# Improving Reliability of High Performing PCB With Advanced Conformal Coating Use

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## ABSTRACT
Recent growth in power electronics has fueled the innovation of Printed Circuit Board (PCB) protecting solutions to ensure smooth operation and reliability of these expensive boards and electronics components. Current PCB design used in Power & Industrial applications, Automotive, Military, Telecommunication, etc. needs stronger protection than ever to protect the boards from harsh external environment. Conformal coating has been used to protect PCB from harsh environment for decades. However, the new high power and complex board designs need a level of protection with circular economies in mind that is not achievable with the existing solutions.

Conformal coating is a chemical coating that is applied to the PCB to conform to the surface topography and act as a barrier against corrosion from external environment. Conventional conformal coatings are based on single polymer systems that may contain solvent for ease of application. Solvents in the system create environmental concerns and increase production cycle times. This has created an opportunity to develop solvent free, hybrid polymer systems that not only meet the performance and reliability needs of complex boards but also meet the emission standards set by various countries.

In this paper we will discuss a newly developed conformal coating system that meets the high performance, reliability and cycle time demand based on the hybrid polymer approach (Urethane Acrylates). Results from a structured Design of Experiment (DOE) using a standard test vehicle will be presented. In addition to the product characterization, reliability test results will be shared. The characterization tests will include agencies tests, such as UL and IPC, for conformal coating.

Keywords: Conformal coating, High reliability, Complex PCB, Hybrid polymer system, Urethane Acrylates, Application method, UL standard.

## INTRODUCTION
Power electronics assemblies (PCB + Microelectronics packaging) are integral parts of power components, power supplies, 5G network, automotive and defense/space applications. Most modern power electronics carry high voltage while exposed to harsh environments. Harsh environments may include high temperature, moisture, corrosive chemicals, particulates, and fungus among others. To add another layer of complexity, these electronics are densely packed with components, leaving very small spaces between the conductors and components. It is not uncommon for particulates to settle in between the conductors even in a cleanroom manufacturing environment. These particulates could pose the risk of a short circuit causing the product to fail if not managed properly. In addition, when electronics are exposed to harsh environments during use, moisture, chemical vapor and ionic can cause electrical shorts and leakage currents if not properly mitigated. One of the most common mitigation strategies is to protect the electronics assemblies with a thin layer of barrier coating known as Conformal Coating.

## CONFORMAL COATING BASICS
Conformal Coatings are a thin, dielectric layer that goes over the PCB and electronic components to protect them from the environment. Typical thickness of this coating is 25-150 microns. As the name implies, it conforms to the topography of the electronic board without adding significant weight. Figure 1 shows a typical board coated with a UV curable conformal coating. There are many benefits to applying conformal coating to a PCB. Some of the key benefits of conformal coatings are extension of usable life, product reliability, high voltage applications, increased surface insulation resistance (SIR) preventing corrosion and protecting against other harsh environmental conditions.

### Conformal Coating Key Considerations
There should be several key considerations taken into account when developing a conformal coating solution for high end applications. Mechanical properties, such as adhesion, modulus, hardness and elongation are critical in providing sound structural integrity to the PCB[1]. Other key considerations are dielectric strength, moisture resistance, operating temperature range and resistance to various chemicals are important for long term reliability.

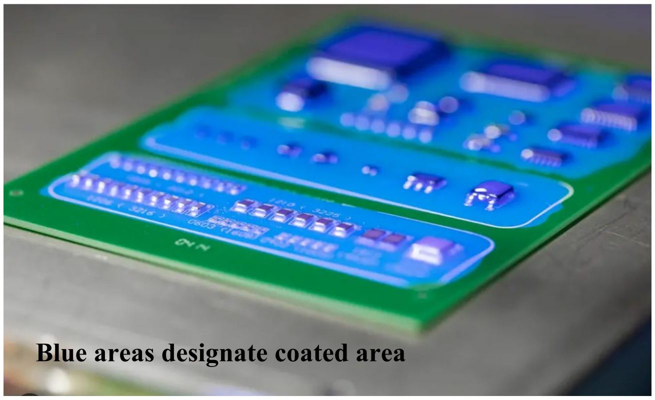



**Figure 1.** Typical conformal coated board viewed under black light.

**Reliability Considerations**

Reliability is defined as "...the ability to function under specific conditions, for a specified period of time without failure." [1]. Reliability, performance and life expectancy of electronics highly depend on the market in which they are deployed. For example, the reliability of electronics used in space applications could be much different from reliability requirements in consumer electronics. There are agencies such as UL, and industry groups such as IPC, that continue to develop test standards for safety and reliability testing. These standards are used as gold standards for testing and selecting high reliable conformal coatings. These agencies also certify products that meet their standards. In addition, conformal coatings suppliers conduct their own standard testing to validate the product usability for certain applications. Table 1 shows the most common agency tests that certify reliability and safety of conformal coatings. Table 2 shows various tests that characterizes conformal coatings and their usability for certain applications.

**Table 1.** Industry certification test for conformal coatings

| Test Standard | Agency | Comments |
|---|---|---|
| MIL-STD 883, M 5011 | DoD | Specific to military and space |
| ASTM E595 | ASTM | General |
| IPC-CC-830 | IPC | Durability against Tshock, moisture, Fungal and flame retardancy |
| UL 746E | UL | Determines coating's insulation properties |
| UL Flame Resistance | UL | Flammability with 94 V ratings |

**Table 2.** Product characterization tests

| Characteristics | Test Standard |
|---|---|
| Hardness | ASTM D2240 |
| Electrical | ASTM 764 |
| Mechanical | ASTM 638 |
| Adhesion | ASTM D3359 |

**TYPES OF CONFORMAL COATINGS**

Traditionally there are five primary types of conformal coatings available in the market: acrylic, epoxy, parylene, polyurethane, and silicone. Recently a new class of conformal coating has become mainstream due to its high performance and reliability. This is known as a hybrid system. This hybrid system is a combination of urethane and acrylate. Below is a brief description of each type of conformal coatings.

**Acrylic**

Acrylic coating, known as Type AR, are one of the easiest conformal coatings used in the industry. It is low cost, easy to apply, and cures in as little as 30 minutes. It has great moisture and fungus resistance. It has good mechanical and electrical properties with long pot-life that is process friendly. Some of the limitations of this coating are its poor resistance to many chlorinated solvents and alcohols and it is not suitable for applications above 125°C.

**Epoxy**

Epoxy coatings, known as Type ER, are usually two-part system which must be mixed right before applying as it is a fast-curing system. Epoxy coatings are tough that provides excellent resistance against moisture, solvents, and high abrasion. One of the main limitations of this coating is its inability to be reworked as it is a thermoset material with high hardness. Its short pot-life can be a challenging when applying to PCB.

**Polyurethane**

Polyurethane conformal coating (Urethane), known as Type UR is one of the best protections against humidity and solvent exposure as well as strong abrasion protection. Its superior dielectric properties open up design options for PCB by allowing the traces to be closer for miniaturization. Due to its strong resistance to solvent, this coating is not recommended when rework is desired. Another downside of UR coating is that it requires longer time to cure as compared to some two-part system.

**Silicone**

Silicone coating, known as Type SR, are high temperature resistant and flexible. It can also be applied at a higher thickness making it suitable for applications where vibration and high temperature exposure is expected. An example in which these conditions are common is the automotive industry. Silicone also has resistance to humidity and corrosion. However, it has lower abrasion and solvent resistance, making its use limited to specialized applications.

**Parylenes**
Parylene, known as Type XY, is a highly specialized coating that is applied from a vapor phase. It can be applied as thin as 10 microns while providing good resistance against temperature and many other stresses. One of the drawbacks of this coating is it method of application. It needs specialized coating equipment and cannot be wet up as an in-line process. In addition, it is difficult to rework as it has strong resistance to most solvents.

**Hybrid-Acrylated Urethane Light Cure System**
Acrylated Urethane, known as light-cure, are gaining popularity due to its many benefits. It brings the best of acrylic and urethane into one system. These coatings are solvent free and cures in seconds under UV light, making it an environmentally friendly process. It may have a secondary cure such as moisture or heat to ensure curing under shadowed area which may not have completely cured during UV exposure. As it is a one-part system, it is highly automation friendly and gives the flexibility in coating thickness. It has great moisture, temperature and solvent resistance. Rework can be challenging for this type of coating as it has high resistance to common solvents. Other areas to watch out for with this type of coatings are coating thickness variation. However, with proper process development most of the application challenges can be overcome.

## APPLICATION METHODS
Conformal coating can be applied in a variety of ways, ranging from manual to highly automated processes. Common methods are brushing, dipping, spraying, dispensing and vapor deposition for Type XY. Table 3 shows application methods and key advantages/disadvantages for each method. This paper focuses on automated machine coating method only.

**Table 3.** Application methods

| Tool | Method | + | - |
|---|---|---|---|
| Brushing | Manual | Rework friendly | No thickness control |
| Aerosol | Manual | Cost effective for low volume | Ventilation required |
| Dip coating | Manual | Coats the whole board | Slow process |
| Atomized spray | Automated | High accuracy & throughput | Process dev. needed |
| Dispensed | Automated | High accuracy & throughput | Hard for thin coating |

## EXPERIMENTAL
In this study, we have taken a structured approach in designing experiments to evaluate a new conformal coating (LOCTITE STYCAST CC8555) from Henkel. Evaluation included product characterization and product reliability assessment. Product characterization was conducted using industry standard test methods and UL agency testing. Table 4 shows the test types and standards.

**Table 4.** CC8555 test type and test standards

| Test type | Test standard |
|---|---|
| Adhesion | ASTM 3359 |
| Surface Insulation Resistance (SIR) | IPC-CC-830B-3.7.1 |
| Mixed Flow Gas (MFG) | GR-63-Core (outdoor) |
| Dielectric Withstand Voltage (DWV) | IPC-TM-650-2.5.7.1 |
| Flammability Rating | UL 94 |
| Electrical TI | UL 746E |

**Test Vehicle**
The Test Vehicle (TV) used in this study was chosen for its combination of high density, through hole, and large BGA components. The TV is shown in Figure 2. Area "A" shows tightly spaced small components that could be a challenge in real application. Area "B" show larger BGA that poses a different challenge (pooling) for processing. Edge and corner pooing sometime cause cracking and delamination after thermal cycling.

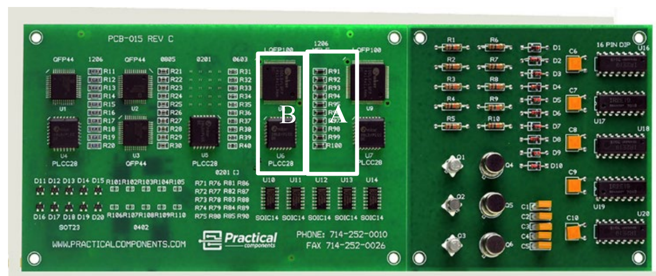



**Figure 2.** Test vehicle: PC015 Rev C Rework Training Board

**Test Method**
CC8555 was characterized using the test standards as shown in Table 4. The experimental matrix for this experiment is shown in Table 5. It includes three types of conformal coatings at three different coating thicknesses. The motivation behind this comparative study was to assess the reliability difference between existing conformal coatings in the market and the new hybrid chemistry based conformal coating.

**Table 5.** Experimental matrix

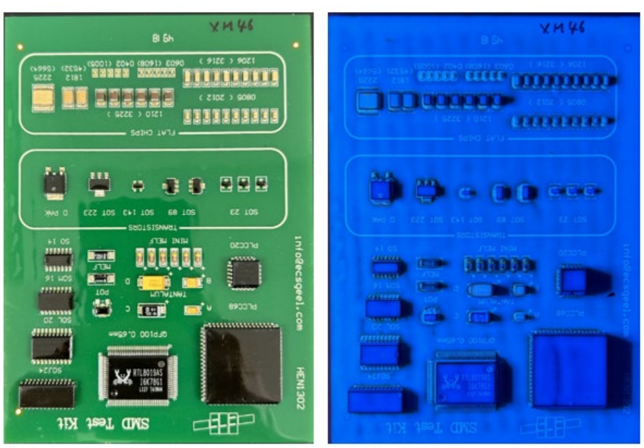
| Factor | Parameter | LEVELS 1 | 2 | 3 | Comment |
|---|---|---|---|---|---|
| A | Coating type | CC8555 | PC40UMF | UV7998 | Products |
| B | Coating thickness | 60 | 100 | 150 | Microns |

Response:Visual inspection for coating defects

Note: all boards were exposed to temp cycling and compared to time 0 board condition

| Qty | Treatment | Coating type | Thickness |
|---|---|---|---|
| 1 | 1 | CC8555 | 60 |
| 1 | 2 | CC8555 | 100 |
| 1 | 3 | CC8555 | 150 |
| 1 | 4 | PC40UMF | 60 |
| 1 | 5 | PC40UMF | 100 |
| 1 | 6 | PC40UMF | 150 |
| 1 | 7 | UV7998 | 60 (70) |
| 1 | 8 | UV7998 | 100 |
| 1 | 9 | UV7998 | 150 |

The TV shown in Figure 2 was coated using an atomized spray coating process that provided good control over the coating thickness and uniformity of the coating. Coating thickness was measured before UV exposure (10 minutes after the coating) with wet-film gauge and was verified with film micrometer after full cure. Boards were cured according to the recommended cure schedule for each product that included UV light cure followed by moisture cure. After complete curing, the boards were inspected and imaged for coating defects to be compared with boards after thermal cycling. Figure 3 shows a typical cured board prior to exposure to thermal cycling. This board was coated using an atomized spray process to achieve a thickness of 75 microns. The blude light image shows a uniform, complete coverage of the coating without any defect.



75 microns coating with/without blue light

**Figure 3**. Typical test board image prior to thermal cycling test

**Reliability Testing**

Cured boards were exposed to thermal cycling from -40 and 125 °C for 1000 hours. Each cycle consisted of 20 minutes at each temperature with a 20-minute dwell time. Inspections were conducted at time 0, 250, 500, 750 and 1000 hours for any defect development such as cracking, delamination, discoloration etc. Special attention was given to areas that had a higher probability of cracking and delamination due to the component edge effect. Cracking and delamination will result in failure.

**RESULTS AND ANALYSIS**

Results from the characterization tests are shown in Table 6, Table 7 and Figures 4, 5, and 6.

**Adhesion Test Result**

Adhesion test was conducted as per ASTM 3359 test method using IPCB-24 boards with a 75µm coating thickness. Boards were crosscut as shown in Figure 4a then peeled off using recommended tape. Boards were then examined under microscope to assess the degree of peel off. After 1000 hours of aging at 85°C/85%RH the coating was able to achieve a 4B rating as shown in Figure 4b.

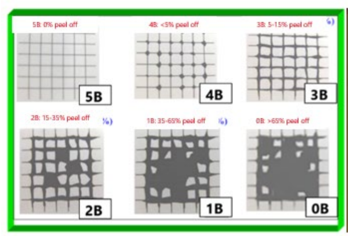




Figure 4a.

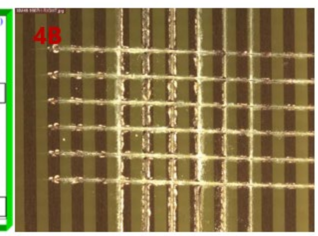




Figure 4b.

**Figure 4a.** shows the crosshatched standard for characterizing coating while **Figure 4b** shows the status CC8555 achieved after aging.

**Surface Insulation Resistance (SIR) Test Result**

SIR testing was conducted using the IPC-CC-830B-3.7.1 test standard with a coating thickness of 50µm at aging conditions of 85°C/85%RH without solder. As shown in Table 6, CC8555 achieved greater than $10^9\Omega$ surface resistance after 1000 hours of exposure to 85°C/85%RH.

**Table 6.** CC8555 SIR Test Results

| Time, hrs | Surface resistance, Ω |
|---|---|
| 0 | 2.22E+12 |
| 200 | 1.93E+09 |
| 400 | 2.17E+09 |
| 600 | 2.76E+09 |
| 700 | 2.95E+09 |
| 1000 | 3.36E+09 |

**Mixed Flow Gas (MFG) Test Result**

The MFG testing was conducted using the GR-63-Core (Outdoor) test standard. IPCB-25 boards were coated with CC8555 to a thickness of 50µm. Gases used for this test were

$Cl_2$ (20ppb), $H_2S$ (100ppb), $NO_2$ (200ppb), $SO_2$ (200ppb) for 10 days at 30°C/70%RH. After 10 days of testing no corrosion was detected as shown in Figure 5.

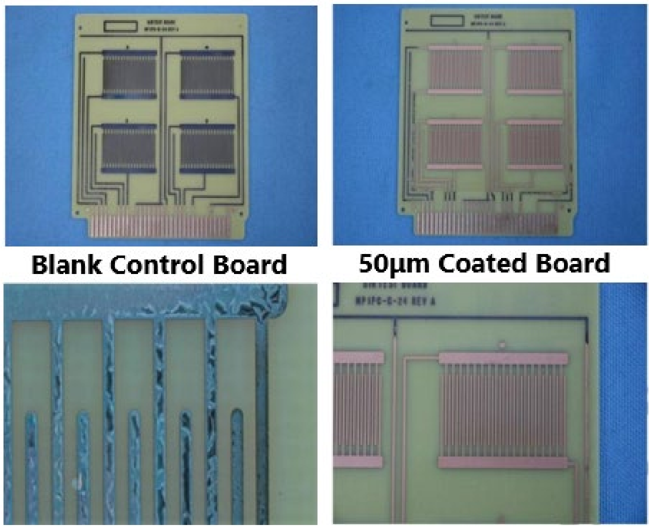



**Figure 5.** Result from MFG testing

**Dielectric Withstand Voltage (DWV) Test Result**

DWV test was conducted using IPC-TM-650-2.5.7.1 test method and IPCB-25D board. Two aging conditions were used for this test: storage at 130°C and sulfur exposure at 70°C for 1000 hours. 1.5kV voltage was applied for 60s. Results showing passing status at various coating thicknesses is shown in Table 7 and Figure 6.

**Table 7.** Results from DWV testing

| Sample | Aging Condition | Coating Thickness/µm | DWV Test after 1000Hrs |
|---|---|---|---|
| Loctite Stycast CC 8555 | 130°C Aging | 50 | Pass |
| | | 75 | Pass |
| | | 100 | Pass |
| | Sulfur exposure (70 °C) | 50 | Pass |
| | | 75 | Pass |
| | | 100 | Pass |

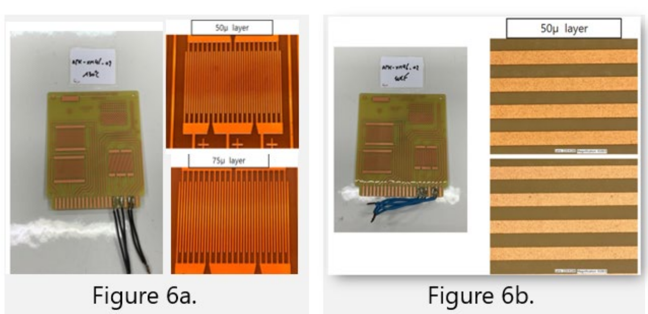



**Figure 6.** 6a. showing board condition after 1000 hours at 130°C and **Figure 6b.** showing board condition after 1000 hours to sulfur exposure at 70°C.

CC8555 has achieved UL 94 V0, RTI rating of 130°C and IPC 830B status.

**Reliability Test Results**

Test boards were taken out of the chamber at regular intervals for inspection from the test chambers, Results were recorded by visual inspection under microscope. Results from the reliability test is presented in Table 8 and Figures 7.

**Table 8.** Delamination results for DOE test matrix

| Coating type | Coating Thickness (µm) | Delam @ 250hrs | Delam @ 1000hrs |
|---|---|---|---|
| CC 8555 | 60 | No | Slight |
| CC 8555 | 100 | No | No |
| CC 8555 | 150 | No | No |
| PC40UMF | 60 | Yes | Yes |
| PC40UMF | 100 | No | Yes |
| PC40UMF | 150 | Yes | Yes |
| UV 7998 | 60 (70) | No | Yes |
| UV 7998 | 100 | No | Yes |
| UV 7998 | 150 | Yes | Yes |

## SUMMARY AND CONCLUSIONS

Demand for ultra-fast charging station, on-board chargers for vehicles, 5G infrastructure, datacenter and many industrial applications requires a level of PCB protection that didn't exist before. Along with the protection against the corrosive environment, higher level of health and safety standards must be met. In this body of work, we have tested a new product from Henkel (LOCTITE STYCAST CC8555) to characterize and assess reliability under harsh environmental in compared to commercially available conformal coatings.

Based on the results we can conclude that the new hybrid chemistry meets key agency standards such as UL 94V0, UL RTI rating of 130°C and IPC 830B status. MFG test results show that CC8555 shows no sign of corrosions. Further, reliability test results shows that the CC8555 shows no cracking or significant delamination after 1000 hours of thermal cycling from -40°C to 125°C. Compared to the older generation of conformal coating, the new hybrid system shows significant improvement in reliability and high temperature safety standards. This is critical for high power and high voltage applications.

We continue to analyze the data from reliability DOE and plan to publish this at a later time. Additional experimental studies are ongoing to evaluate industry leading hybrid conformal coating to provide the end users to select the right coating for their applications. As a next step, we will continue to conduct additional study to further understand the reliability and performance against similar coatings.

## RECOMMENDATIONS

The authors recognize that every application is unique and different, although studies like this provides a starting point for coating selection, it must be tested in real applications to ensure that the selected conformal coating meets all performance and reliability requirements.

## ACKNOWLEDGEMENT

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