dendritic growth.

Tin Whisker Mitigation

- RoHS compliant assemblies have a higher risk for tin whisker growth. Conformal coating captures and contains any whiskers that may form over time.

Why No Clean?

- Eliminates costs associated with board washing.
- Leadless packages and low stand-off devices are mandating the use of no clean to prevent flux entrapment of water clean chemistries.
- Greater through-put for high volume manufacturing.

The Problem

- Large OEM manufacturer receiving field returns on hundreds of thousands of dollars in equipment.
- FA revealed that corrosion caused by environmental factors degraded solder connections leading to failed circuitry.
- Mitigation strategies including sealing and filtration did not prevent the corrosion from occurring.

The Solution?

- Conformal coatings were evaluated as a solution but it was unclear if:
- A) Application was feasible with the design of the assemblies.
- B) Conformal coating would be compatible with the no clean materials in use?
- C) Would it solve the problem?

Different Guidelines

TEXAS INSTRUMENTS SCBA017D

3.3 Stencil Design

The difference in size between the large exposed pad and small terminal leads of the QFN presents a challenge in producing an even solder-line thickness. Because of this, careful consideration must be given to stencil design. Stencil thickness, as well as the etched-pattern geometry, determines the volume of solder paste deposited on the land pattern. Stencil alignment accuracy and consistent solder-volume transfer is critical for uniform results in the solder-reflow process. Usually, stencils are made of polymer or stainless steel, with stainless steel being more durable and providing less deformation in the squeegee step. Apertures should be trapezoidal in cross section to ensure uniform release of the solder paste and to reduce smearing. The solder-joint thickness for QFN terminal leads should be 50 µm to 75 µm. Stencil thickness usually is in the 100-µm to 150-µm (0.004 in. to 0.006 in.) range, assuming proper area ratio requirements are satisfied (see IPC-7525).[9] If a step-down stencil design is not used, the SMT device(s) that are the limiting factor on the PCB determine the actual thickness of the stencil.

A squeegee with a durometer measurement of 95, or harder, should be used. The blade angle and speed must be optimized to ensure even paste transfer. Characterization of the stencil output is recommended before placing parts.

As a guide, a stencil thickness of 0.1016 mm to 0.125 mm (4 mils to 5 mils) for these QFN packages is recommended. Figures 28 through 30 detail the stencil recommendations for the 14-, 16-, and 20-pin QFN packages. All designs below have area ratios >0.66 and paste-transfer efficiencies of 73% for terminal pads and 100% for thermal pads at a stencil thickness of 0.127 mm (5 mils). At a stencil thickness of 0.1016 mm (4 mils), the area ratio is 0.86, terminal-pad paste-transfer efficiency is 89% and 100% for the thermal pad. The slotted-thermal-pad stencil design is recommended to prevent the QFN package from floating during reflow and causing opens between the terminal leads and pads. This feature also allows adequate room for outgassing of paste during the reflow operation, thus minimizing voids.

A low residue, no clean Type 3 or Type 4 solder paste is recommended.

The Details

Which Conformal Coating?

Ideal characteristics – One-part system, long pot life, low curing temperature, short drying* time, environmentally friendly.

*Drying = Dry to touch

Cured = Fully Cross-linked

Material Options

Acrylics

Thermoplastics dissolved in solvents – no cross-linking

Strengths	Weaknesses
Air Dry	VOC Bearing Solvents
Easy Solvent Rework	Poor Solvent Resistance
Good Moisture Barrier	Flammable
Ease of Use	Soften in High Temp

Material Options

Urethanes

Cure through cross-linking

Strengths	Weaknesses
Solvent Resistant	Some contain VOC's
Humidity Resistant	Rework
Abrasion Resistant	Cure rate environmentally dependent
Dielectric Properties	Worker health risks

Material Options

Silicones

Cure through moisture cross-linking

Strengths	Weaknesses
Humidity Resistant	Abrasion
Moisture Resistant	Workplace Contamination
Flexibility	Sulfide Corrosion
Temperature Tolerant	

Material Options

Epoxies

Usually two-part systems

Strengths	Weaknesses
Humidity Resistant	Two-Part
Moisture Resistant	Rework
Abrasion Resistant	Pot life
Dielectric Properties	

The Selection

UV Curable Urethane

Strengths	Weaknesses
Protective Properties	Capital Investment
Through Put	Rework
Environment Impact	Shadowing
UV Inspection	

Implementation Requirements

- All conformal coating manufacturers recommend a clean board for coating purposes. Contamination leads to:
- Corrosion
- Non-wetting
- Delamination

Implementation Requirements

Sources of Contamination

- Flux residue
- Finger prints
- Board fab chemistry i.e. plating chemistry, masking agents, mold release, inks
- Oils, dust, dirt
- The choice to apply coating over no clean required all of these avenues for contaminates to be effectively controlled.

Implementation Requirements

Conformal Coating Application

- Automated precision spray robots were selected.

Curing Method

- UV cure ‘ovens’ for tack-free handling. Secondary cure mechanism in selected material for increased robustness and shadowed areas.

Determining Compatibility with Flux Residues

Three test criteria were used to assess the performance of the combination of the conformal coating and AIM no clean flux residue.

- IPC J-Std-004 SIR Testing
- IPC CC-830
- ASTM – D3359

Determining Compatibility with Flux Residues

SIR Coupon Preparation

- Three (3) IPC B-24 coupons were printed with solder paste and reflowed.

- Coupons were coated using automatic robotic dispensing equipment. Application thickness was targeted at 3 mil.

- Boards were processed through a UV oven for 2 cycles of approximately 2 minutes each pass.

- Boards cured in ambient conditions for an additional 7 days to facilitate secondary cure mechanism.

Determining Compatibility with Flux Residues

SIR Test Method

REQUIREMENTS: The insulation resistance of each comb pattern shall be 1 x 108 ohms minimum after 36 hours exposure to temperature and humidity. Any reason for deleting values (scratches, condensation, bridged conductors, outlying points, etc.) must be noted. Rejection of results for more than 2 combs for a given condition shall require the test to be repeated.

The specimens shall also be examined for dendritic growth or corrosion at 10X to 30X magnification with backlighting within 24 hours of completing the testing.

Dendritic growth that spans 25% or more of the original spacing will constitute a failure.

Determining Compatibility with Flux Residues

SIR Test Method

METHOD: Teflon coated wires were attached to the terminal areas of the IPC-B-24 coupons with rosin (R) flux and solid core solder wire. Aluminum foil was used to protect the comb patterns from flux spitting during the soldering process. The flux residues were not removed from the terminal areas.

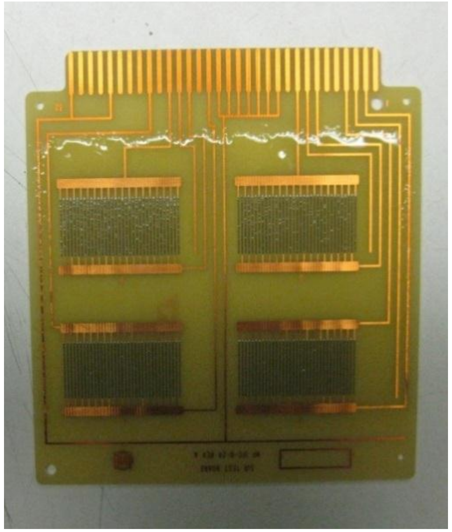
The coupons were placed in an environmental chamber in a vertical position such that airflow was parallel to the board surfaces, with at least ½ inch spacing between coupons.

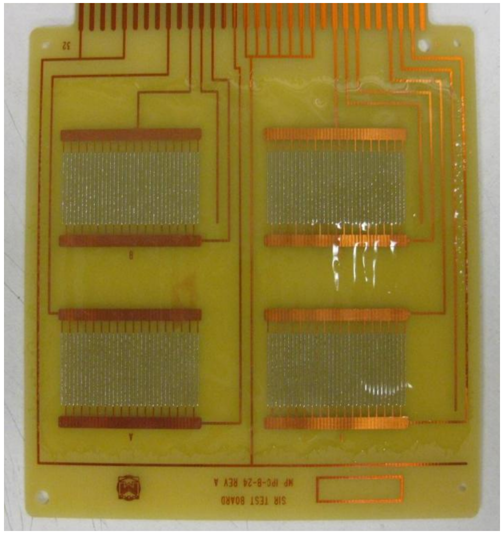
A bias of 5 volts DC was applied to all test coupons. The chamber was set to 25° C and 50% RH and the samples allowed to dwell at these conditions for 1 hour. The temperature was then ramped to 40° C while keeping the humidity at 50% for 15 minutes. Over a 30 minute period, the relative humidity was ramped to and 90 $\pm$3% RH. The coupons were allowed to equilibrate for one hour before measurements were taken. Measurements were taken every 20 minutes.

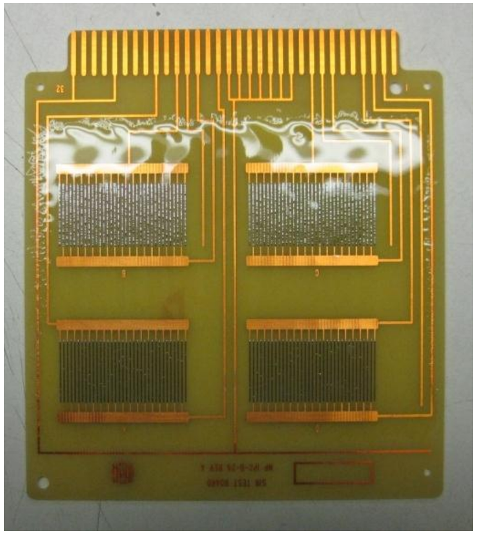
Determining Compatibility with Flux Residues

RESULTS

Upon removal from the test chamber and a complete inspection, no mealing, blistering, delamination, or other forms of degradation were observed.



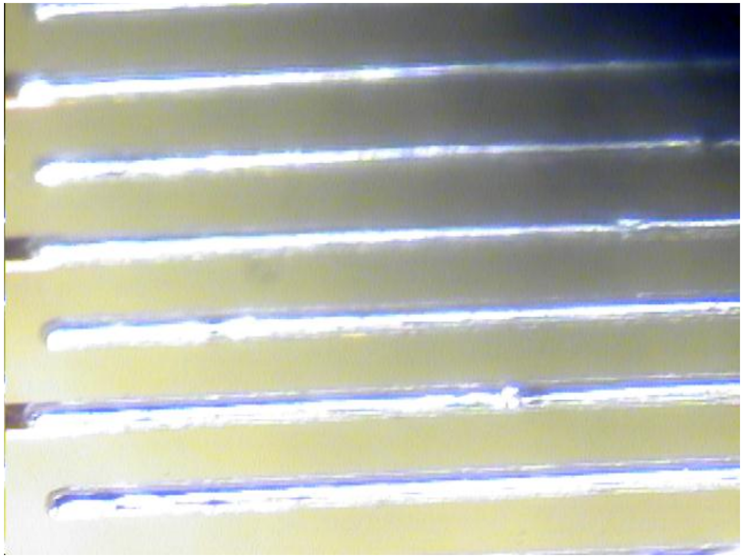


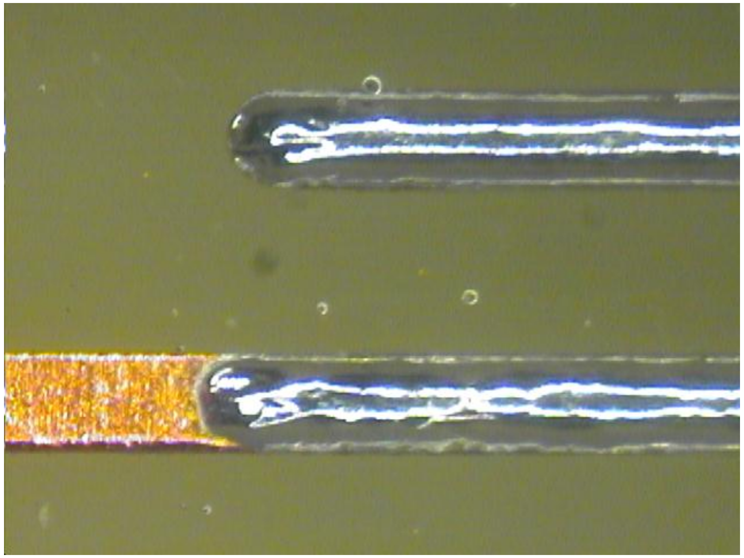


Determining Compatibility with Flux Residues

RESULTS

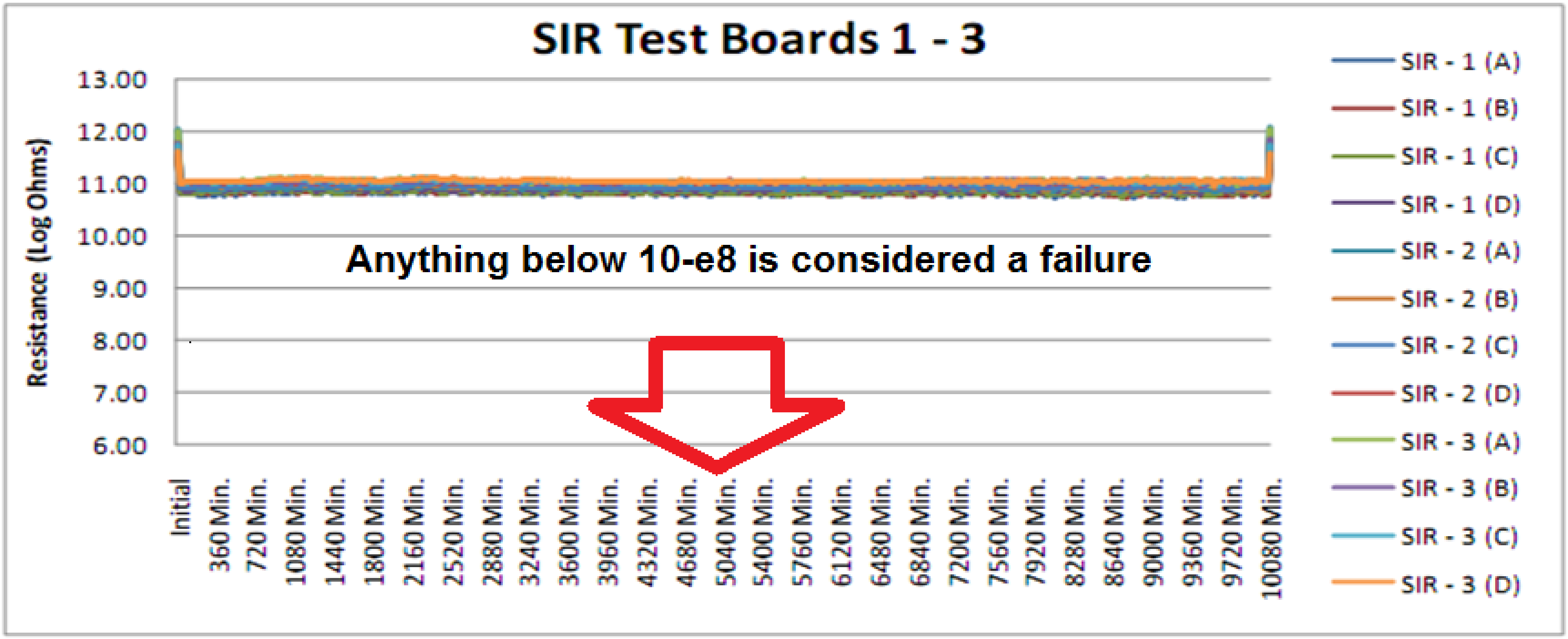
Upon removal from the test chamber and a complete inspection, no mealing, blistering, delamination, or other forms of degradation were observed.





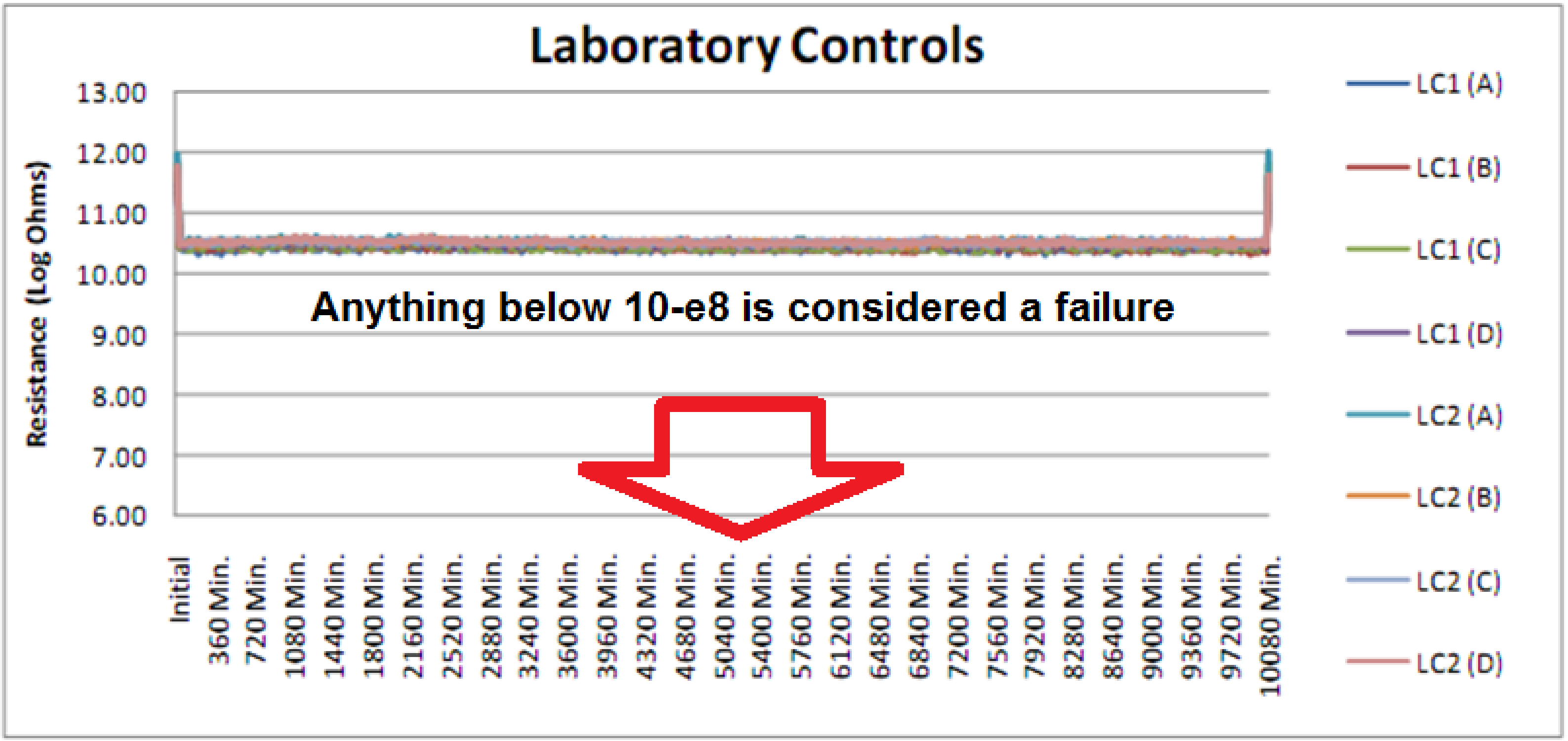
Determining Compatibility with Flux Residues

RESULTS



Determining Compatibility with Flux Residues

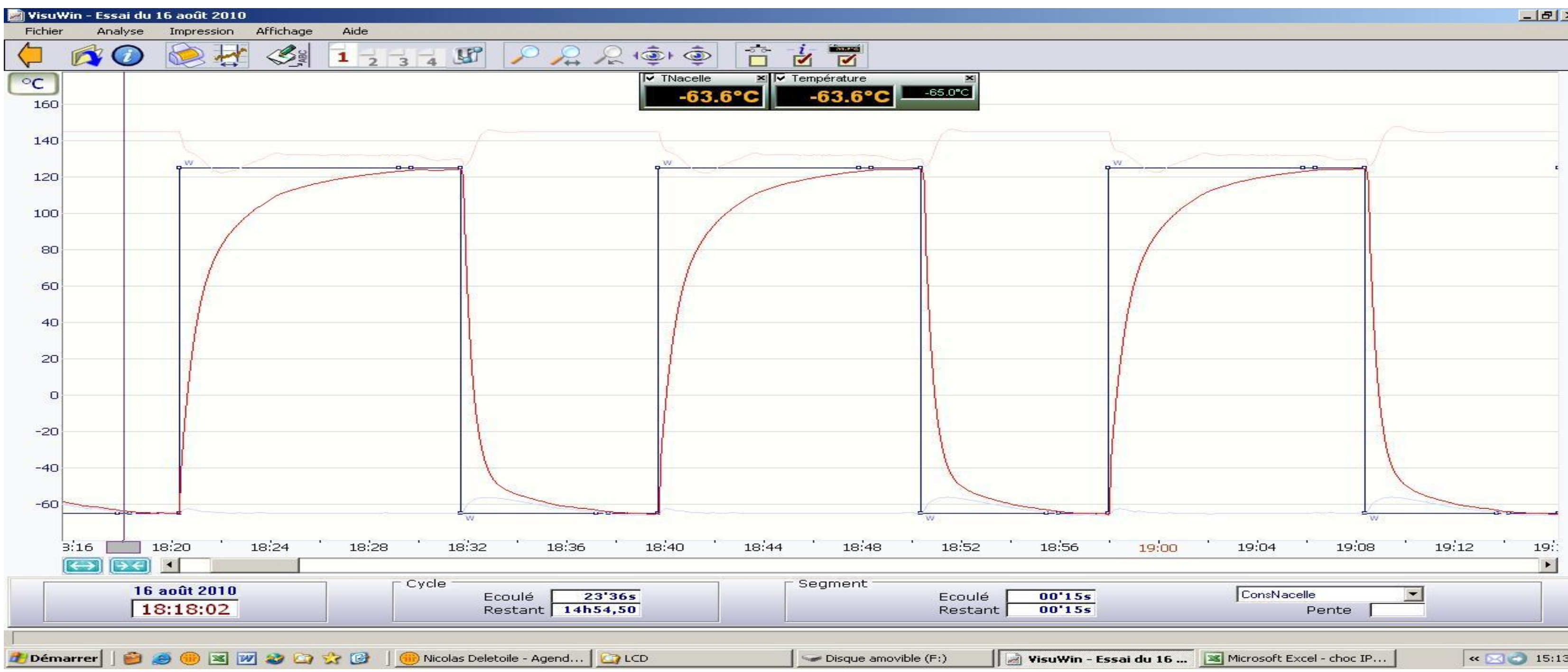
RESULTS



Determining Compatibility with Flux Residues

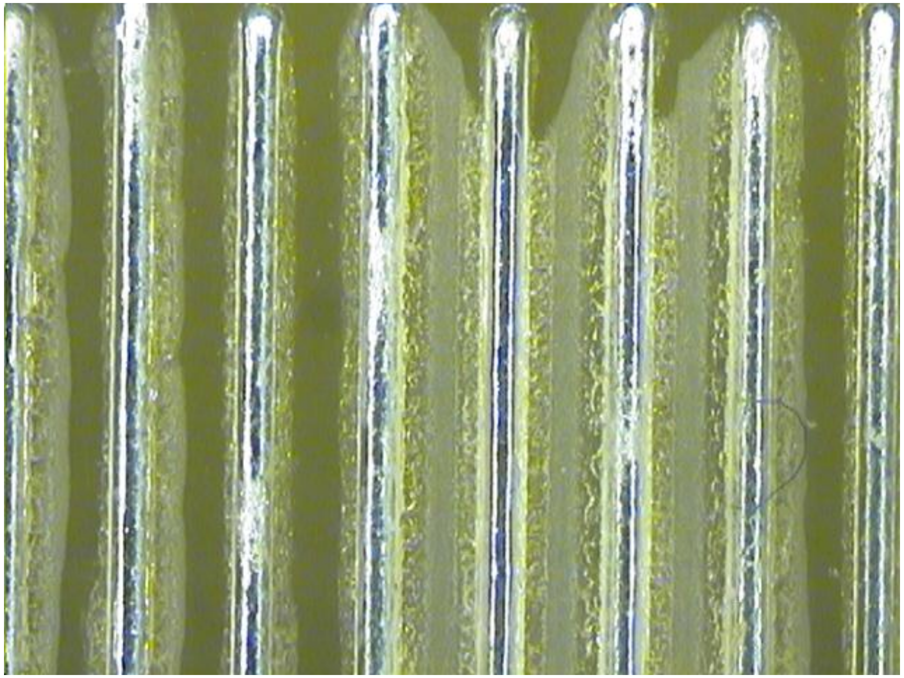
Thermal Shock

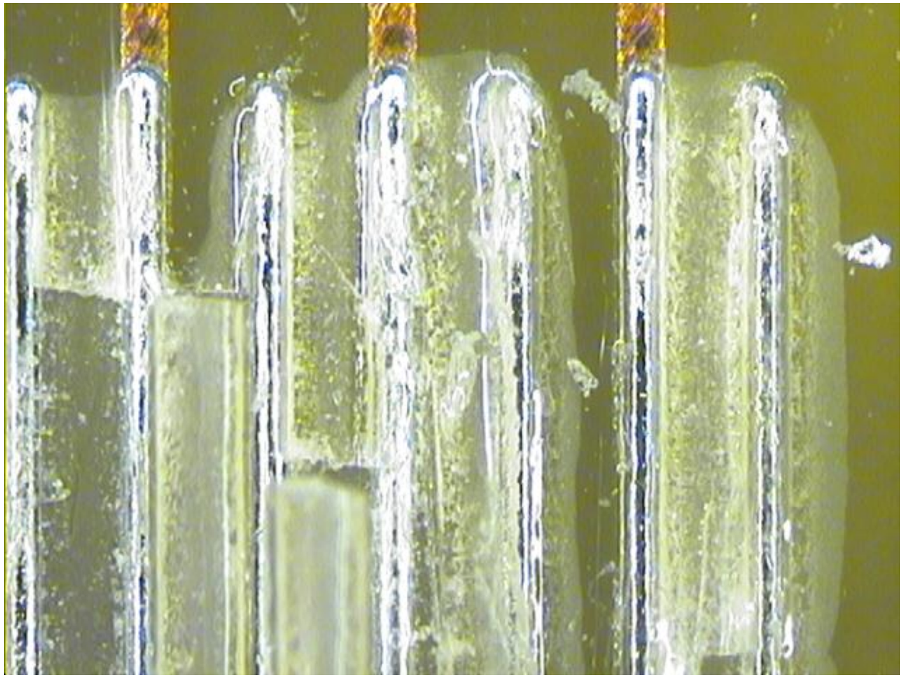
-60C to +125C



Determining Compatibility with Flux Residues

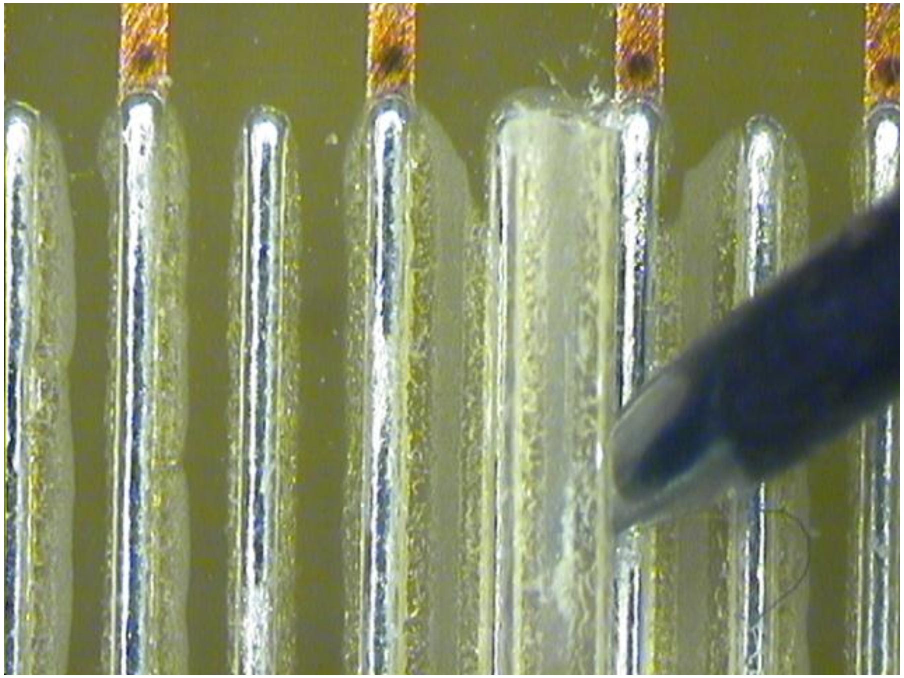
Thermal Shock Results

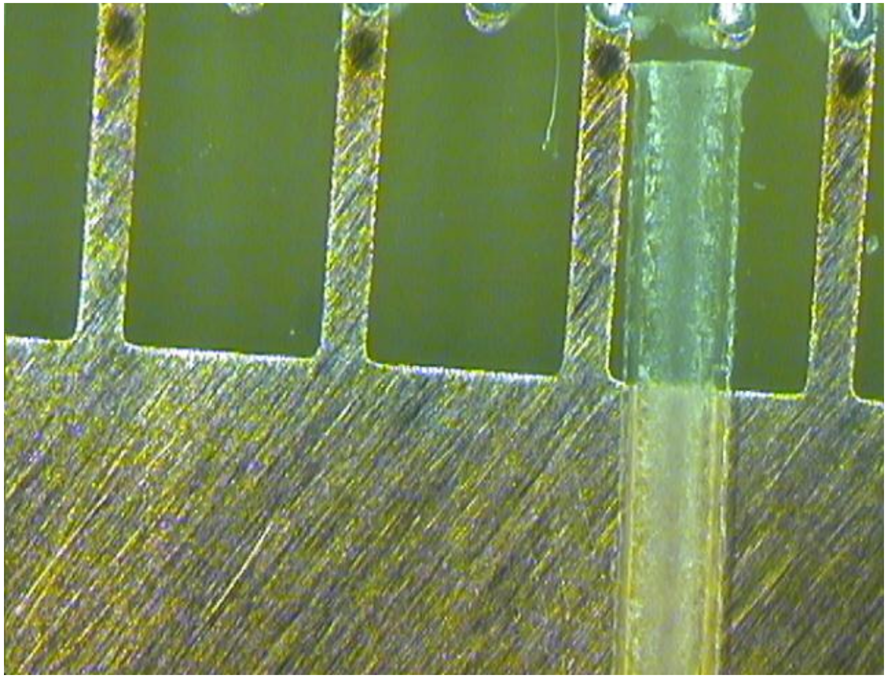




Determining Compatibility with Flux Residues

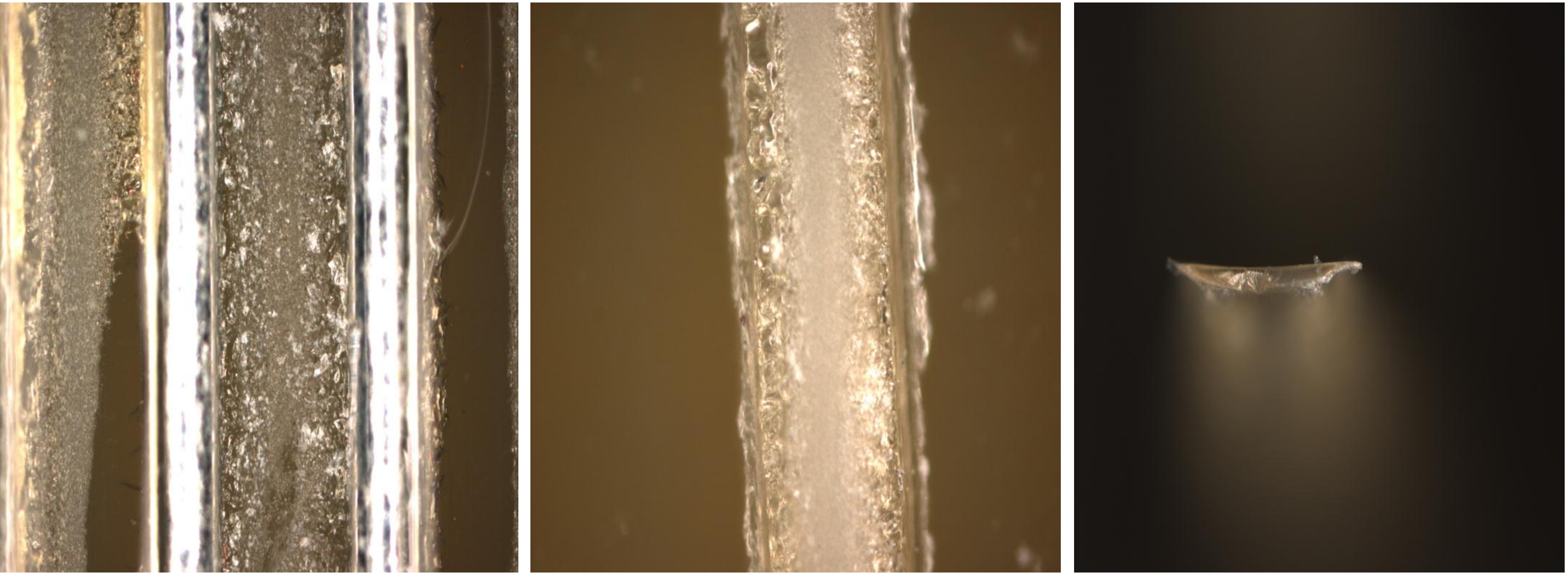
Thermal Shock Results





Determining Compatibility with Flux Residues

Thermal Shock Results



Determining Compatibility with Flux Residues

Thermal Shock Results

Analysis of delamination indicated a cohesive failure of the residue rather than a separation of the coating from the residue. This was believed to have occurred on the cold side of the thermal shock with a CTE mismatch leading to stresses applied to the flux residue causing cracking.

Subsequent testing with more ductile flux residue and lower durometer conformal coating did not exhibit this failure mode.

Determining Compatibility with Flux Residues

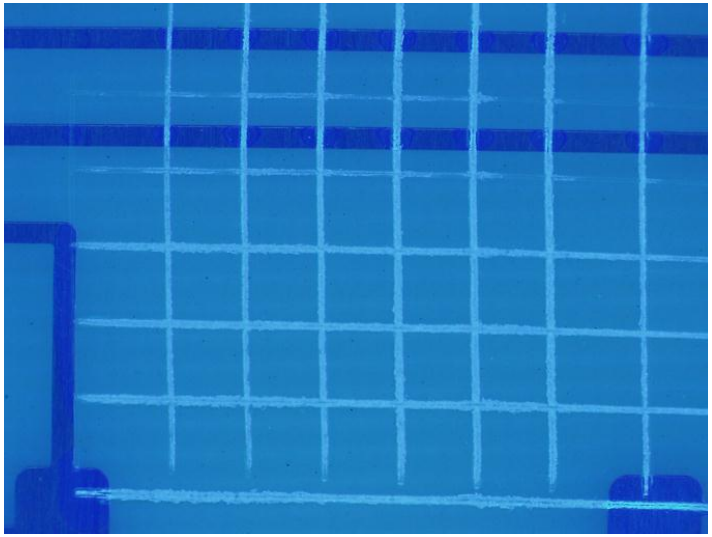
Thermal Shock Results

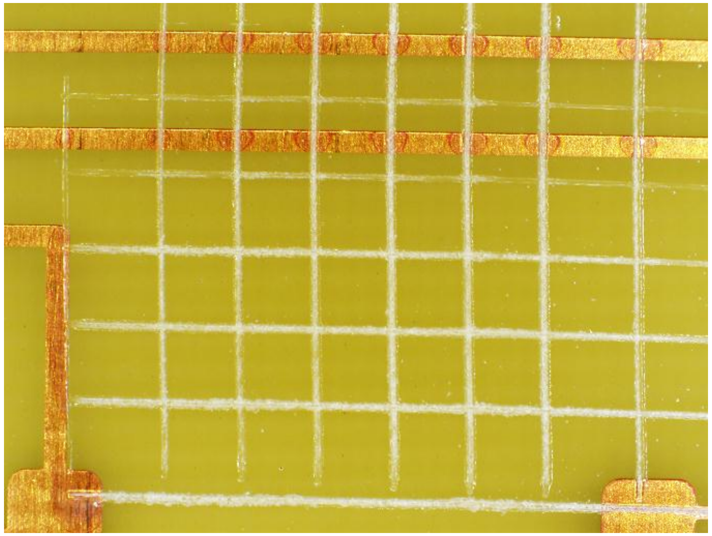
Modification of the cycle from -60C to -25C eliminated the delamination condition as well. It was decided by the customer that this was acceptable in context of the mission profile of the assembly in use.

Determining Compatibility with Flux Residues

ASTM – D3359 Test Results

The result was 5B, meaning no loss of adhesion was observed, as demonstrated visually below in both black and white light.





Conclusion

- It is possible to successfully apply conformal coatings over no clean flux residues.
- It is necessary to perform adequate testing for the requirements of the intended application and that the desired out come can be achieved.

Future Work

- Expansion of material compatibility matrix

- Study of the economic impact of eliminating the wash process for assemblies to be conformally coated

Special thanks to:

BOSE

WHELEN ENGINEERING COMPANY INC

Schneider Electric

DYMAX

HumiSeal

CHASE

www.aimsolder.com
www.leadfree.com