As originally published in the SMTA Proceedings.

Conformal Coatings – New Solutions to Existing Problems

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ABSTRACT

Conformal Coatings are used to protect Printed Circuit Boards (PCBs) against the effects of moisture and corrosive environments. The performance of the conformal coating often is limited by certain common failure modes, including entrapped bubbles in cured coating, lack of protection of component edges, and defects developing during thermal excursions. Humiseal, along with other conformal coating manufacturers have worked to develop materials that overcome these shortcomings. This paper describes Research and Development work carried out by Humiseal to investigate root causes of these problems, and to introduce materials with improved performance.

Key Words: Conformal Coatings, High Reliability Electronics, LED UV cure, Sharp Edge Coverage, Bubble Entrapment, UVA, Conformal Coating, High Protective Qualities, Harsh Environments.

INTRODUCTION

Conformal coatings have established an important role in the protection of Printed Circuit Boards (PCBs) against the negative effects of humidity, corrosive environments and dirt. They are used widely in electronics, having particular use in automotive, military, avionics and industrial-controls electronics, where product high reliability and long lifespan are required. Conformal coatings are polymers which are applied to the top surface of the fully assembled PCB as one of the final stages of assembly. Various polymer chemistries are used in conformal coatings, each of which have various advantages and disadvantages. For instance, polyurethane polymers are known to be tough and provide high chemical and abrasion resistance [4]. A drawback to using polyurethanes is the difficulty of coating removal (which may be required if the PCB needs repair) An alternative polymer type is acrylic. These polymers are widely used in conformal coatings, offering good protection against humidity, but allowing easy chemical removal by solvents and strippers [5].

Traditional conformal coatings are formulated as polymer solutions in volatile solvents and have generally been applied to PCBs by hand spray, selective spray coating or dipping coating. The choice of coating method is selected according to user needs and board design.

Whilst the application and use of conformal coatings is both straightforward and well developed, certain key problems remain during their usage.

- Application processes can often introduce bubbles into coatings. If these bubbles are retained in the cured coating, they can be considered as defects and lead to potential failure.
- Thermal Shock resistance of coatings is a continuing concern, often being used as a measure of long-term coating reliability and durability. Certain coating types, particularly UV curable, can develop defects in such test sequences, which limits their adoption.
- Component coverage is an increasing concern, which is becoming more relevant due to densification of board design and more rigorous operating conditions.

Many of these disadvantages are recognised by coating users, and as such, coating suppliers are developing and introducing coatings with improved properties. These coatings can be applied in the same manner, generally using similar or the same spray application equipment. Coatings are applied by spray coating or dip coating, then cured either by solvent evaporation/heat or using a UV conveyor oven equipped with a high intensity mercury discharge light or LED UV light. The comparison of the cure of solvent-based and UV curable conformal coatings is giving in **Figure 1**.

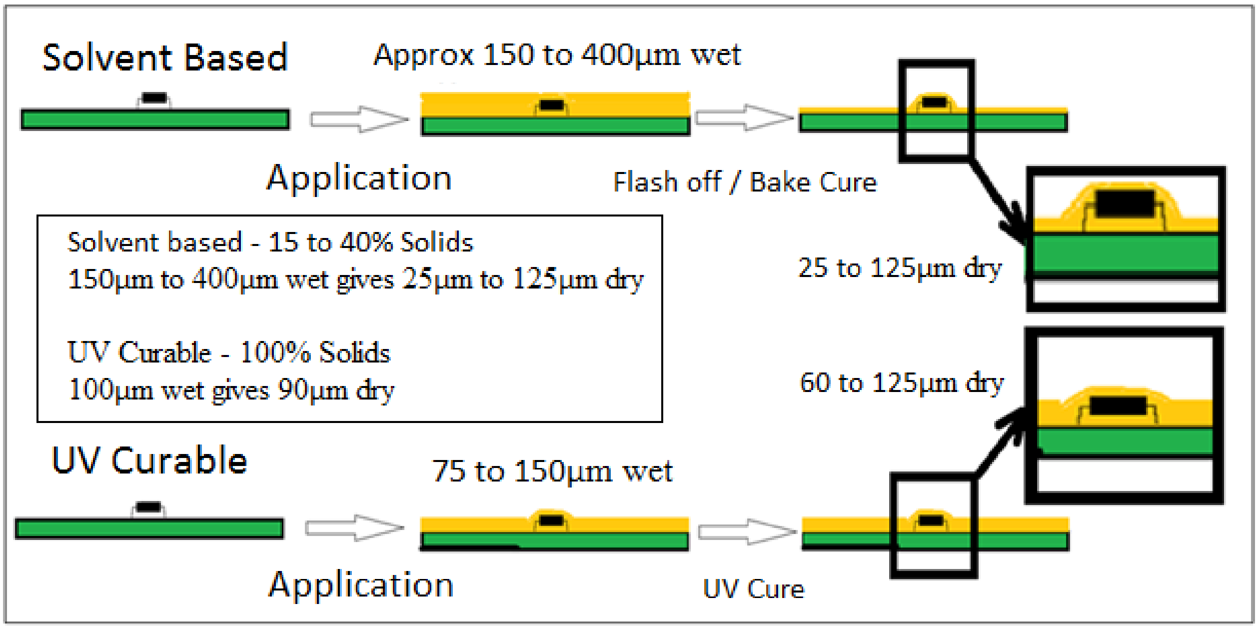


Figure 1: Comparison of cure processes for solvent and UV curable conformal coatings.

BACKGROUND

A significant body of research and development has been completed by Humiseal (part of Chase Corporation) and other conformal coating suppliers to develop coatings with improved performance, particularly to minimise issues such as bubbles, cracks and lack of edge coverage.

Bubbles are often trapped in coatings, partly due to application method, and partly due to curing method. Small bubbles tend to be caused during spray application processes, whereas large bubbles maybe formed during thermal or UV cure. Users of coating have evaluated many work-rounds. However, certain combinations of board design, component type and coating type consistently give issues with bubbles. A good balance between all parameters are not always possible:

- Higher coating thickness are good for component coverage, but encourages bubbles, and may exceed maxima in certain areas.
- Short flash-off times may improve throughput, but may trap solvent, causing bubbles.
- High temperatures ensures full cure, but may lead to solvent boiling and bubbles.

As a result, materials have been developed which help eliminate bubble entrapment. Solvent choices with varying surface energies and drying rates are used which effectively ‘squeeze’ the bubbles during evaporation. These solvent choices provide significantly reduced or no bubbles in the dried coating, while maintaining a good surface. Details are given in the results section.

Cracks during thermal shock testing are an increasing concern for users of UV curable coatings. Thermal shock testing is often used to demonstrate long-term reliability of a coating, imparting a high level of degradation into the coating in a short time period. It also assesses the effects of the mismatch of the Coefficients of Thermal Expansion (CTE mismatch) of the coating and the PCB/components.

Known factors that affect performance in thermal shock tests are:

- Coating type
    - Rubbers & Silicones most durable
    - Hard PUs least durable
- Coating cure level
- Coating thickness
- Solvent entrapment
- Interactions with Manufacturing residues
- Changes in physical properties during testing

A body of research demonstrates that developing UV LED cured materials could lead to higher performing products. The current research shows that a combination of optimal LED UV cure and materials with optimum physical properties to minimise the effects CTE mismatch and shrinkage leads to high performing coatings.

Lack of conformal coating corner coverage or sharp edge coverage can lead to increased failures in high humidity and corrosive environments. These problems have become more exacerbated with increased component densities and the use of Surface Mount Technology components with rectangular form and metallised ends. Such components with 90° corners and vertical edges provide a difficult target for conformal coatings, requiring them to have competing properties:

- to be able to flow and level to provide adequate horizontal coverage and minimal bubble entrapment.
- to be able to resist slump from vertical edges, which would lead to exposed component corners.

To overcome these challenges, coating manufactures have shown coatings which may be 2-part formulations, providing a very fast cure to minimise slump. Also, materials which cure quickly with LED UV light (spot cure) have also been shown; these are ‘frozen’ in place immediately after spraying, hence reducing/eliminating slump.

These and other approaches have merit, providing improved sharp edge coverage.

However, drawbacks may include:

Fast Curing 2-part materials
- More materials to source.
- Require dedicated mixer systems
- May yield coatings with poor levelling or bubble entrapment.

LED spot cure:
- Adds complication to process.
- High sensitivity of coatings may lead to wrinkles/premature cure.

Apply multiple layers – dry in between
- Slow, high material demands

Recent development work by Humiseal have developed coatings that overcome such issues, as described in results section below. Methods are used to produce products that are readily sprayable but which have low slump and capillarity at rest, due to careful choice of viscosity.

EXPERIMENTAL RESULTS

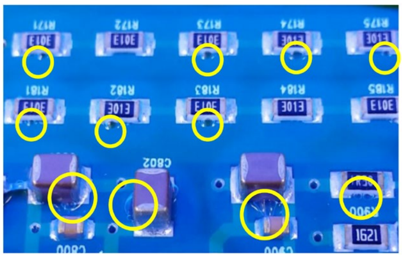
Bubble Reducing Coatings.

As discussed above, solvent based coatings can be improved by carefully selecting solvents with varying drying rates and surface tensions in order to give an overall change in surface tension towards the end of the drying sequence. Lower surface tensions encourage liquid flow and capillarity, whereas higher surface tensions encourage liquids to bead. Bubbles are trapped in liquids when the surface tension on the bubble/liquid interface is higher than the surrounding bulk liquid. This prevents easy bubble dispersal.

As such, a range of solvent based conformal coatings was prepared with a standard base solvent (n-Butyl Acetate), with additional up to 20% solvent components with varying surface tensions. All the additional solvents had volatilities lower than the base n-Butyl Acetate, so would be retained in the drying film until the last stages of the evaporation process.

Standard test boards were then coated with this range of coatings. Spray application and high film thicknesses were used to encourage bubble formation.

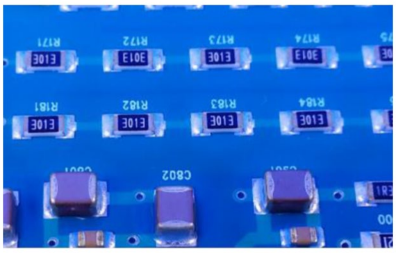
After full cure, each board was examined for bubble entrapment on component edges. The general trend towards bubble entrapment with increasing final solvent surface tension was seen. Figure 2 and Fgure 3 below show examples at both extremes, and represent a good example of the effects seen.



Multiple bubbles retained on components and small defects observed.

Particularly prevalent with high application speeds and high coating viscosities

Figure 2: High Surface Tension Solvent @ 10%



Minimal bubbles and defects observed.

Bubbles are ‘squeezed out’ during flash-off

Figure 3: Low Surface tension Solvent at 10%

These results suggest that bubbles can be reduced or eliminated by careful selection of solvents – particularly the use of low surface tension solvents with lower volatility. As such, this method is exploited to develop a range of products which exhibit low bubble entrapment, irrespective of application method and coating thickness.

LED Curable UV coatings

Humiseal have carried out a large body of research to design UVA LED-curable conformal coatings. The main obstacle that was found during the development program was that UVA LED light was poor at providing a tack-free surface to the coating. All organic polymers absorb UV light, especially shorter wavelength UVB and UVC light. UVA light penetrates deep into the coating, whereas UVB and UVC penetrate less deeply, with UVC only reaching the first few microns of the coating’s surface. Hence coatings that cure specifically by UVA-only light cure more consistently. Mercury discharge curable coatings exploit the UVC content of the lamp output, to provide a tack free surface (the UVC light only interacts with the coating surface). Consequently, UVC photoinitiators are included in the formulations in high concentrations to provide the tack free surface. These photoinitiators, however, do not provide any cure potential with UVA light, which required the new LED cure formulations to be redesigned. It should be noted that many UVA photoinitiators do not provide sufficient surface cure, due to the effects of oxygen inhibition [6]. Hence photoinitiator selection has been an important factor in the formulation stage.

UV wavelengths for each UV band are:

- UVA = 320µm to 400µm
- UVB = 280µm to 320µm
- UVC = 100µm to 280µm

Figure 4 shows how the different UV wavebands penetrate into the thickness of the coating, due to absorption by organic polymers.

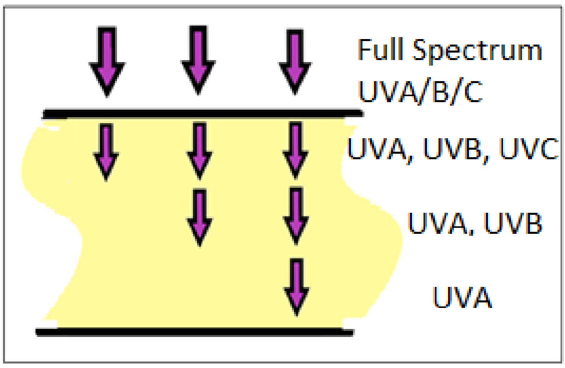


Figure 4: The penetration of UV wavebands into conformal coatings.

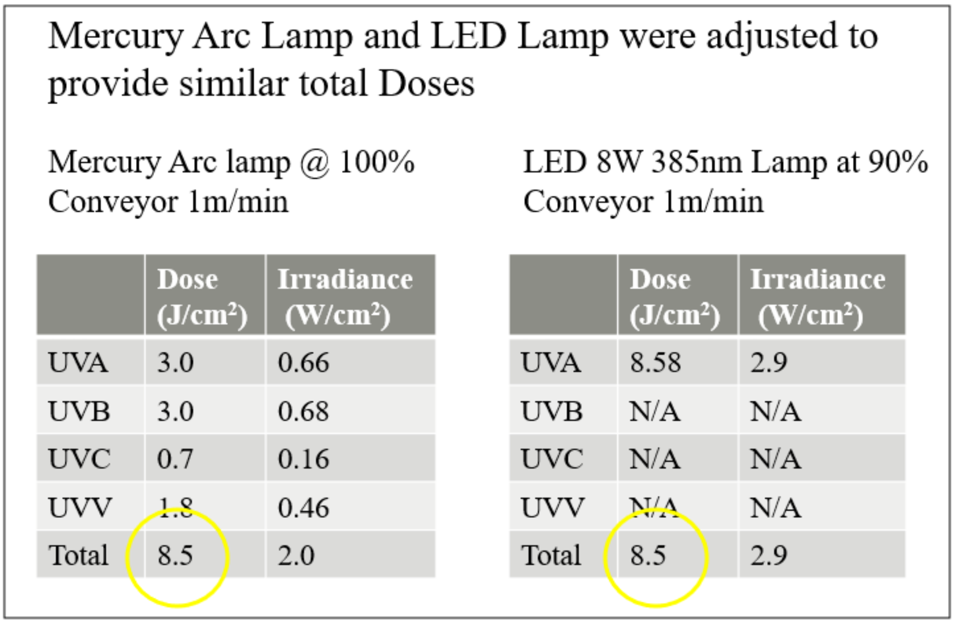
The choice of photoinitiator was optimised by assessing the weight loss on heating of various formulas. This technique involves curing a standardised sample of coating, then monitoring the weight loss with heating at 85°C against time. This test reveals the degree of polymerisation of the coating. If a UV curable formula does not contain the correct concentration or selection of photoinitiators, or contains polymer precursors with poor potential for polymerisation, a significant amount of weight loss is seen upon heating, due to volatilisation. Formulas with highest weight retentions in this test show more stable physical properties.

Two sets of UVA LED curable experimental formulas were trialled, and were compared with an industry standard mercury arc lamp curable coating:

1. 'UVA LED Coating Round 1' represents an early prototype coating using a proven photoinitiator blend used in coating manufacture
2. 'UVA LED Coating Round 2' represents a finalised coating, with improved photoinitiator blend, and including additional cure accelerants
3. 'Commercial Coating Mercury Cure' represents a current high-performance coating used widely in Automotive industry

The curing systems were adjusted to give the same total UV dose, although the mercury lamp gave a broad spectrum of UV light output. The distribution of UV light output of the two systems is shown in **Table 1**.

Table 1: Comparison of UV Light output of UVA LED[1] and Mercury Arc[2] Light units.



Mercury Arc Lamp and LED Lamp were adjusted to provide similar total Doses

Mercury Arc lamp @ 100%
Conveyor 1m/min

	Dose (J/cm^2)	Irradiance (W/cm^2)
UVA	3.0	0.66
UVB	3.0	0.68
UVC	0.7	0.16
UVV	1.8	0.46
Total	8.5	2.0

LED 8W 385nm Lamp at 90%
Conveyor 1m/min

	Dose (J/cm^2)	Irradiance (W/cm^2)
UVA	8.58	2.9
UVB	N/A	N/A
UVC	N/A	N/A
UVV	N/A	N/A
Total	8.5	2.9

Three 2g samples were taken per coating-type and were then cured with the appropriate light source. After cure, the samples were stored at 85°C using an Espec Environmental Chamber[3], with daily measurement of weight loss. The results are shown in in **Figure 3**.

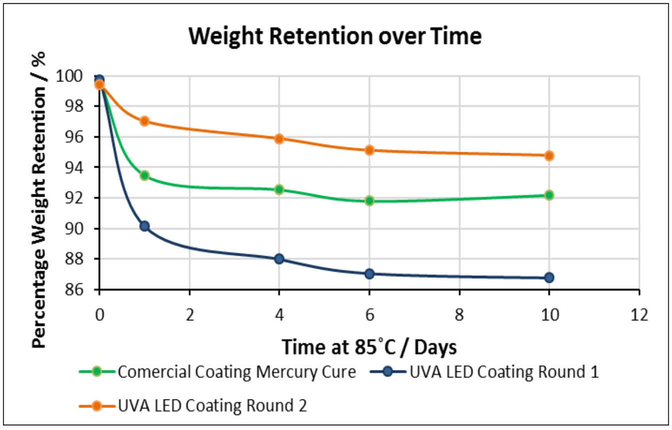
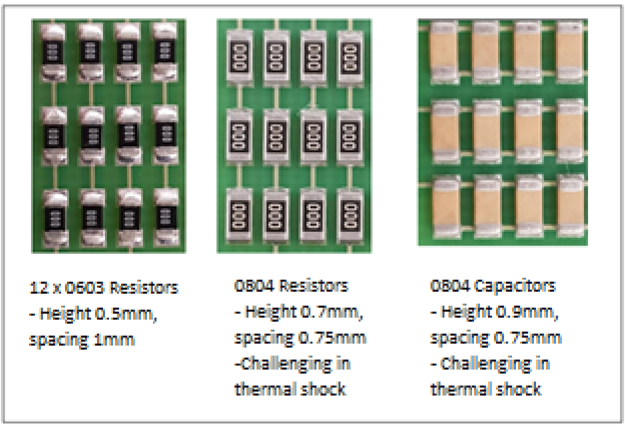


Figure 5: Weight retention over time at 85°C of UV LED and Mercury Arc cured coatings.

The results indicate that UVA LED Coating Round 2 showed significantly less weight loss during heating than the other test samples, which would lead to greater physical stability during the coating lifetime. The effects of Thermal Shock Testing on coated electronic assemblies is often used to model reliability over the lifetime of the coating. To this end, Humiseal frequently performs thermal shock test sequences on coated standardised test boards (**Figure 6**).

The test boards comprise of arrays of SMD components of different sizes and heights, assembled with different heights and spacings. 0603, 0804 resistors and 0804 ceramic capacitors are chosen as test components.



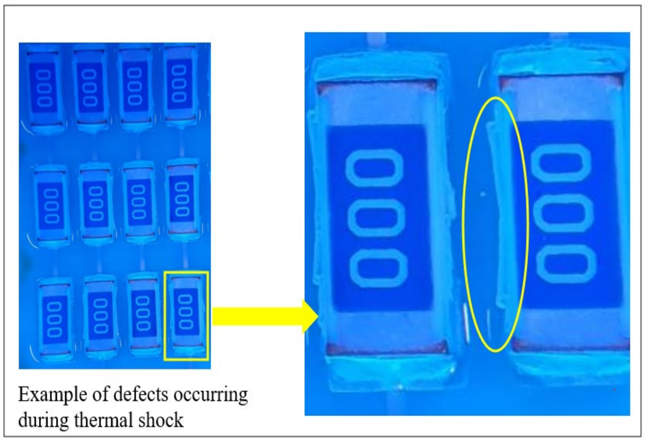
12 x 0603 Resistors
- Height 0.5mm,
spacing 1mm

0804 Resistors
- Height 0.7mm,
spacing 0.75mm
-Challenging in
thermal shock

0804 Capacitors
- Height 0.9mm,
spacing 0.75mm
- Challenging in
thermal shock

Figure 6: Selective areas on standard test board used for quantification of Thermal Shock performance.

Boards are examined periodically during the testing sequence, and an estimate of the number of coating defects is made. These coating failures often appear as cracks in thick areas between the components, or delamination from component tops and sides. These defects are easily visualised by microscope inspection with a 'black light' UV inspection torch, as shown in **Figure 7**.



Example of defects occurring
during thermal shock

Figure 7: Examples of defects on 0804 resistors seen at 30x magnification during Thermal Shock Testing.

The results in weight retention testing were correlated with the performance of each of the coatings 1, 2 and 3 (as outlined previously) in thermal shock. The boards were coated using PVA atomised spray selective coating equipment[4] at 60µm and 120µm thickness, then cured using the appropriate UV Light units. The boards were stored for 7 days at 25°C prior to commencing the Thermal Shock test to allow secondary cure processes to complete.

Testing was carried out in an Espec TSE-11 Thermal Shock Chamber[5], with visual microscope inspection every 250 cycles up to 1000 cycles, -40°C to +85°C, 15 minutes dwell, ROC >30 °C/min.

Figure 8 and **Figure 9** display examples of defects observed with Coating 1 and minimal defects observed with Coating 2 respectively. The results in the weight retention study were found to serve as an early indication to the performance of the coating in Thermal Shock. Both the high weight loss of Coating 1 and poor performance in Thermal Shock Testing emphasise the importance of optimisation of the photoinitator package.

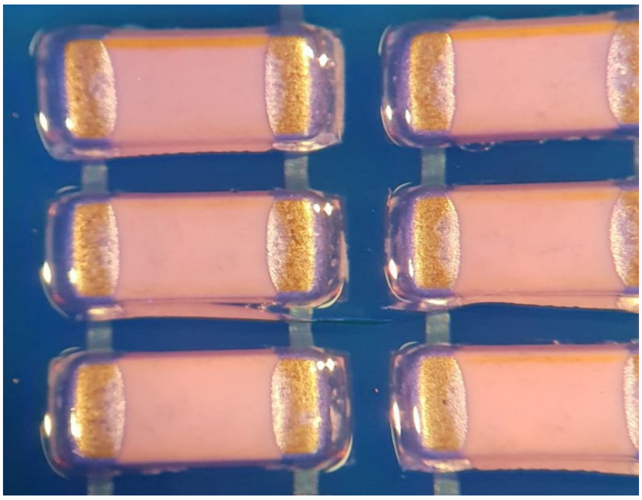


Figure 8: UVA LED coating round 1 (un-optimised coating), showing evidence of defects at 250 cycles.

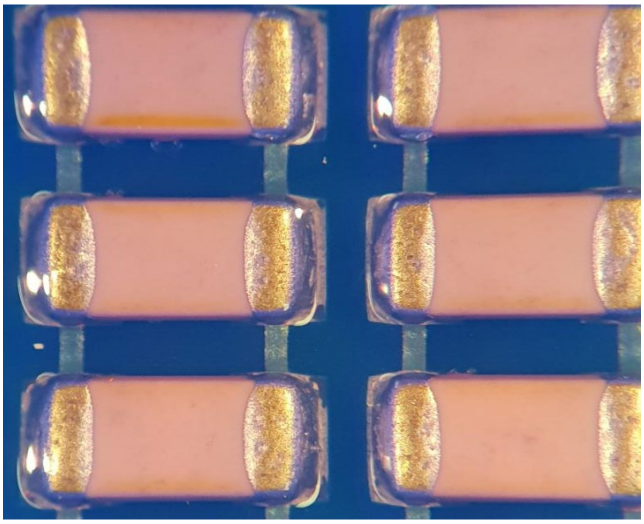


Figure 9: UVA LED coating round 2 (optimised coating), no defects at 250 cycles (contrast with Figure 6).

The percentage of observed defects at 250, 500, 750 and 1000 cycles at 60µm and 120µm are shown in **Figure 10** and **Figure 11**. Microscope inspection[6] of each board indicates that the use of UVA LED Light is beneficial in reducing/eliminating cracks and defects in the coating.

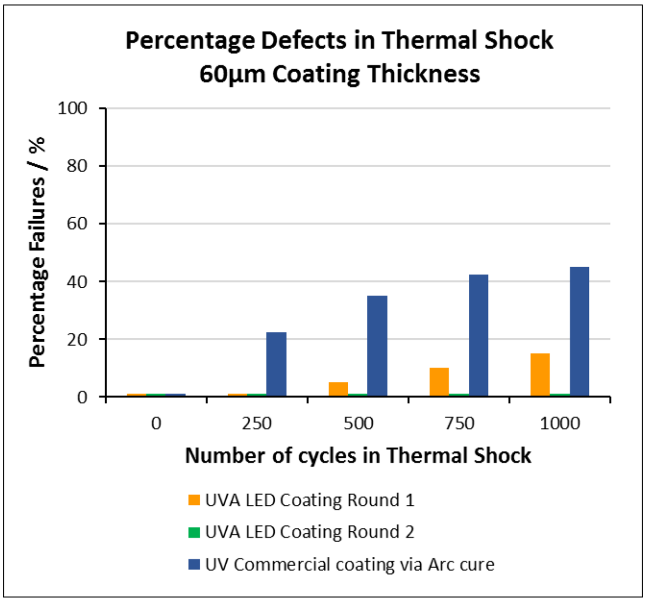


Figure 10: Observed defects during Thermal Shock, 60µm coating thickness.

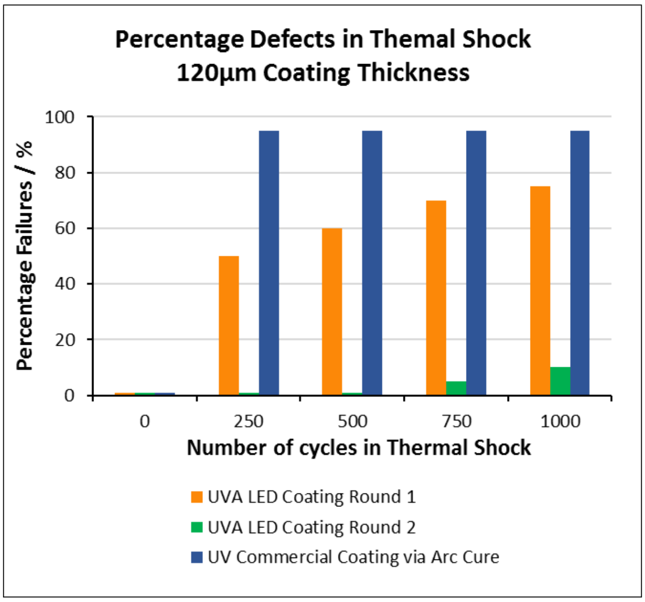


Figure 11: Observed defects during Thermal Shock, 120µm coating thickness.

The UVA LED curable coatings had significantly fewer observed defects compared with the Arc cured material, and in addition the ‘UVA LED Coating Round 2’ showed very good performance with zero observed defects at 60µm.

To this end, Humiseal further developed and exploited the techniques describe, to introduce a range of LED curable coatings with high performance in Thermal Shock testing, and by exploiting other techniques described elsewhere to provide materials with good insulation and chemical resistance properties.

Coatings with Improved coverage

Coatings have been formulated to improve sharp edge coverage by reducing flow and slump to controlled levels using idealised viscosities. The most beneficial effects were seen in conjunction with solvents; presumably the evaporation of solvents during the spray process also increased the speed of viscosity increase during drying processes. Excellent results were achieved with solvent-based rubber coatings. Materials were used to provide reduced slump during drying, and solvent choices made to exacerbate the effect.

Multiple rubber-based coatings were prepared; a currently altered materials to provide idealised control of viscosity. All coatings were applied onto standard test boards, comprised of a mix of SMT components and geometries. Application was using an atomised spray process. Each coating was applied using the maximum wet coating thickness that was possible in one layer.

It was apparent that the experimental coatings could be applied at higher thicknesses without excessive flow and migration – this is important to provide good application accuracy.

After full cure, the sharp edge coverage of all coatings was assessed by cross sectioning of various SMT components and subsequent microscopic analysis. Populated test boards were coated with either an unmodified rubber coating, or a rubber coating with optimised coverage. The characteristics of the unmodified coating limited application thickness to approximate average of 45µm due to excessive flow. Whereas the optimised coating had minimal flow, thus was able to be applied at higher thicknesses. 75µm was applied, which represents highest suggested thickness per IPC CC 830 work standard.

The summary of the coating thicknesses is given in the following **Table 2**:

Table 2 – approximate coating thicknesses in varying areas for unmodified and optimised coatings

Location	Unmodified Coating	Edge Coverage Modified Coating
Flat surface	~ 45um	~75um
QFP Leg Bend	no coating	~80um
QFP Foot	~50um	~80um
0604 Resistor Top Edge	C1 – no coating C2 ~5um	C1 ~ 70um C2 ~ 80um
0604 Resistor Base	C1 ~100um C2 ~ 115um	C1 ~ 90um C2 ~ 130um

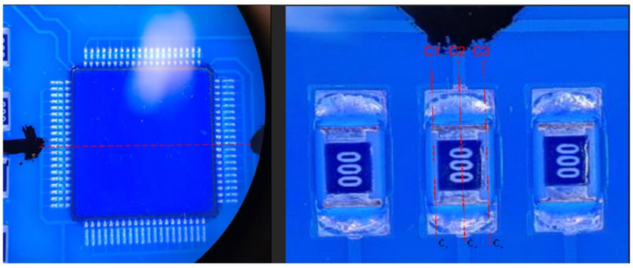


Figure 12: Figure 12 shows the cross-section lines. Cross-sections were cut through centre of a QFP leg, and through edge (C1, C3) and centre of an SMT resistor.

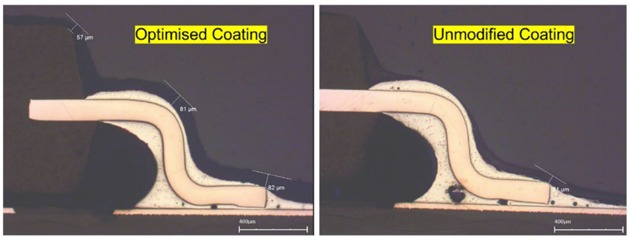


Figure 13: Figure 13 shows the comparison between the coverage of each coating on QFP legs. The unmodified coating is seen to have very low coverage on the bend of the leg, with the coating slumping significantly onto the foot, where thicknesses of 51 µm were seen. However, the edge coverage optimised coating is seen to have an even coverage of the leg, showing thicknesses of approximately 80µm on all areas, and demonstrating minimal slump down the length of the leg.

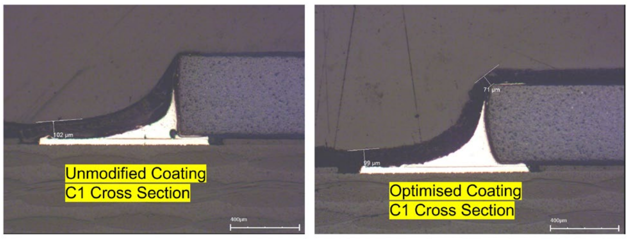


Figure 14: Figure 14 shows the comparison between the coverage of the unmodified coating on SMT 0604 resistors along cross section lines C1 and C2. The unmodified coating is seen to have very low coverage on the top edges, with the coating slumping significantly onto the pad where thicknesses of >100µm were seen.

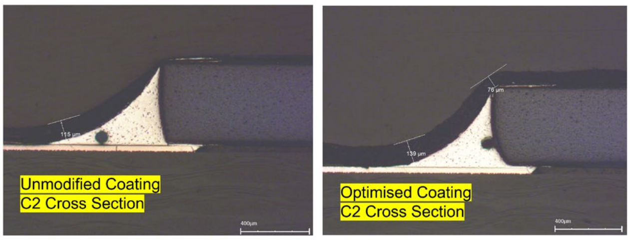


Figure 15: Figure 15 shows the coverage of the edge coverage optimised coating. Thicknesses of 70µm are seen on the top edges, and 90µm on the pad.

CONCLUSION

Progress has been made developing improved products in all three problem categories.

Coatings with reduced bubble entrapment have been developed which will allow faster processing in a wider range of products to marketed in multiple product categories, including acrylic and polyurethane. The reduction in bubble entrapment will allow faster processing with less bubble entrapment more readily on a wide range of board types.

UVA LED curable conformal coatings show performance equalling or exceeding the current UV curable conformal coatings products cured exclusively by mercury discharge lamps. They show great potential for delivering high protection of PCBs. The increased protection is very pronounced in tests of Thermal Shock resistance, which rely on physical stability of the coatings. The increased deep penetration of UVA light into organic polymers produces a uniform cure profile, leading to polymers with consistent properties. This improvement in cure is evidenced by less weight loss during post UV-cure heating tests. These results will form the basis of new UV coating designs, which will also exploit the other processing advantages of LED cure, such as reduced heat, increased equipment reliability and no ozone generation.

Coatings with improved sharp edge coverage continue to be developed, and show great promise to provide easy to apply coatings with significantly increased protection against moisture ingress and corrosion.

EQUIPMENT AND METHODS

1. Excelitas AC8150 385nm 14w/cm² LED system
2. Jenton International JA150VPXi 140W Arc System
3. ESPEC Environmental Chamber: Model PHP-2J ISO-TECH DC Power Supply IPS 1603D
4. PVA 350 Platform Atomised spray using FCS300-ES Valve
5. Espec TSE-11 Chamber
6. Motec SMZ186 at 30x magnification
7. Concoat AutoSir
8. Seaward HAL2 Dielectric tester with IPC B25A boards

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ACKNOWLEDGEMENTS

The author would like to acknowledge and thank colleagues at Humiseal Europe (Danielle Bradley, Cerys Jones, Monika Dybalska and Vlad David) for assistance in preparing and coating samples used in the testing described in this paper, and also colleagues at Chase Corporation (Rachana Upadhyay, Matthew Eveline, and Bijan Radmard) for contributions for design and assistance with testing regimes and methods.