peters
Coating Innovations
for Electronics

REPORT

Thick film coating materials and fast conformal coating processes – a contradiction?

Dr. Manfred Suppa
Michael Kollasa

Report no. 152 E

Table of contents

---

[1] Twin-Cure (trademark pending)

Introduction

Protective coatings – also termed conformal coatings – are lacquer systems that are designed to protect assemblies from failures, even under unfavourable ambient conditions. Conformal coatings, in particular, provide protection from moisture loading under a variety of climatic conditions, from dirt and other contaminations as well as from a number of organic solvents and other chemicals.

1. General demands on conformal coatings

The general demands on conformal coatings are, among others, included in the following national and/or international regulation codes:

- **IPC CC 830,** Qualification and Performance of Electrical Insulating Compounds for Printed Board Assemblies
- **IEC 1086-1 to 3,** Specification for coatings for loaded printed wire boards (conformal coatings)
- **IEC 464-3-1,** Varnishes used for electrical insulations
- **DIN 46449,** insulation lacquers and insulating resin compounds in electrical engineering, conformal coatings, test procedures
- **DIN VDE 0110-3,** insulation co-ordination for operating materials in low-voltage units part 3: application of coatings for the purpose of insulation co-ordination on printed circuit board assemblies
- **UL 746 C/E,** Standard for Safety of Polymeric Materials – Industrial Laminates, Filament, Wound Tubing, Vulcanised Fibre and Materials used in Printed Wiring Boards

The following IPC draft guideline is of informative nature

- **IPC HDBK-830** (draft 3, March 2000), Guideline for Design, Selection and Application of Conformal Coatings

Further demand catalogues exist at various users, especially in the automotive and aerospace industries.

The following constitute essential demands on conformal coatings:

- easy processibility, inc. drying rate, viscosity adjustment
- mechanical properties
- electrical properties
- thermal properties
- chemical and physical properties

mechanical properties	electrical properties	thermal properties	chemical and physical properties
adhesive strength tensile strength compressive strength flexural strength E-module (Young's module) hardness	resistivity surface resistivity tracking resistance dielectric breakdown dielectric loss dielectric constant	coefficient of expansion thermal conductivity dimensional stability glass transition temperature flammability	water absorption permeability chemical resistance tropic resistance electrolytic corrosion solvent resistance

figure 1: General demands on a conformal coating/coating material

The following examination particularly highlights the climatic loadings and their consequences. The demands on climatic resistance are naturally coupled with mechanical and/or electrical properties. The possible climatic loads – in the sense of ambient parameters – that may occur during the functions of an electronic assembly are the following:

- high/low air humidity,
- high/low temperatures,
- low air pressure,
- fast climate changes,
- dewing,
- microbiological load,
- contamination.

One generalised demand on an electronic assembly is the guarantee of the functional safety in case of dewing – in consideration of various climatic conditions such as temperature. The demands in the case of loading by humidity are subjected to a more detailed examination hereunder.

2. Climatic loading in norms for the qualification of conformal coatings

The testing of the climatic safety is regulated in a simplified form in various norms. There is, among others, the demand for a resistance of the conformal coating to moist ambient conditions, particularly the maintenance of the insulation effect. For example, the following load parameters and limit values are listed:

IPC CC 830:

Insulation resistance:	**During and after Moisture**
Class 1 and 2:	100 MOhm
Class 3:	500 MOhm

“Climate and testing conditions, respectively”: Cycling test 65 °C/25 °C at 90 – 98 p.c. relative humidity (defined time and ramps); measurements are taken on an IPC test board.

The class 1 demand applies to the normal field of application, which includes entertainment electronics, as well as non-critical industry electronics.

The class 2 demand applies to computer and telecommunication electronics as well as non-critical military applications.

The class 3 demand covers life-preserving electronics as well as electronic applications where a failure would be intolerable.

IEC 1086 1 to 3:
Insulation resistance after damp heat: > 1 x 10^{10} Ohm

“Climate and testing conditions, respectively”: 10 days of constant climate 40 °C at 93 p.c. relative humidity, measurements are taken on a defined IPC test board after reconditioning at room temperature.

Although IEC 1086-1 differentiates between general demand (Class I) and high reliability (Class II), it does not make any difference in this test.

IEC 464-3-1:
Volume resistivity after immersion:
Before: > 10^{12} Ohm x cm

Afterwards: > 10^8 Ohm x cm

Effect of the immersion on the dielectric breakdown:

Afterwards: > 40 kV/cm

“Climate and testing conditions, respectively”: constant water temperature of 23 °C for a period of 7 days (distilled water).

DIN 46449:
Specific volume resistivity as a function of the storage in water after 24, 48, 96 and, if necessary, 240 hrs.

No limit values are stated.

DIN VDE 0110-3:
Insulation resistance: ≥ 100 MOhm

“Climate and testing conditions, respectively”: 4 days at a constant climate of 40 °C at 93 p.c. relative humidity; measurements are taken on a defined IPC test board.

UL 746 C:
Measured values are the dielectric breakdown, at least 50 p.c. of the value for the unconditioned sample and at least 1 kV for 60 s.
UL 746 C differentiates between three conditioning processes:

- Environmental Cycling Conditioning
  In this conditioning process, one differentiates between indoor end-use applications and outdoor end-use applications:
  "indoor end-use application": 24 hrs at performance temperature, 96 hrs at 35 °C/ 90 p.c. relative humidity, 8 hrs at 0 °C
  "outdoor end-use application": 24 hrs of water storage at 25 °C, 24 hrs at performance temperature, 96 hrs at 35 °C/90 p.c. relative humidity, 8 hrs at - 35 °C
- Humidity Conditioning
  “Climate and testing conditions, respectively”: 7 days at constant climate 35 °C at 90 – 95 p.c. relative humidity; the measurement is taken on a special UL test board within 2 minutes after its removal from the humidity chamber.
- Thermal Conditioning
  Not subjected to examination in this context; the process involved is a “dry” cycle.

Reference is made to the IEC series “Basic Environmental Testing Procedures” comprising about 70 test procedures, which cover a large variety of climatic and mechanical loading parameters.

3. Which physical differences exist between high air humidity and dewing?

An atmospheric loading under usual climates is always accompanied by a moisture load with the coating of the assembly being in equilibrium with the steam of the atmosphere. Since no polymer is steam-proof(!) a given share of water is thus always dissolved in the polymer. As temperature and air humidity increase, more water can be deposited in the polymer.

In these cases, the equilibrium ‘water dissolved in polymer’ to the ‘steam pressure of the water in the air’ is the physically decisive process.

At the same time, at a relative humidity of 40 % extremely thin water films develop in the molecular range. At a relative humidity of about 60 p.c., a film 1 to 4 molecular layers thick has formed on the surface. A film of said thickness can already alternate with hygroscopic – i.e. water-attracting contaminations on the film surface.

Note: Most assemblies operate under such conditions and, as a rule, no additional conformal coating is required.

At a relative humidity of 80 p.c., about 10 molecular layers have formed. These already behave similar to “normal” water; solution processes of salt can begin on the surface and ionic processes occur.

In the case of dewing, the conditions are different. Dewing occurs when the saturation steam pressure at a given temperature is exceeded; when a cold component is transferred into a warm atmosphere, the air directly bordering on the assembly will cool down. Since cold air can absorb less water than hot air, the water will condense and can visibly deposit on the assembly in the form of droplets. Physically, this process can be compared with the formation of fog in spring and fall. The danger of falling below this dew-point is particularly great at low temperatures between 0 and 10 °C.

In the case of dewing, some laws of nature change. The water dissolved in the polymer is no longer in equilibrium with the steam in the air, but in equilibrium with the water condensed on the assembly or lacquer surface. The natural laws now becoming effective can be summarised under the term osmosis. This has far-reaching consequences and is dealt with in detail below.

Osmosis means that every agent dissolved in water dilutes until the osmotic pressure of the generated solution is equivalent to that of the water or drop of water on the lacquer film. This affects, for example, salts, i.e. even traces of hand sweat on the printed circuit board, but also water-soluble components of the flux agent. These osmotic effects drastically reduce the electrical resistance values and can even lead to blistering.

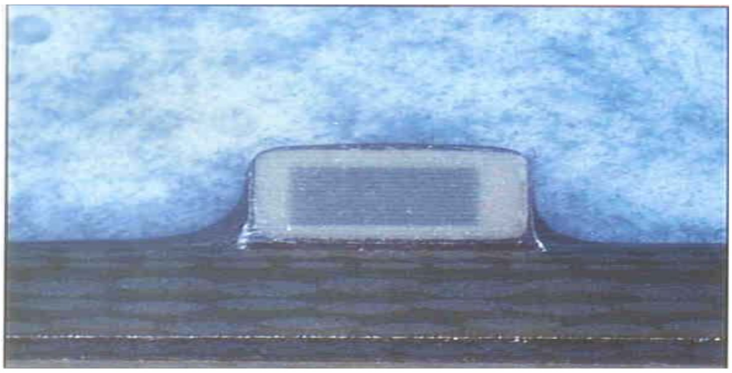
These processes, summarised under the term osmosis, call for an examination of both the printed circuit board pretreatment prior to conformal coating and of the coating agent.

This examination of the moisture loadings, that have to be rated in a physically different manner, has its consequences in the selection of the testing units for the qualification of conformal coatings. The temperature-moisture load at a high air humidity of 90 – 98 p.c. relative humidity and constant temperature does not lead to dewing. In the case of a superimposed temperature cycle, the air humidity is adjusted and – depending on the efficiency of the unit – dewing is excluded. Analyses with the so-called “condensation unit” as per IEC 60 068-2-3 (in compliance with DIN 50 017) effect a constant dewing and thus trigger the osmotic processes described above.

An added problem may be created by a loading with dirt particles or pollutants deposited from the ambient air, but also by contaminations caused by operating agents existing in the environment of the assembly such as fuels, oils etc. in engine compartments.

4. Examination of thick film protective coatings

The aggressiveness and loads especially of those climatic conditions under which assemblies are operated are increasing more and more. In some cases, conformal coatings employed are overtaxed regarding their protective effect, especially when dewing of the assembly takes place. This overtaxing must not be attributed so much to the inadequate efficiency or quality of the polymers or binding agents used but rather to the currently common used layer thicknesses; in this context, especially the edge coverage of the areas to be protected plays an important part!



conventional lacquer on a component 4-fold

In accordance with IPC-2221, layer thickness recommendations of 30 to 130 µm exist for conformal coatings on acrylic, epoxy and urethane resin basis and of 50 – 150 µm for silicone resins. The layer thickness has a substantial influence on the protective effect of coatings. The film thickness is almost directly proportional to the migration resistance, i.e. a duplication of the film thickness also almost doubles the migration resistance and thus the protective effect. This makes the solution of the problem look quite simple: Using the lacquers available on the market, higher film thicknesses are applied and the protective effect is improved. This approach, however, rather leads to contrary effects.

Regarding the usual conformal coatings, the general truth is that lacquer films dry slower the thicker they are applied. This is physically understandable, because the solvent in the wet lacquer film has to cover a longer distance in order to leave the lacquer film. In the case of the oxidatively drying lacquers, the oxygen also has to cover longer distances in order to fully cure the lacquer film. These delays in the drying process are not just linear, i.e. double layer is not equivalent to duplicated drying time. The dependence is rather of an exponential nature, i.e. double layer rather corresponds to about quadruple drying time. The time required to reach the desired ultimate properties, such as adhesion and electrical insulation, will become much longer and is then also more sensitive towards layer thickness fluctuations that are inevitably encountered on an assembly. In addition, these coatings are particularly sensitive towards an early encapsulation or climatic load, owing to the so-called solvent retention. In this context, we refer to our paper no. 150 “Protective lacquers and casting compounds as coating material for electronic printed circuit assemblies – fields of application, requirement profiles, processing –“, which we will gladly make available to you upon request.

A second solution presenting itself is the duplicated lacquer coating that is also practised frequently. Generally, the same statements also apply to this approach. The process times become much longer. A bad process control results in the additional danger of wrinkling or “pulling”. Moreover, these solutions cannot be regarded as optimum regarding the imminent VOC guideline[2] because it is the point of this guideline to register and reduce the

---

[2] VOC = Volatile Organic Compound

consumption of solvents.

Possible solution approaches result from the intention of employing lacquer systems with a higher solids content. However, even the use of these lacquer systems results in an extended drying period even though less solvents are used. A higher solid at comparable viscosity means a low molecular resin and thus, basically a slower drying cycle because more resin molecules have to be interconnected for filming. Again, the greater layer thickness delays the emission of the solvents from the film. Naturally, solvent-free coating agents, of course, constitute a technically and ecologically reasonable solution. Their chemical basis is generally known from the casting compounds and casting resins. In this context the limits between casting resins/casting compounds and conformal coatings become blurred. The disadvantages of the casting resins and casting compounds are known; these are mainly 2-pack systems with a significantly higher viscosity and, owing to their 2-pack character, a more expensive processing, compared to the conformal coatings. Another possible solution would be powder-coating, but these coatings require high temperatures of more than 130 °C for curing. Furthermore, the wetting of fine structures and, particularly, the underfilling of components is inadequate. Moisture-curing 1-pack polyurethanes constitute another possible solution but, besides the disadvantage of an equally slow drying process and their sensitivity towards moisture on the assemblies, these agents have a definitely limited storage stability. This becomes particularly apparent when the containers have to be opened several times.

Finally, we have the conventional UV-curing lacquers; these stand out for the fact that they can have a very low viscosity, are, as a rule, solvent-free and are particularly fast drying. However, they do have a considerable disadvantage: UV lacquers only dry in those areas where the UV radiation reaches the binding agent direct. In shadow zones, i.e. especially underneath the components, no curing takes place at first and the lacquer system in those areas remains sticky and cannot provide the protective effect required. On the contrary, these areas not only constitute a considerable weakening of the protective potential, they can even lead to the failure of the entire assembly, particularly in view of more stringent climatic loads, i.e. dewing. With such products one therefore frequently finds the instruction to perform a thermal post-treatment mostly at temperatures above 100 °C by means of which a film formation can then also be initiated in the shadow zones. This substantially restricts the use of such systems or even renders it impossible.

5. Assembly coating by means of the Twin-Cure ® system

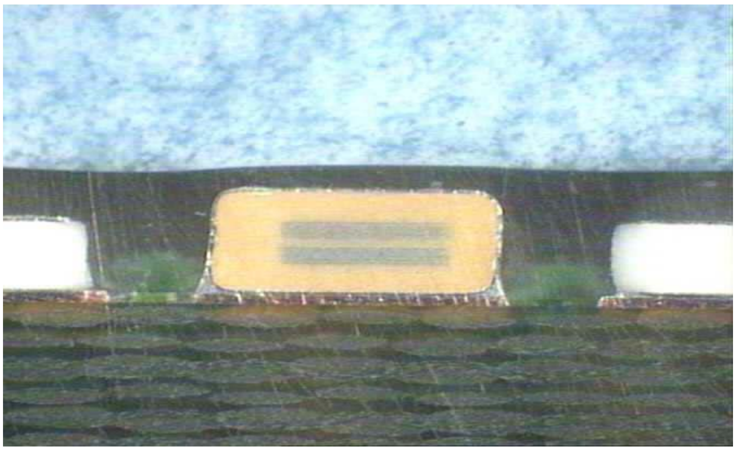
In view of the foregoing discussion it is particularly good and interesting news that we, Lackwerke Peters, were in a position to present for the first time a “world novelty” – a thick film lacquer named

Twin-Cure ® DSL 1600 FLZ (Index FLZ = fluorescent)

on the occasion of the SMT fair in Nuremberg in April 2001. The excellent properties of this special lacquer add up to its capability of eliminating numerous problems related to the coating of printed circuit board assemblies.

The **Twin-Cure ®** system is based on the principle that two different chemical curing mechanisms that complement each other occur in the drying process. In the first phase, the **Twin-Cure ®** system is subjected to a UV drying process and after a very short period of time is dried to such an extent that it can be “handled” without any reservation. In a second, slower drying phase, a chemical cross-linking by the ever present air humidity takes place – particularly in the shadow zones, i.e. in those areas in which a UV light-initiated cross-linking cannot be implemented. By means of this cross-linking mechanism, so-called PUR curing, the air humidity diffusing into the polymer is “intercepted” and used for a polymerisation and further curing of the lacquer in the shadow zone.

The layer thicknesses that can be achieved with this lacquer system in one coating cycle range from about 200 µm to 2,000 µm.



Twin-Cure ® on component 4-fold

There is no doubt that this is a genuine thick film lacquer combining the advantages of the increased resistances with those of a process-friendly drying. Depending on the film thickness applied, this thick film coating material can also effect component fixing in order to avoid vibration. Owing to its dual cross-linking mechanism, this lacquer system results in a clearly lower shrinkage in the cross-linking process than comparable conventional UV systems. Since **Twin-Cure ®** is a solvent-free coating material, it offers an optimal solution in view of the coming VOC guideline, in conjunction with a better protection of assemblies.

The gap between conventional protective coatings and casting compounds is closed, both from an economic point of view and regarding the protective effect.

6. Application and curing

The application of the **Twin-Cure ®** conformal coating system is generally feasible with all common coating methods.

However, some distinctive features have to be considered: Owing to the high lacquer viscosity, for instance, the use of the Select-Coat-procedure that is very popular in Europe, is not possible. In the USA, such highly viscous media are often applied by means of the Swirl-Coat-method. The relatively low-cost changeover results in high-quality coats that are variable over a wide range of film thicknesses.

Owing to the sensitivity of the lacquer system to moisture, steps have to be taken when it is processed by dip-coating in order to avoid air contact of the lacquer surface, for instance, by using inert gas. Processing without any problems is possible using the selective dip-coating systems available. Attention should be paid to the fact again that contact with moisture must be avoided.

The curing of the **Twin-Cure** ® system can be effected by means of standard UV drying units. This system already cures at a relatively low exposure energy; layer thicknesses of 0.8 to 1.2 mm, for instance, can be cured without problems at an energy of only 1.500 mJ/cm². If a higher film thickness is desired, the exposure energy has to be increased accordingly.

As described above, the lacquer cures in shadow areas with the aid of moisture; depending on the layout, this reaction is terminated after 8 – 14 days. The curing process can be accelerated by increasing the temperature in this case as well.

7. Properties

Two cross-linking mechanisms of different speeds occur in the chemical cross-linking process. The UV cross-linking that occurs first very quickly generates a protective filter that is already mechanically loadable and which – regarding its electrical insulation properties – already complies with the demands on a conformal coating. In the shadow zones, however, the film formation is achieved via the PUR-curing only. This reaction proceeds much slower and is terminated after about 8 to 14 days, depending on the ambient conditions.

Property	Test method	UV + 14 days of PUR-curing
dielectric breakdown	VDE 0303, part 2	90 kV/mm
volume resistivity	VDE 0303, part 3	5 x 10^{13} Ω/cm
surface resistance	VDE 0303, part 3	2 x 10^{14} Ω
moisture resistance and insulation resistance	IPC-CC-830, 3.8.1	> 1 x 10^{9} Ω
tracking resistance on base material with CTI 300	IEC 112 in connection with VDE 0109, part 2	CTI 600
condensation test, 4 days 60 °C, 40 V	based on DIN 50017	no E-corrosion or migration
Thermal shock test, 5 cycles		no change in lacquer film
steam test 60 min. storage		no change in lacquer film

table 2: Properties after combined UV + PUR curing

The above values refer to a lacquer film thickness of 200 – 300 µm only. Even better values are reached in the case of higher film thicknesses.
Particularly the condensation resistance of the **Twin-Cure** ® system is clearly higher than that of conventional protective coatings. On the one hand, this is due to the comparatively high degree of cross-linking and, on the other hand, to the high coat thickness. Moreover, any moisture penetrating prior to the complete curing is intercepted and used for further cross-linking and thus “improvement” of the **Twin-Cure** ® system. The chemical resistance, too, must be classified much higher. Thus, **Twin-Cure** ® films are definitely resistant to concentrated acids and lyes as well as other aggressive media.

On account of the special chemical structure of the binding agent used, a very good adhesion to the usual electronics substrates is achieved after the combined curing process.

Another advantage is the higher temperature resistance. In the case of oxidatively curing lacquer systems – at operating temperatures above 130 °C – a constrained further oxidation and thus embrittlement of the lacquer film occurs. Above all, this manifests itself in a distinct brown colouration and a rapid decrease of the tracking resistance, which is reduced to the value of the base material. Even after a permanent storage of 300 hours at

150 °C, however, **Twin-Cure** ® still has a CTI value of 600 and the lacquer film merely shows a very slight yellowing.

For a better control of completeness, the **Twin-Cure** ® **DSL 1600 FLZ** was given a fluorescent adjustment (Index FLZ). The fluorescence can be checked by means of conventional UV control light lamps.

The following summary of the most important properties of this new thick film coating system clearly proves that Lackwerke Peters have succeeded in creating an epoch-making novelty:

- based on a high-quality polymeride of polyurethane resin (PUR) and polyacrylate resin (AY)
- owing to the fluorescent adjustment (Index FLZ) the coating can be easily and reliably controlled under UV light
- solvent free – a technically and ecologically reasonable solution, also in view of the EU-VOC guideline (VOC = Volatile Organic Compounds)
- suited for thick film application in only one coating process up to 2,000 µm
- generally suited for all common lacquer application processes
- easily handled 1-pack system with the properties and resistances of a 2-pack systems
- fast UV curing with a radiation energy of about 1,500 mJ/cm²
- mechanically loadable protection with electrical insulation properties available immediately after UV curing
- cures in shadow areas owing to progressive chemical cross-linking interaction with the existing air humidity
- short process times in spite of high coating thicknesses owing to the optimally synchronised curing mechanisms
- excellent edge coverage, outstanding adhesion and low shrinkage
- excellent wetting and underfilling of components
- hence additional component fixing
- the high lacquer coats guarantee a lasting protection from component vibration
- excellent climatic, chemical and mechanical load capacity and resistance to, for instance, condensation and dewing acids, lyes and other aggressive media
- overall outstanding electrical properties (refer to table 2, page 9)
- particularly high tracking resistance with CTI 600

8. Conclusion

The new conformal coating system **Twin-Cure** ® **DSL 1600 FLZ** offers decisive advantages over conventional protective coatings. It combines the advantages of a fast UV cure with the ability of cross-linking even in shadow areas by further reaction in an easily handled 1-pack system with the resistance of a 2-pack system. Even thick film applications can be realised in shortest process times.

The film thicknesses that can be achieved range up to 2,000 µm. This material can be called a genuine thick film lacquer that combines the advantages of increased resistances with those of a process-friendly drying process. **Twin-Cure ® DSL 1600 FLZ** offers maximum efficiencies regarding possible climatic, chemical and mechanical loads even though residues of no-clean fluxing agents exist on the assembly surface. Owing to the variety of flux agents available on the market, however, we suggest preliminary tests to be performed. Since the material involved is a solvent-free coating material, it already constitutes an optimum solution in view of the forthcoming VOC guideline, together with an improved protection of assemblies. Depending on the film thickness, this thick film lacquer can also ensure the fixing of components in order to avoid vibration. On account of the fluorescent adjustment, the lacquer coat can be reliably controlled under UV light.