THE IMPORTANCE OF CONFORMAL COATING THICKNESS AND EDGE COVERAGE

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ABSTRACT

As electronics continue to become ever more densely populated, and expected to operate in ever more hostile environments, the use of conformal coating is becoming more and more essential to protect the assembly from its operating environment, and ensure acceptable reliability for the application intended.

Conformal coated assemblies are often exposed to harsh operating environments, including high humidity, high temperatures, corrosive gases, condensing environments and rapid changes in operating temperature.

It is important that the conformal coating can withstand its anticipated operating environment. In previous papers, populated SIR (Surface Insulation Resistance) test assemblies were subjected to a harsh sequential load and their ability to withstand corrosion was assessed by SIR.

During this testing it was seen that most of the coatings tested failed to provide good protection during powered salt-spray testing. Further testing, performed under condensing conditions, confirmed the importance of, and difficulty in, achieving good coverage with liquid applied conformal coatings.

In this paper, we compare the performance of new silicone and urethane materials, designed for coverage and thickness, with a popular acrylic and ultra-thin material, in a variety of experiments designed to determine, how thick is thick enough?

Key words: conformal coatings, salt-water, immersion, condensation, coating thickness, coating coverage, silicone, urethane, acrylic, ultra-thin, fluoro-polymer.

INTRODUCTION

With the increased adoption of electronics in our everyday lives, and the increasingly demanding operating environments and reliability requirements, the use of conformal coating as a means of enhancing electronic reliability continues to grow in importance, particularly in safety critical applications.

In many high reliability applications, e.g. automotive, cleaning prior to coating is not routinely performed, the system of coating and assembly residues must be able to withstand the anticipated operating environment. Assembly process residues, and airborne contaminants in the operating environment can lead to the creation of metallic dendritic growth, leading to leakage currents which can degrade circuit performance or lead to premature circuit assembly failure.

IPC-CC-830B outlines the performance requirements and test methodology for conformal coating materials. The testing is performed on flat, scrupulously clean test coupons made from a variety of FR4 and glass substrates. There is no consideration of process residues, solder resist or component geometry in CC-830. Whilst this is understandable from a material performance specification, it does mean that the standard struggles to differentiate performance between materials. Adhesion to solder-resist, compatibility with process or no-clean residues, and coverage of conductive surfaces such as component leads, the influence of the coating on solder joint life or the influence of the solder-joint and leads on the coating material's thermal shock performance do not form part of the qualification document, but are key performance criteria for conformal coatings in real world applications, hence the title of this series of papers.

IPC-J-STD-001 describes the acceptable coating thickness range, by generic chemistry type, but only refers to flat, unencumbered areas of the board.

Conformal coatings can be effective at preventing environmental contamination reaching the board assembly. However, they are not necessarily inherently water-proof, and defects or gaps in the film can allow the transportation of potentially corrosive species to susceptible parts of the assembly.

In a forthcoming white-paper, 'IPC-TR-587 Conformal Coating Material & Application "State of theIndustry" Assessment Report', led by Dave Hillman[1], a variety of liquid applied conformal coatings and application processes were used to coat and cure assemblies. These assemblies were then cross-sectioned and examined for thickness. One of the standout features, was just how difficult it was to successfully coat the mid-points of component leads and other sharp edges or vertical surfaces as shown for example in fig 1. There are hundreds of cross-sections showing the same challenges

Whilst the white-paper highlights some of the challenges faced in optimising the application of conformal coatings, but doesn't really give any guidance on what is acceptable thickness or coverage (which wasn't the intention). The aim of this paper is to help understand what thickness should be targeted as good enough to provide protection, using both DI water and saline solution to simulate real-life contaminants.

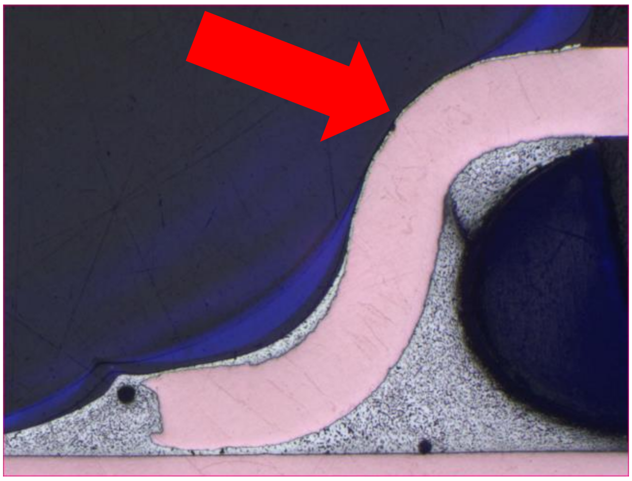

Fig 1. Cross-section of QFP lead showing negligible coating coverage on knee bend.

EXPERIMENTAL 1

For simplicity, the following simple test set-up was created to measure the SIR of a variety of coating materials under conditions approaching immersion.

Conformal coatings were applied to the IPC B-24 test coupon at a variety of wet-film thicknesses, to achieve the required dry film thicknesses. In the case of the UT coating, the application of multiple coating layers was necessary to achieve the required thicknesses.

Table 1 shows the coating materials and dry-film thicknesses that were tested for SIR under water-saturation conditions:

Table 1. Coating types and thickness

Coating	T1 (µm)	T2 (µm)	T3 (µm)	T4 (µm)
UT	3	5	25	100
AR	5	15	25	150
SR	50	100	150	250
UR	50	100	150	250

Dry-film coating thicknesses were verified by mechanical means using a micrometer to subtract the thickness of the test boards from that of the coated boards at pre-determined positions.

Surface Insulation Resistance Testing

All SIR measurements were made by a calibrated Auto-SIR^{TM}-256 automated electrometer, using a calibrated test-rack for ease of data collection as shown below in figure 2.

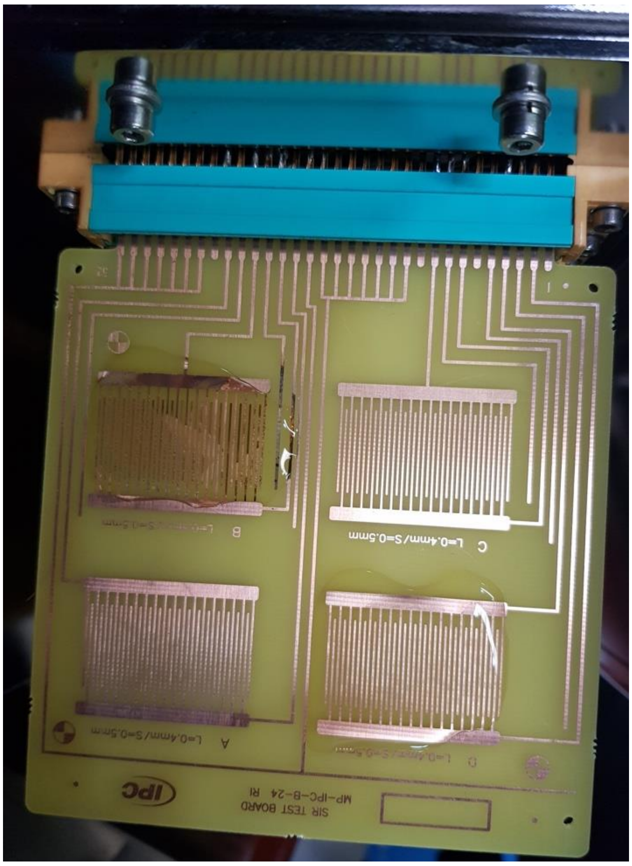

Fig 2. IPC-B24 coupon mounted horizontally in SIR test rack.

Materials

3.5% saline solution was prepared by dissolving 35g NaCl in 900ml of DI water, and then topping up to 1L with DI in a volumetric flask.

Conformal coatings were applied to the IPC-B24 test boards using drawdown bars and cured according to their data sheets. Coated test boards were left for 7 days at 25°C and 50% RH to reach optimum properties prior to test.

The IPC-B-24 test boards were cleaned with IPA prior to the application of coating materials or being testing uncoated as a control, with the exception of a no-clean solder paste, which was tested uncleaned and uncoated as another control.

5ml of 3.5% saline was applied to each comb immediately prior to the commencement of each SIR test.

SIR Test Conditions

All SIR tests were performed at 25°C and 50% (ambient lab conditions). 10V was applied continuously, SIR measurements were recorded every minute. The duration of the SIR test was 500 mins

Results 1

The results obtained for the various coating materials when saturated with liquid DI water are shown in Table 2. The leakage current is calculated by Ohms law from the Resistance and Voltage. The SIR values obtained for the uncoated, no clean solder paste, UT and AR coated boards were very similar at normal thicknesses. The UT (ultra-thin) coating showed significant improvements in SIR at a coating thickness of 100µm. Additional thickness didn't seem to improve the SIR of the saturated AR coating, with values remaining low, even at 150µm thickness. However, there were no visible signs of corrosion, arcing or any other signs of excessive current leakage

Table 2. SIR values of coatings saturated with liquid DI water.

liq water	SIR 1 / Ohms	Leakage current / A	SIR 500 / Ohms	leakage Current / A2
Uncoated	6.70E+06	1.49E-06	1.05E+07	9.55E-07
PASTE	6.56E+06	1.52E-06	1.66E+07	6.03E-07
UT 3	6.60E+06	1.52E-06	1.07E+07	9.33E-07
UT 5	6.65E+06	1.50E-06	1.10E+07	9.12E-07
UT 25	1.20E+07	8.33E-07	1.38E+07	7.24E-07
UT100	1.20E+10	8.33E-10	1.05E+07	9.55E-07
AR 5	6.60E+07	1.52E-07	1.29E+07	7.76E-07
AR 15	6.65E+07	1.50E-07	1.10E+07	9.12E-07
AR 25	6.67E+07	1.50E-07	1.32E+07	7.59E-07
AR 150	6.97E+07	1.43E-07	1.58E+07	6.31E-07
SR 50	1.16E+11	8.62E-11	4.68E+10	2.14E-10
SR 100	9.17E+09	1.09E-09	5.50E+10	1.82E-10
SR 150	1.07E+11	9.36E-11	8.91E+11	1.12E-11
SR 250	1.12E+12	8.96E-12	8.91E+11	1.12E-11
UR 50	9.00E+10	1.11E-10	1.48E+10	6.76E-10
UR 100	1.23E+11	8.13E-11	8.32E+10	1.20E-10
UR 150	5.01E+11	2.00E-11	5.13E+11	1.95E-11
UR 250	1.02E+12	9.76E-12	8.91E+11	1.12E-11

When we consider the results for the 3.5% saline solution, as shown in Table 3. The insulation resistance has dropped further, and the calculated leakage current has increased in all cases except the very thick UT coatings, and the SR and UR materials. Some slight corrosion was seen on the uncoated, uncoated no-clean solder-paste boards as well as the UT and AR, although not to the extent that would be expected from the SIR measurements.

Table 3. SIR results of coatings saturated with 3.5% saline solution.

Saline	SIR 1 / Ohms	Leakage current / A	SIR 500 / Ohms	leakage Current / A2
Uncoated	6.60E+06	1.52E-06	5.01E+04	2.00E-04
PASTE	6.53E+06	1.53E-06	1.26E+04	7.94E-04
UT 3	6.50E+06	1.54E-06	5.01E+04	2.00E-04
UT 5	6.57E+06	1.52E-06	4.79E+04	2.09E-04
UT 25	1.28E+08	7.81E-08	6.17E+05	1.62E-05
UT100	1.18E+10	8.47E-10	1.62E+10	6.17E-10
AR 5	6.58E+07	1.52E-07	5.25E+04	1.91E-04
AR 15	6.53E+07	1.53E-07	5.37E+04	1.86E-04
AR 25	6.73E+07	1.49E-07	6.17E+04	1.62E-04
AR 150	6.81E+07	1.47E-07	3.16E+06	3.16E-06
SR 50	1.20E+10	8.33E-10	4.79E+10	2.09E-10
SR 100	1.01E+11	9.87E-11	6.92E+10	1.45E-10
SR 150	1.07E+11	9.36E-11	1.66E+11	6.03E-11
SR 250	1.10E+12	9.07E-12	2.14E+11	4.68E-11
UR 50	8.62E+10	1.16E-10	9.77E+10	1.02E-10
UR 100	9.55E+10	1.05E-10	1.41E+11	7.08E-11
UR 150	6.31E+11	1.58E-11	4.57E+11	2.19E-11
UR 250	1.14E+12	8.77E-12	5.25E+11	1.91E-11

However, the Auto-SIR™ contains a 1MΩ resistor to limit current flow and preserve evidence of dendritic growth.

Experimental 2.

It was decided to directly measure the leakage current using a Keysight 34465A Digital Multimeter. In this experiment, 1 drop of saline solution was pipetted onto the test coupon, data logging was started and then the voltage was applied. Measurements were logged automatically at 1s intervals and an example is plotted in Fig 3 below.

Results 2

Extensive corrosion could be seen forming almost immediately on both the uncoated paste and 5 micron UT coated board as shown in figs 4-5 below. Within 100 seconds the UT coated board displayed the same leakage current as the uncoated no-clean paste.

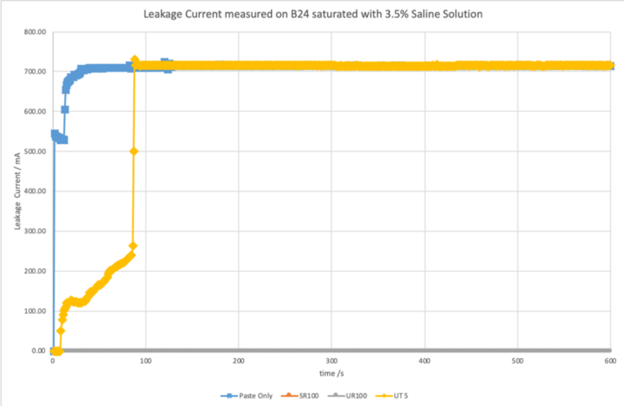

Fig 3. leakage current measurements for different coatings and thicknesses.

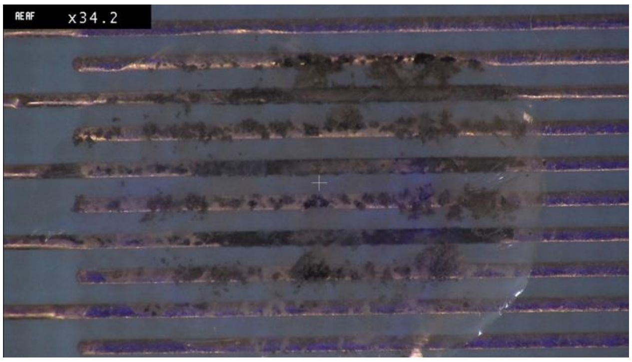

Fig 4. corrosion products forming on no-clean solder paste after 30 seconds powered with saline saturation

Fig 5. corrosion products forming on UT-5 micron after 30 seconds powered with saline saturation

The minimum thickness tested to achieve a corrosion free 1800s saturation with the 3.5% saline is shown in table 4.

Table 4. Minimum thickness tested to survive corrosion-free saline saturation.

Coating	Thickness	Max Leakage Current (mA)	Corrosion
UR	50	0.001	NO
SR	50	0.001	NO
AR	150	39	NO
UT	25	119	NO
Uncoated	NA	723	YES
NC paste	NA	732	YES

The acrylic and UT materials tested at greater than normal use thickness, still yielded a significantly higher leakage current than either the urethane or silicone material tested.

Experimental 3

Flat test-boards can yield interesting information, but customers produce 3D populated assemblies. Therefore, the previous experiment was reproduced using a QFN modified, fully populated IPC-B52 test assembly, assembled with a no-clean paste. Based on the previous results, the urethane and silicone materials were spray applied at a target thickness of 200 microns. The acrylic material was double-dip coated to yield a nominal thickness of 74 microns. The UT material was dip-coated 5 times to yield a nominal thickness of 13 microns.

The boards were immersed (taking care to keep the connector out of the saline solution) and all components were powered at 10V. The boards were tested until the leakage current exceeded 200mA between the QFP leads and the time recorded. The boards were then visually inspected for signs of corrosion.

Results 3

The results of the B-52 immersion in saline solution are summarised in Table 5 below.

Table 5. Summary of B-52 immersion testing

Coating	Thickness / uM	Time to 200mA	Corrosion
UR	200	>30 Hours	No
SR	200	>30 Hours	No
AR	74	19 Seconds	Yes
UT	13	9 Seconds	Yes

The Ultra-thin coating was the fastest to reach the leakage current threshold at just 9 seconds. Corrosion was readily visible on all components, but was especially prevalent on QFN components due to the exposed metallisation of the traces (most pads were solder mask defined) as shown in figs 6-8.

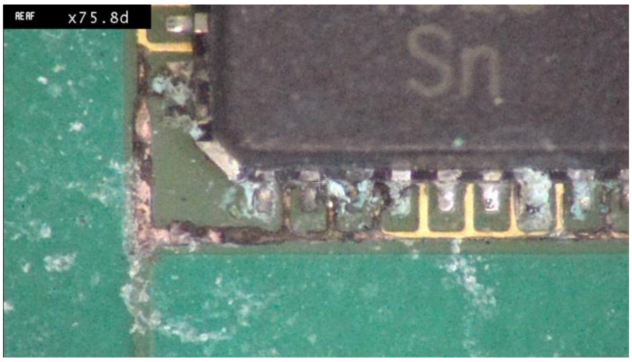

Fig 6. corrosion of UT coated QFN.

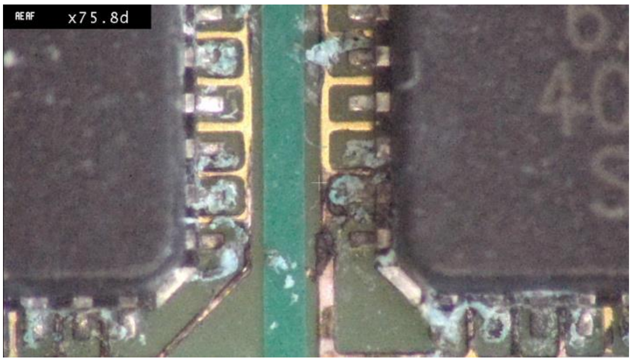

Fig 7. Corrosion of UT coated QFN array

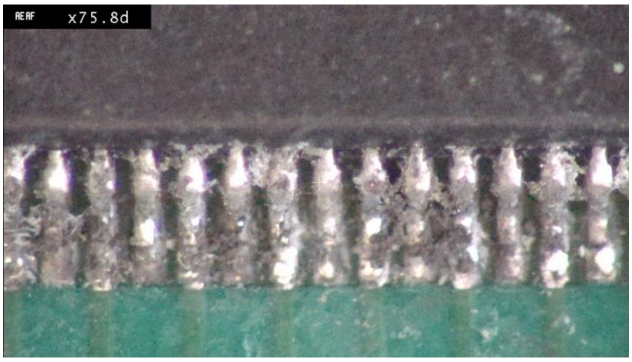

Fig 8. Corrosion of UT coated QFP leads

The acrylic material reached the threshold leakage current in just 19s. The corrosion seen was not as extensive as seen with the UT coating, but was already quite apparent, as shown in figs 9-11

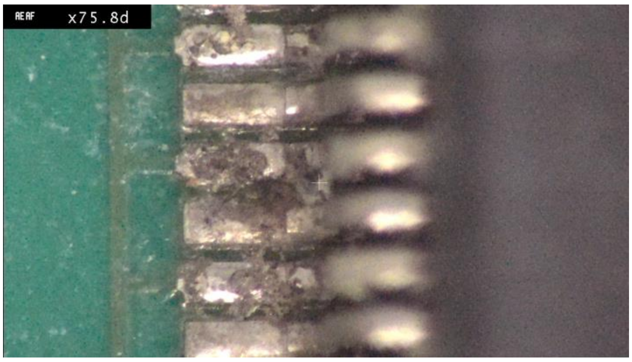

Fig 9. Corrosion evident on AR coated QFP leads

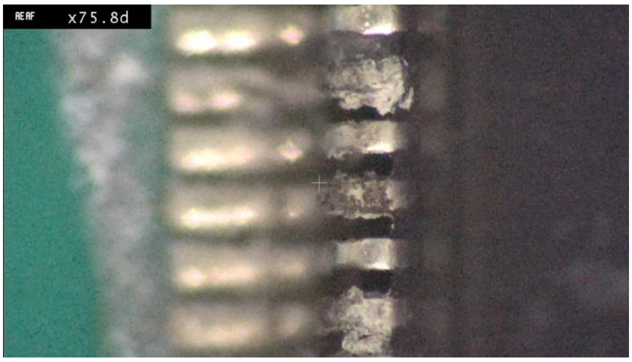

Fig 10. Corrosion evident on AR coated QFP leads

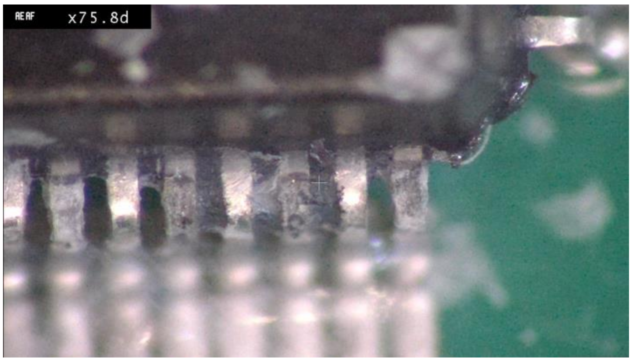

Fig 11. Corrosion evident on and between AR coated QFP leads.

The Silicone and Urethane materials both withstood 30 hours immersion in the saline solution without reaching the threshold leakage current. During the visual inspection (Figs 12-17) there was very little difference in appearance of the boards after testing was complete.

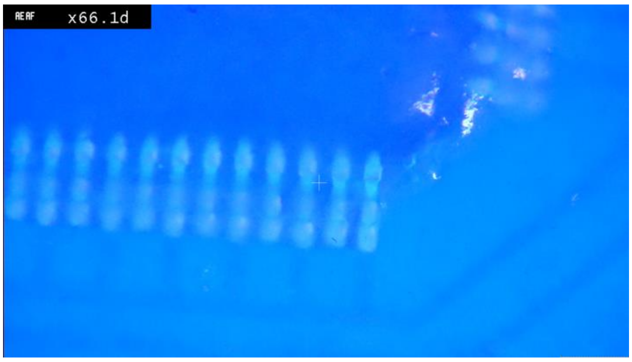

Fig 12. UR coated QFP leads under blacklight showing coverage.

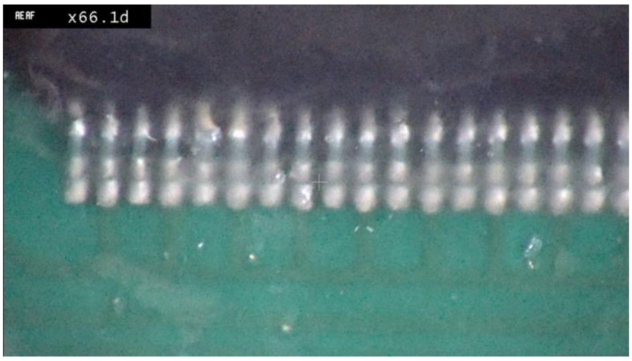

Fig 13. UR coated QFP under white light – no evidence of corrosion.

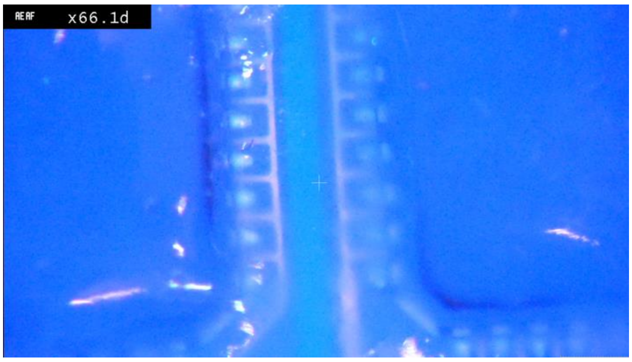

Fig 14. UR Coated QFN under black-light showing coverage

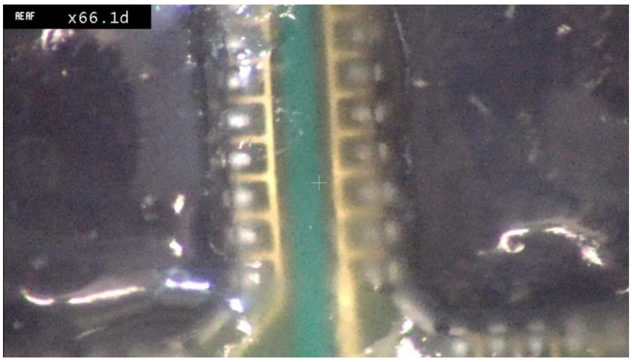

Fig 15. UR Coated QFN showing no evidence of corrosion

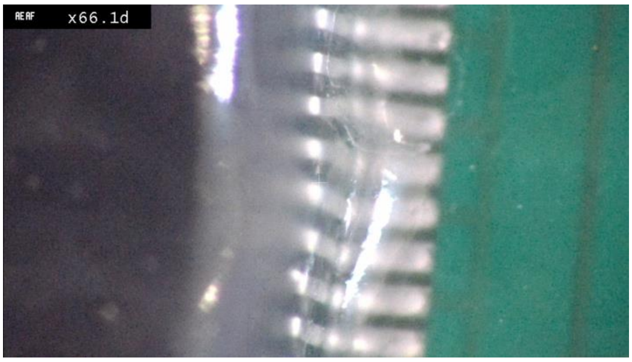

Fig 16. SR coated QFP lead showing no evidence of corrosion.

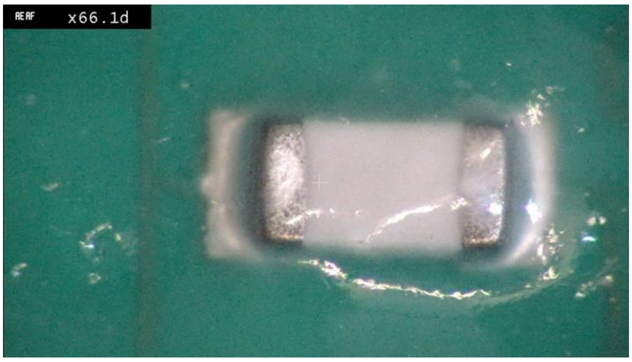

Fig 17. SR coated discrete showing no evidence of corrosion.

Conclusions

From these relatively simple experiments, it is clear that thickness and coverage are of vital importance in determining whether an assembly will survive life in the field, whether the risk of failure comes from humidity, condensation, salt-splashes, arcing or tin whisker formation.

Immersion testing has traditionally been an extremely difficult test to pass with conventional conformal coatings. The new Silicone and Urethane coatings were formulated to address the coverage and thickness issues so prevalent with liquid applied coatings.

It can be seen from the results of the first experiment that the acrylic material did not significantly improve the SIR value when saturated, even at 150 microns. The ultra-thin material, defined as being < 12.5 microns required 25 microns to show any improvement over no coating, and even at 100 microns did not match the insulation capabilities of the Silicone or Urethane materials.

In the second experiment, by omitting the current limiting resistor and measuring the actual leakage current, we were able to see again that the conventional and ultra-thin materials yielded significantly greater leakage currents than the silicone and urethane materials.

Extending this methodology to a populated B-52 assembly and looking at topography and components as opposed to flat SIR combs, we once again saw the silicone and urethane materials provide a dramatic improvement in the survival time immersed, powered-up in 3.5% saline solution. The silicone and urethane material survived these conditions for 30 hours without evidence of corrosion or excessive leakage current, whereas the acrylic and ultra-thin material survived less than 20 seconds, despite the application of multiple coats.

The Urethane board was cross-sectioned to investigate the thickness of material applied by the selective spray-process, as well as the degree of coverage, looking at the QFP, which was where the leakage current was measured, in figs 18-20, it is apparent how well the component was coated and the result is not surprising considering typical coverage seen in fig 1.

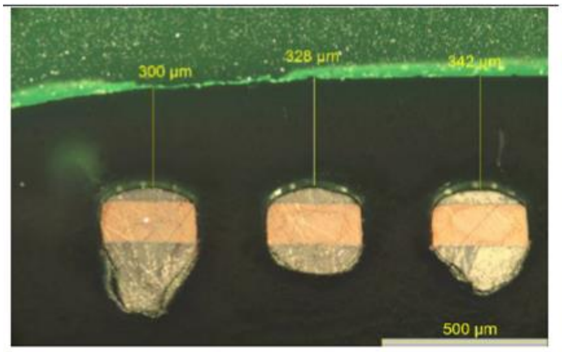

Fig 18. UR coverage of QFP lead down through plane of lead

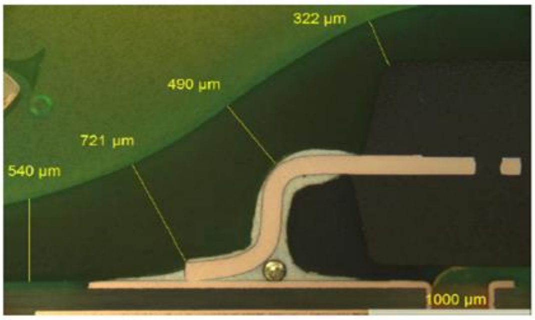

Fig 19. UR coverage of QFP lead

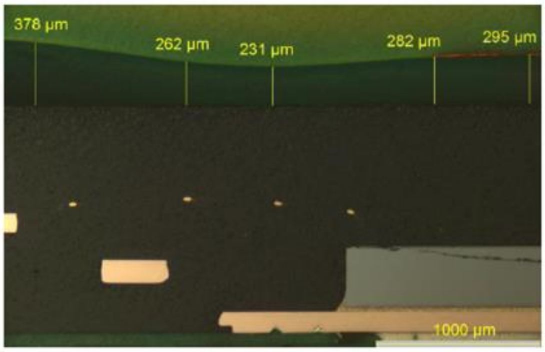

Fig 20. UR coverage of QFP package

REFERENCES

IPC-TR-587 Conformal Coating Material & Application "State of the Industry" Assessment Report.