Evaluating Conformal Coatings Ability to Protect During Condensation Testing

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Abstract
It is well known that condensation films on electronic assemblies are an extremely stressful environment, and for this reason conformal coatings are commonly used [1,2,3]. These coatings must completely cover the component, but often struggle to do this along sharp edges due to surface tension effects within the coating. In condensing conditions a continuous water film between exposed component terminations will act as a pathway and potentially allowing catastrophic short circuits to form. The condensation test has been a difficult test to perform until recently, where the introduction of a temperature controlled platen within a damp heat chamber (DHC) has allowed controlled condensation levels to be achieved [4]. A commercial condensation system has been developed that works under the control of a surface insulation resistance tester. The system is compact and is retrofittable to a DHC. The selected coatings cover a range of coating technologies, that reflect the enhancements that have been achieved in the ability to coat successfully. Cross sectioning is planned to reveal localized issues and correlate this with the electrical measurements. The testing investigated the variation between components in combination with coating coverage.

Introduction
Water on electronics can lead to failure. Yet electronics by necessity often are needed to function in damp or condensing environments with water present. Precautionary techniques include the application of polymer coatings. While coatings can provide excellent liquid barriers, they can be deficient in their ability to cover the 90˚ edges, that are common in the cuboid shape of electronic components. In the safety critical world of avionic and automotive electronics it is necessary to demonstrate robustness of electronic systems in the presences of surface water.

The electronics industry has long sought an effective and reproducible method for producing condensation in a controlled way to facilitate repeatable testing of electronic assemblies. Before 2015, achieving condensation in a closed environment relied on a separate tray of heated water within a humidity chamber, or forcing rapid changes in temperature and humidity to cause transient condensation. These methods while written into standards produced questionable results, and would not pass a Gage R&R assessment. Such a test that has gained an important industry position is the BMW condensation test as defined in BMW standard GS 95011-4, also referred to as LV 124 K-15 [5], and specifies a cyclic condensation (dewing) profile for automotive electronic assemblies. These methods modify the normal operation of a damp heat chamber away from its nominal condition, wherein an installed water bath is heated to produce an excess of water vapour causing condensation throughout the chamber. It is the temperature of the water bath that is controlling the condensation, and not the temperature of the test board. Hence there is no direct control of the temperature below the dew point (TBDP) of the sample, and therefore no direct control of where and how much condensation is generated. A method of achieving controlled condensation in a damp heat chamber is required, that works alongside the normal operation of a DHC.

A new concept for testing electronics in condensing conditions was introduced and described in 2016 [4]. In this earlier method a platen was introduced into the damp heat chamber with an accurately controlled surface temperature. Test PCBs mounted flush on the platen hence follow its temperature. At 40°C/90%RH the dew point is 38.04˚C, and 0.1˚C drop in the platen temperature will cause a 0.1˚C drop below the dew point, and condensation will ensue. In the system introduced here a Peltier based heat exchanger outside the DHC circulates a liquid through a second platen inside the DHC. To achieve the desired temperature of the platen a feedback system is used to control the sample temperature. A similar approach has been adopted in [6,7] in the study of flash overs in power generation and heat exchangers. In both these studies samples were mounted on Peltier platens.

Since the condensation process is continuous, thus at fixed TBDP the amount of condensation steadily increases. The lower the TBDP the faster the condensation will grow. The sensitivity to the TBDP is illustrated in Figure 1, where the SIR response of a IPC B53 C.1 200µm gap pattern is shown as the platen temperature is dropped.

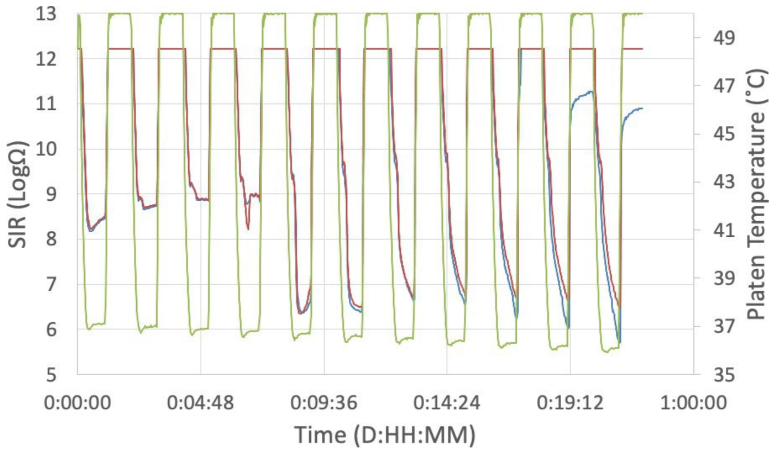

Figure 1. SIR response to condensation cycling

In this example the environment condition is 40˚C/85%RH, which equates to a dew point of 37.0˚C. The first step down is to 37.2˚C and then 0.1˚C step down in each following cycle. The high board temperature is 50˚C, and each segment in the profile is 1 hour long. At 36.9˚C we can see a temporary drop in SIR, but at 0.2˚C TBDP, the SIR is definitely affected. These results show that the sample temperature must be controlled to at least or better than 0.1˚C. It is this requirement that previous methods have struggled to meet.

Experimental

As discussed above a platen system was used, and this was manufactured by GEN3 and the AutoCHT is shown in Figure 2. This system takes 3 NPL TB164 test boards.

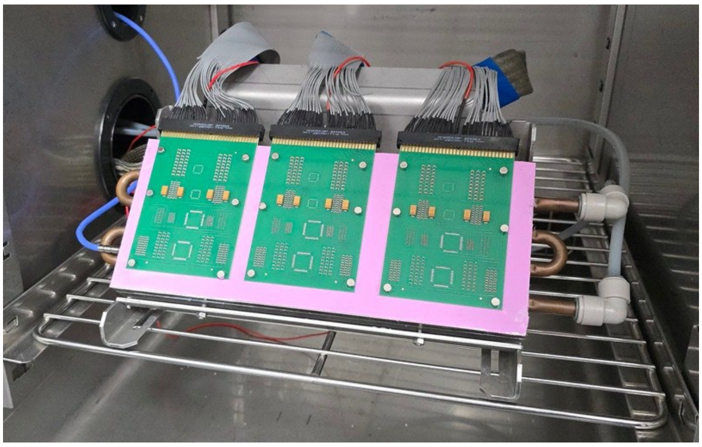

Figure 2. the GEN3 AutoCHT with three NPL TB164 boards mounted on the platen

In this experiment the following test conditions were used. The DHC was set to a constant 40˚C/85%RH, and a bias of 50V was applied to the samples. At 40˚C/85%RH the dew point is 37.0˚C. For this experiment the platen was stepped down from 37.2 to 2˚C below the dew point (BDP), in 0.2˚C steps. Between each dewing condition the chamber was returned to 50˚C, or 13˚C above the dew point. Each segment had a 1 hour duration, and hence the total experiment took 25 hours. The response of the platen to this programme is shown in Figure 3.

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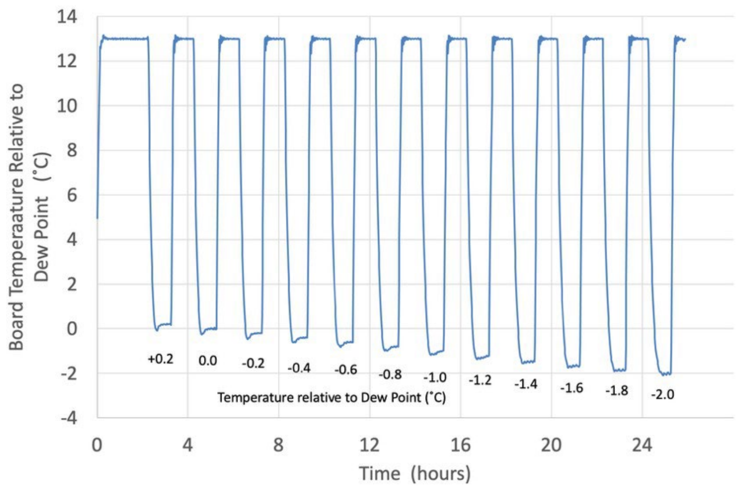
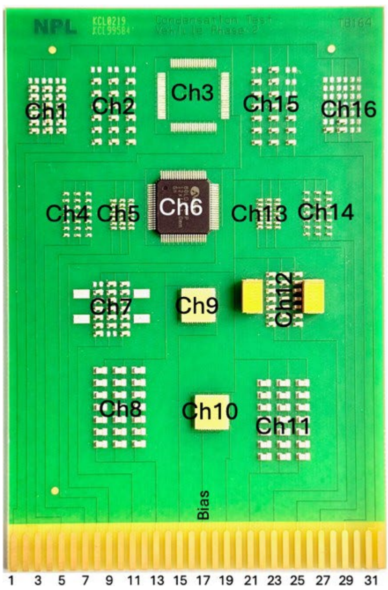


Figure 3. Condensation profile cycles. The DHC was at 40˚C/85%RH, with a Dew Point of 37.0˚C

Test board
The boards under test are based on the NPL TB164. This is a 16 channel board with 3 sizes of chip capacitors (0402, 0603, 0805), dummy QFP 80, and a dummy QFN and are shown in Figure 4. In addition the 0402 and 0603 are arranged in two different layout densities, and furthermore on two 0603 patterns (Ch7 and Ch12) there are large Tantalum capacitors fitted either side of the 0603 pattern. In this work three test boards were mounted on the platen for each run.



Pin 1	Ch 1	C0603	Dense
Pin 3	Ch 2	C0603	Open
Pin 5	Ch 3	QFP	
Pin 7	Ch 4	C0402	Open
Pin 8	Ch 5	C0402	Dense
Pin 9	Ch 6	QFP	
Pin 11	Ch 7	C0603	By Tant
Pin 13	Ch 8	C0805	
Pin 15	Ch 9	QFN	
Pin 17	Bias		
Pin 19	Ch 10	QFN	
Pin 21	Ch 11	C0805	
Pin 23	Ch 12	C0603	By Tant
Pin 25	Ch 13	C0402	Dense
Pin 27	Ch 14	C0402	Open
Pin 29	Ch 15	C0603	Open
Pin 31	Ch 16	C0603	Dense

Figure 4. Test board with components, and table of connections, components and layout

Coatings
MacDermid Alpha coated 26 boards, and there were 2 control uncoated boards, and are described in Table 1.

Table 1. Coatings used in this study, with the number of boards

No of Boards	Coating
2	MSR 1 / 50µm
2	MSR 2 / 50µm
2	MSR 3 / 50µm
3	Acrylic / 50µm
3	Urethane Acrylate / 100µm
3	Urethane Acrylate / 200µm
3	Urethane Acrylate / 300µm

2	Urethane Acrylate / 300µm + 3mm dispense
3	MSR 4 / 50µm
3	MSR 5 / 50µm
2	Ctrl1 &2

There are three basic coating types: MSR (modified silicone rubber), an Acrylic, and an Urethane Acrylate with UV cure. The boards with a Urethane Acrylate / 300µm + 3mm dispense, included an extra 3mm dispensed bead around the QFPs to thicken the coating over the QFPs.

Results

The test sequence was run as described above, generating 448 component data sets, and examples are given in the next two figures. The first is a typical result from a control board, showing the result for a 0402 component array, channel 14. The results are plotted as leakage current in microamps, and on a log scale. Figure 5 clearly shows the current increasing as the dewing condition is introduced. Using the IPC-J-Std-001 failure criterion for SIR of $10^8\Omega$, this corresponds to 0.5µA, and we can see that just after 12 hours this failure point is reached at 0.8˚C BDP.

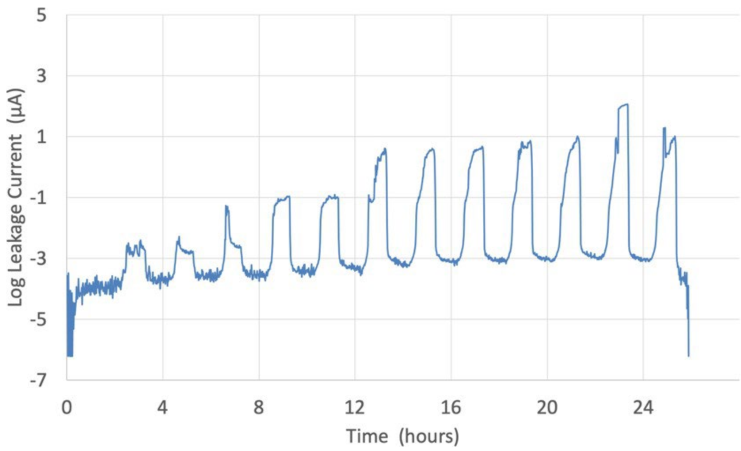


Figure 5. Leakage current from a control board and a 0402 pattern

The results for all components on this control board, which are uncoated, are shown in Figure 6.

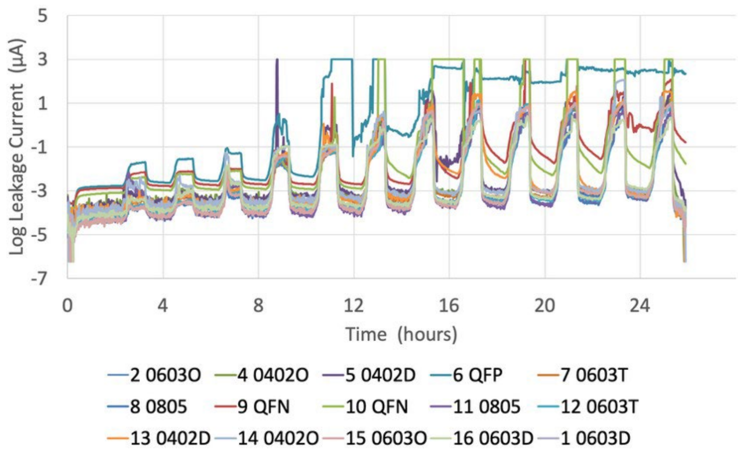


Figure 6. Leakage current from a control board for all component patterns

The results for a QFP, coated (MSR 3 / 50µm) and for a control board are shown in Figure 7.

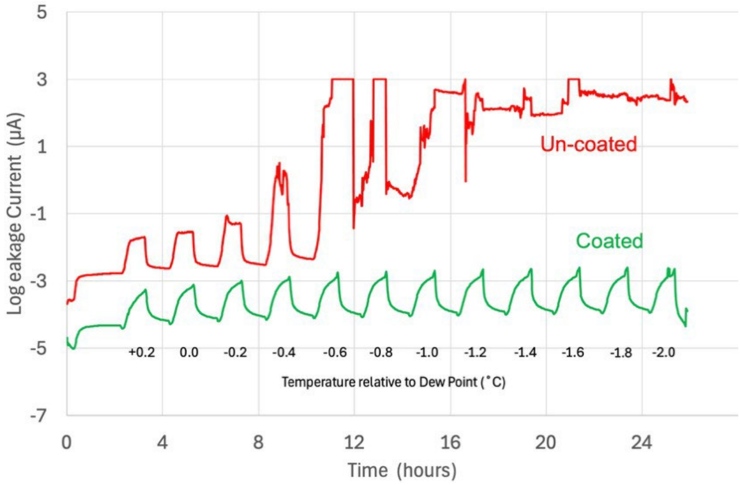


Figure 7. Leakage current from a control board and a coated board for a QFP

This clearly shows the benefit of a good coating at limiting the leakage current to approximately 1nA, with little sensitivity to the dewing condition.

Analysing the complete dataset and identifying the temperature BDP (TBDP) at which the current exceeds 0.5µA the following figures were constructed. Figure 8 shows the performance across all the 0402 patterns as a function of the coating chemistry. The TBDP at failure is clearly dependent on coating, with only two coatings offering significant protection over that seen with the control boards.

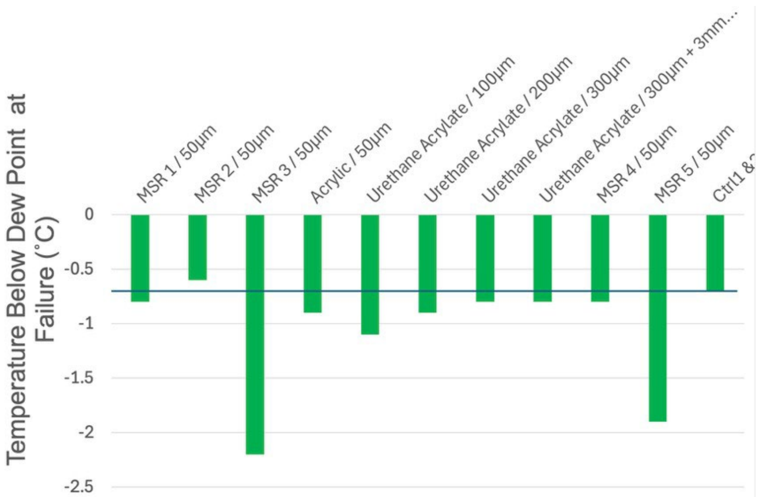


Figure 8. The TBDP at failure for 0402 components for all coating types.
The horizontal line is the failure level for 0402 on the control board.

The following Figure 9 shows the results for 4 component classes. The results for the 0805 were uniform across all coatings with very little dependency on coating, and all values <1nA.

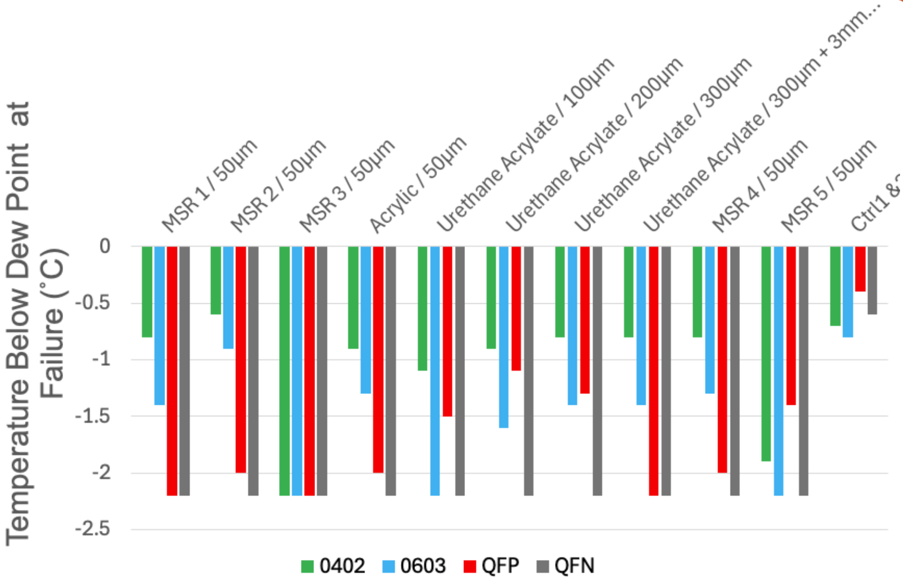


Figure 9. The TBDP at failure for 0402, 0603, QFP, QFN components for all coating types

Figure 9 above shows that the QFN responded well to any of the coatings, with no failure detected up 2˚C BDP. The QFPs which had the least resilience on the control boards, responded well to coatings. The 0402s responded poorly to coating, with only two coatings offering good protection, but with the 0603s there was a more positive response to coating.

In Figure 10 the "Increased Dewing Resilience" (IDR) is plotted. The IDR factor is the TBDP of a coated board at the failure point, subtracting the TBDP of the control board failure point, and then expressing this as a positive number. The greater the Increased Dewing Resilience (IDR) the greater the protection from the coating. The IDR for the 0402, 0603, QFPs are plotted, and then an average of all three. This shows that the MSR3 coating stands out as the best at protecting these components.

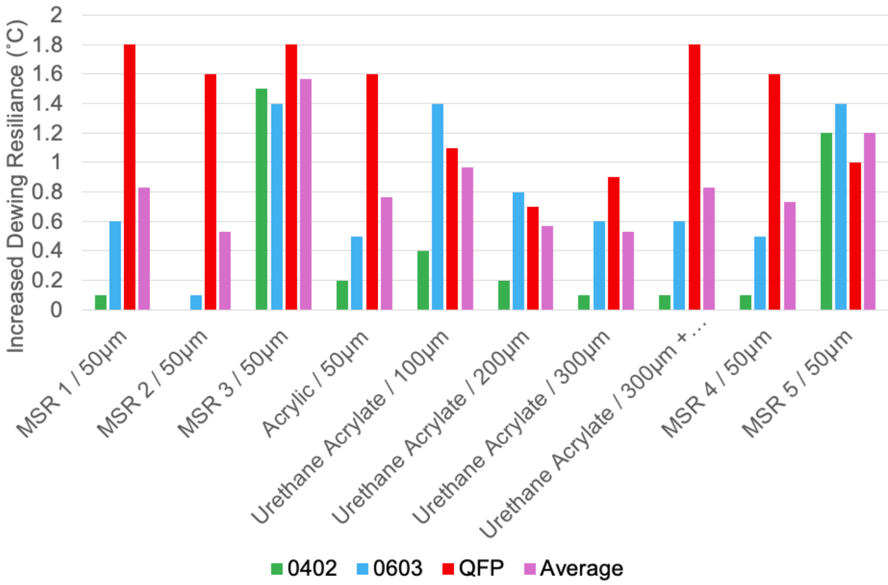


Figure 10. The IDRfor 0402, 0603, QFP, and an average, components for all coating types

Discussion

Condensation can be catastrophic for electronics, the formation of a conducting water film can lead to instant failure. For this reason electronics are protected by conformally coating a protective coating. The 3D shape of components lead to challenges in achieving uniform coverage, particularly with sharp edge coverage being particularly difficult. Coating formulations struggle with competing requirements from the physical and chemical properties. Surface tension effects tend to pull back from the sharp edge. The condensation test measures the effectiveness of a coating, its ability to cover all variations in shape, material, surface roughness and surface energy. In addition component density, and the location of adjacent components can be an influencing factor.

Here we see for this particular experiment that 0402 were the most challenging and that two of the 10 coatings worked well. The QFNs responded well to any coating, whereas there was an increased variability in the response with the QFPs. The 0603 components performed better than the 0402, and responded well to the same two coatings seen with the 0402. With the three component types, QFP, 0603 and 0402 there was a trend of reducing coating protection as the urethane acrylate coating was thickened.

Condensation build up is very sensitive to the TBDP, the work here shows that a change of 0.1˚C is significant. Previous studies and methodologies have applied a particular operating mode of the damp heat chamber, or the introduction of an additional source of water vapour, as in the BMW-K15 test [5]. These methods are not well controlled and achieving a set TBDP across a number of test boards is challenging.

The platen concept originally outlined in [4] overcomes the deficiencies seen in previous test methodologies. The platen temperature is controlled independent of the DHC, with the DHC running in its preferred stable condition. The use of a metal platen allows temperature uniformity over a large area. The results show that samples respond very quickly to the presence of condensation, with the leakage current tracking very well with the condensation cycling. The cycling approach allows a study with different platen temperatures. Temperature cycling assists in avoiding the dynamic effect of continuous thickening of the condensed water film. The test duration is also important, in this study each run lasted 25 hour tests, whereas a SIR test lasts 1 week. Typically SIR tests are poor at identifying deficient coating coverage, whereas in condensation testing that weakness can be identified very quickly. In the future, with enough knowledge and understanding, it may be sufficient to run a test at a single TBDP, providing rapid qualification of coatings.

The equipment used here is the first commercial system in the market and has been used here to characterise 10 different coatings. This study's focus is to show that the approach used here can readily differentiate between different coatings, and allow a ranking to be produced. More certainty in these results would require more testing for each condition than was possible in this study.

Conclusion

The new condensation tester has been used successfully to characterise conformal coatings applied to protect electronic assemblies from the effect of condensation. This system readily shows differences in condensation in 0.1˚C steps.

Platen technology offers a superior and an alternative approach to that based on the modification of the normal operation of a DHC, as prescribed in the BMW-K15 test.

This study illustrates how 10 coatings can be characterised in terms of the protection they offer. It is also possible to assess simultaneously the response of different components with the same coating in one condensation test. The condensation test measures the effectiveness of a coating and is sensitive to a number of factors that include component shape, surface factors and the arrangement of adjacent components.

A new platen condensation equipment has been developed, and is the first commercial condensation system. The system is compact and is retrofittable to a DHC.

References

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