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APPROACH ON THE PREVENTION AND METHODS OF ELIMINATING DEFECTS OCCURRING IN THE SELECTIVE COATING PROCESS USING A 1K MATERIAL

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Abstract: *For almost any power electronic systems, the basic infrastructure consists of Printed Circuit Boards (PCBs). High Performance electronic products often include conformal coating materials to protect printed circuit assemblies from moisture, dirt or other detrimental environmental hazards and, also, to provide durable insulation for reducing thermal and mechanical stress on the components and to reduces the risk of electrical shorts and leakage currents. In this study, PCBs with conformal coating of 1K material were examined. A significant part of conducted research is concentrated in the development of the specific methods for these coatings diagnostics and defects prevention.*

Key words: *PCB, conformal coating, lacquer, protect, defects*

1. INTRODUCTION

Conformal coating materials are typically applied as a thin layer on the surface of electronic components and PCBs to provide protection against various environmental factors. These coatings are designed to resist the ingress of contaminants such as dust, ions, moisture, and chemicals that could potentially damage the components. The coating layer acts as a durable insulation that prevents ionic migration and reduces thermal and mechanical stress on the components.

2. COMMON PCB COATING DEFECTS

Surface disturbance may either occur as a disturbance in the flow of the coating material or be caused by insufficient substrate wetting. In the applied film. they are described as follows: capillary flow, de-wetting, orange peel, bubbles.

2.1 Capillary flow

Capillary flow is the phenomenon that occurs due the ability of a liquid to flow in narrow spaces against gravity, known as capillary action. When a conformal coating is applied to a substrate, such as PCB, and there are uneven surface areas or gaps present, the liquid coating can move from areas of high surface tension to areas of low surface tension. Some area of the PBS can even be left uncoated. Capillary flow can be influenced by various factors, including the viscosity of the liquid coating, the size and geometry of the gaps or openings and the proper substrate preparation. Understanding this behavior and taking precautions during the coating process can help ensure consistent and reliable results. The uneven finish can be caused by factors such as: inadequate surface preparation, inconsistent paint application (too thinly or too thickly), poor drying and curing conditions. What initially appears to be an optical defect may tum out to be a flaw, especially under high moisture and/or thermal shock loads; depending on the type of coating, this may lead to crack formation in individual cases. The only remedy here would be to minimize the capillarity effect. [1]

2.2 De-wetting

De-wetting is a phenomenon in which a liquid conformal coating does not spread evenly across a surface. Particular areas of the coating may bead up while others appear correctly applied. It happens due to various factors such as surface roughness, surface energy differences and surface nonionic contamination. Handling, manufacturing and transport processes are common sources of nonionic contaminants. When contaminants on the substrate are incompatible with the coating, it causes the surface to resist spreading in those areas. Generally, the conformal coating will bead up and move away from the following contaminants: process oils, flux residues, mold-release agents, fingerprints.

Whether contaminants appear on the substrate during assembly or are introduced during soldering, all must be removed with careful cleaning. To prevent de-wetting phenomenon, the substrate material needs to be spotless before applying the conformal coating. Select low-residue materials to control the process more effectively. [1]

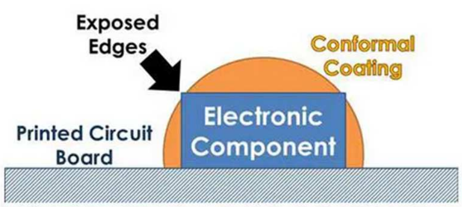


Fig. 1. De-wetting phenomenon. [2]

2.3 Orange-peel

Orange peel is characterized by its uneven texture and appearance, which is comparable to that of dull orange skin. Mottled textures in the conformal coating may prove to be cosmetic and non-critical. However, they usually indicate a process flaw that must be modified. [1]

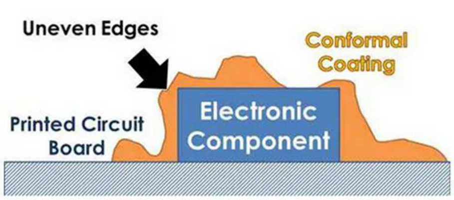


Fig. 2. Orange-peel phenomenon. [2]

2.4 Bubbles

Bubbles results when air pockets get caught behind a layer of conformal coating, They commonly occur when the coating fails to level and adhere to the substrate. Applying conformal coating with a brush may also create bubbles in the hardening surface. Any bubbles present in a coating weaken the protective effect, as they reduce the layer thickness in this spot by the diameter of the bubble. Moreover, they represent a physical impairment of the film - by initiating cracks during thermal cycling for example. Ln addition, there is the risk of permeating materials (moisture) to condense from the bubble. [1]

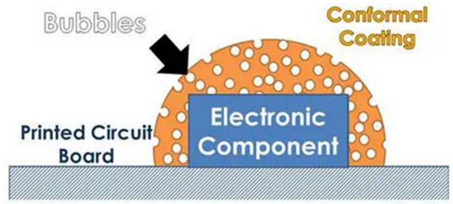


Fig. 3. Bubble phenomenon. [2]

3. IMPACT OF IMPROPER CONFORMAL PROCESS

3.1 Capillary flow impact

The most frequent reasons for capillary flow are: low surface energy of the substrate; high surface tension of the coating material; low viscosity of the coating material; and excessively thick coating applied to the substrate. In order to prevent these issues, make sure the substrate is clean before coating it, use solvent-based coating rather than water-based coating, reduce coating thickness, and heat the board before coating to speed up the drying process. [2]

3.2 De-wetting impact

When contaminants on the substrate are incompatible with the coating, it causes the surface to resist spreading in those areas. The following contaminants will typically cause the conformal coating to bead up and move away: fingerprints, flux residues, mold-release agents, and process oils.

Whether contaminants appear on the substrate during assembly or are introduced during soldering, all must be removed with careful cleaning. Make sure the substrate material is immaculate before applying the conformal coating to avoid the de-wetting phenomenon. Select low-residue materials to control the process more effectively. [2]

3.3 Orange-peel impact

There can be multiple causes for orange peel such as: improper application of the coating materials, high viscosity of the coating material from incorrect thinners, insufficient coating applied to the substrate, and coating applied too thick to the substrate, not enough time curing, low air pressure leading to uneven atomization.

To mitigate the effect of orange peel needs to optimize the spraying technique to manufacturer specifications, choose a different thinner to reduce the viscosity, and apply the coating to the appropriate thickness.To expedite the curing process, extend the "flash-off time" to allow the solvents to evaporate before raising the temperature. [2]

3.4 Bubbles occurrence impact

Common causes of bubbles and foam are: contaminants on the surface of the substrate, coating applied too thick to the substrate, high viscosity of the coating material, high temperature during curing, coating cured too quickly, coating applied under improper pressure or with the wrong equipment settings.
Some tips to help prevent these issues are: use a lower viscosity formula of the conformal coating, apply multiple thin coats, allowing bubbles to dissipate between layers, blend coats applied so they flow easily into all areas of the substrate, and ensure the coating is applied only to the recommended thickness [2].

4. PCB DESIGN AND VARIETY OF SAMPLES

An electronic assembly known as a printed circuit board (PCB) connects components electrically by means of copper conductors. Electronic components are mechanically supported by printed circuit boards, enabling devices to be installed in enclosures. A PCB design needs to follow a certain sequence of steps that corresponds with the integrated circuit packaging, manufacturing procedure, and bare circuit board structure. [2]

5. DEVELOPMENT OF METHODS FOR COATING DEFECT DIAGNOSIS AND PREVENTION

Fourier-transform infrared spectroscopy (FTIR) analysis of the unwetted area on the A component from an Sample.

The purpose of this analysis is to investigate a possible existing contamination on the A component, that prevents the conformal coating from adhering to the component.
Figure 4 shows the optical inspection of the A component. The numbers mark investigated areas:

1. Wetted area (conformal coating)
2. Semi-wetted area (thin film of conformal coating)
3. De-wetted area (no or very low conformal coating)

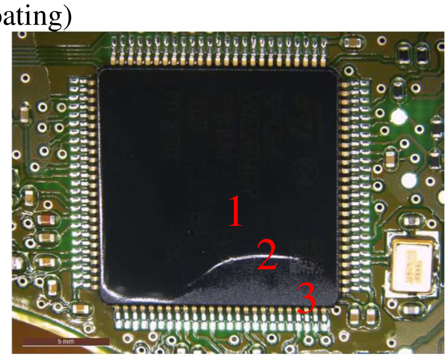
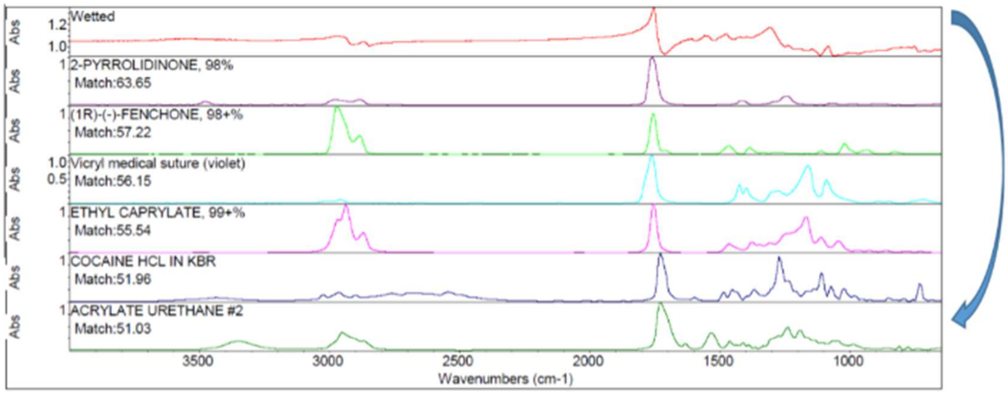


Fig. 4. Optical inspection of A component.

5.1 Results of the FTIR analysis

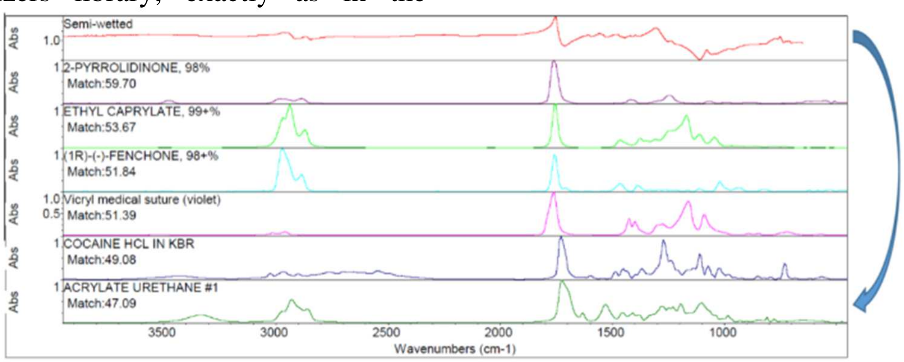
Figure 5 shows the first six matches obtained based on the correlation between the absorption spectrum of the wetted area and the existing chemical spectra in the OMNIC database library. According to OMNIC database library, the most relevant correlation of the collected spectrum, indicated with blue arrow is acrylate urethane from HR Polymer Additives and Plasticizers library, with 51,03% match. The existing materials/compounds spectra in the OMNIC library do not fully reproduce the spectral characteristic of the measured spectrum from contamination, thus the sample might be a combination of more compounds and acrylate urethane might be one of them. Acrylic, urethane and silicone resins are used in conformal coatings. [3]



Index	Match	Compound name	Library
108	63.65	2-PYRROLIDINONE, 98%	Aldrich Vapor Phase Sample Library
84	57.22	(1R)-(-)-FENCHONE, 98+%	Aldrich Vapor Phase Sample Library
712	56.15	Vicryl medical suture (violet)	HR Hummel Polymer and Additives
37	55.54	ETHYL CAPRYLATE, 99+%	Aldrich Vapor Phase Sample Library
1	51.96	COCAINE HCL IN KBR	Georgia State Crime Lab Sample Library
286	51.03	ACRYLATE URETHANE #2	HR Polymer Additives and Plasticizers
296	50.55	ACRYLIC POLYMER #1	HR Polymer Additives and Plasticizers
100	49.16	(1R)-(+)-CAMPHOR	Aldrich Vapor Phase Sample Library
86	48.90	(+/-)-CAMPHOR, 97%	Aldrich Vapor Phase Sample Library
63	48.77	N-ETHYLURETHANE, 99%	Aldrich Vapor Phase Sample Library
36	48.67	Poly(acrylic acid)	HR Specta Polymers and Plasticizers by ATR - corrected
285	48.67	ACRYLATE URETHANE #1	HR Polymer Additives and Plasticizers
114	48.59	Poly(Acrylic Acid) 49-24% in water	HR Specta Polymers and Plasticizers by ATR - corrected
479	47.34	Acrylic resin, isocyanate-crosslinkable	HR Hummel Polymer and Additives
1622	47.33	Dimethyl tartrate, L(+)-	HR Hummel Polymer and Additives
1163	47.11	Hydrocarbons, mostly aliphatic	HR Hummel Polymer and Additives
542	46.55	Polyurethane, with NCO residues	HR Hummel Polymer and Additives
169	46.48	Poly(styrene:acrylate ester)	HR Hummel Polymer and Additives
189	46.14	Polyacrylate resin	HR Hummel Polymer and Additives
149	45.96	Poly(acrylate:styrene)	HR Hummel Polymer and Additives

ig. 5. FTIR spectrum of the wetted area.

Figure 6 shows the first six matches obtained based on the correlation between the absorption spectrum of the semi-wetted area and the existing chemical spectra in the OMNIC database library. According to OMNIC database library, the most relevant correlation of the collected spectrum, indicated with blue arrow, is acrylate urethane from HR Polymer Additives and Plasticizers library, exactly as in the previous measurement, with 47,09% match. Existing materials/compounds spectra in the OMNIC library do not fully reproduce the spectral characteristic of the measured spectrum from contamination, thus the sample might be a combination of more compounds and acrylate urethane might be one of them.



Index	Match	Compound name	Library
108	59.70	2-PYRROLIDINONE, 98%	Aldrich Vapor Phase Sample Library
37	53.67	ETHYL CAPRYLATE, 99+%	Aldrich Vapor Phase Sample Library
84	51.84	(1R)-(-)-FENCHONE, 98+%	Aldrich Vapor Phase Sample Library
712	51.39	Vicryl medical suture (violet)	HR Hummel Polymer and Additives
1	49.08	COCAINE HCL IN KBR	Georgia State Crime Lab Sample Library
285	47.09	ACRYLATE URETHANE #1	HR Polymer Additives and Plasticizers
296	46.69	ACRYLIC POLYMER #1	HR Polymer Additives and Plasticizers
63	46.05	N-ETHYLURETHANE, 99%	Aldrich Vapor Phase Sample Library
286	44.55	ACRYLATE URETHANE #2	HR Polymer Additives and Plasticizers
4	44.35	POLYESTER, TEREPHTHALATE	Hummel Polymer Sample Library
1457	43.98	ACETYL TRIBUTYL CITRATE #3	HR Polymer Additives and Plasticizers
100	43.41	(1R)-(+)-CAMPHOR	Aldrich Vapor Phase Sample Library
86	42.84	(+/-)-CAMPHOR, 97%	Aldrich Vapor Phase Sample Library
204	42.47	TRIHEXYL O-BUTYRYLCITRATE, 99%	HR Aldrich Esters, Lactones, and Anhydrides
443	42.21	PYRUVIC ALDEHYDE, 40 WT. % SOLUTION IN WATER	HR Aldrich Aldehydes and Ketones
841	42.13	Cellulose acetate butyrate	HR Nicolet Sampler Library
395	42.01	POLYACRYLIC #3	HR Polymer Additives and Plasticizers
114	41.93	Poly(Acrylic Acid) 49-24% in water	HR Specta Polymers and Plasticizers by ATR - corrected
842	41.83	Poly(1,2-propylene carbonate)	HR Hummel Polymer and Additives
1622	41.71	Dimethyl tartrate, L(+)-	HR Hummel Polymer and Additives

Fig. 6. FTIR spectrum of semi-wetted area.

The comparison between the absorption spectra of the wetted and semi-wetted areas and acrylate urethane are shown in Figure 7. The two measured spectra are identical, showing that the same compound is find on both areas, and also similar to acrylate urethane. At 2968 cm^{-1} and 2865 cm^{-1} the stretching vibrations of the C-H group can be found. The C=O stretching vibration lies at 1754 cm^{-1}. The peak at 1559 cm^{-1} belongs to the CONH stretching, whereas the 1474 cm^{-1} peak represents the bending vibration of the C-H group. The absorption band at 1307 cm^{-1} corresponds to the stretching vibration of the C-N group and at 1078 cm^{-1} the stretching vibration of the C-O-C group can be found. [4]

Figure 8 shows the first six matches obtained based on the correlation between the absorption spectrum of the de-wetted area and the existing chemical spectra in the OMNIC database library. According to OMNIC database library, the best correlation of the collected spectrum, indicated with blue arrow, is alkyd from HR Hummel Polymer and Additives, with 55,04% match.

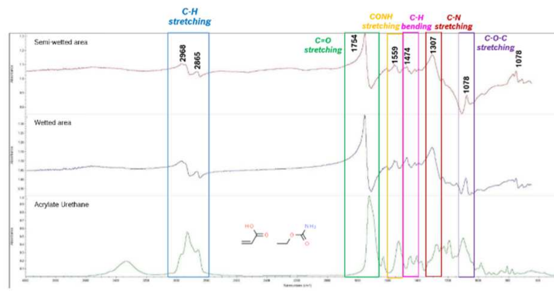
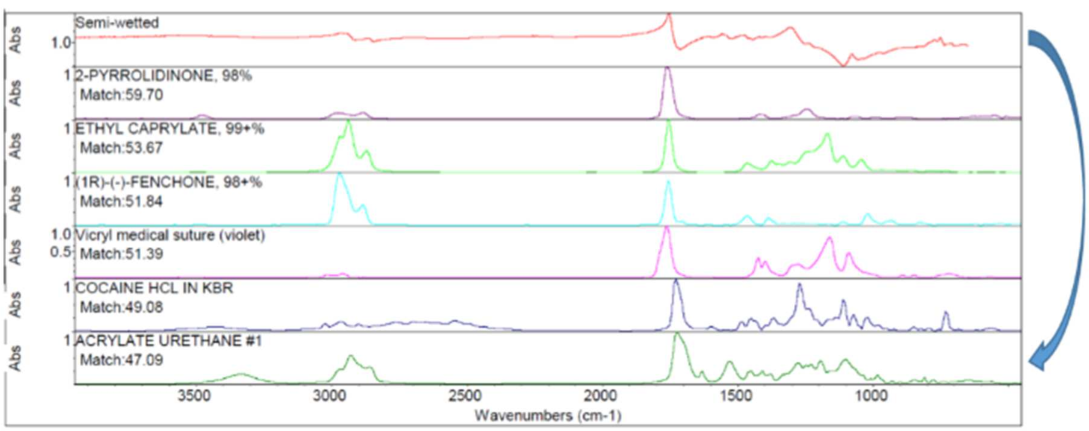


Fig. 7. Comparison between the absorption spectra of the semi-wetted and wetted areas and acrylate urethane.



Index	Match	Compound name	Library
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84	51.84	(1R)-(-)-FENCHONE, 98+%	Aldrich Vapor Phase Sample Library
712	51.39	Vicryl medical suture (violet)	HR Hummel Polymer and Additives
1	49.08	COCAINE HCL IN KBR	Georgia State Crime Lab Sample Library
285	47.09	ACRYLATE URETHANE #1	HR Polymer Additives and Plasticizers
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286	44.55	ACRYLATE URETHANE #2	HR Polymer Additives and Plasticizers
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1457	43.98	ACETYL TRIBUTYL CITRATE #3	HR Polymer Additives and Plasticizers
100	43.41	(1R)-(+)-CAMPHOR	Aldrich Vapor Phase Sample Library
86	42.84	(+/-)-CAMPHOR, 97%	Aldrich Vapor Phase Sample Library
204	42.47	TRIHEXYL O-BUTYRYLCITRATE, 99%	HR Aldrich Esters, Lactones, and Anhydrides
443	42.21	PYRUVIC ALDEHYDE, 40 WT. % SOLUTION IN WATER	HR Aldrich Aldehydes and Ketones
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842	41.83	Poly(1,2-propylene carbonate)	HR Hummel Polymer and Additives
1622	41.71	Dimethyl tartrate, L(+)-	HR Hummel Polymer and Additives

Fig. 8. FTIR spectrum of the de-wetted area.

The existing materials/compounds spectrum in the OMNIC library do not fully reproduce the spectral characteristic of the measured spectrum from contamination, thus the sample might be a combination of more compounds and alkyd might be one of them. One of the alkyd uses is as a compound of flux. [4]

The comparison between the absorption spectra of the de-wetted area and alkyd is shown in Figure 9. The absorption bands at 2969 cm^{-1} and 2871 cm^{-1} belong to the stretching vibration of the C-H group. The peak at 1758 cm^{-1} corresponds to the stretching vibration of the C=O group. The peaks from 1608 cm^{-1} to 1497 cm^{-1} indicate the aromatic C=C stretching. The

1428 cm^{-1} and 1304 cm^{-1} absorption bands correspond to the C-H bending vibration, while the bands at 1237 cm^{-1}, 1176 cm^{-1} and 1084 cm^{-1} are attributed to the C-O stretching. [5]

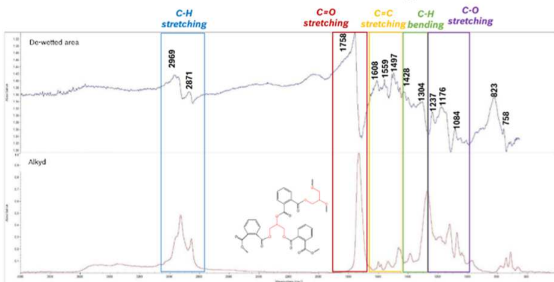

Fig. 9. Comparison between the absorption spectra of the de-wetted area and alkyd.

6. CONCLUSION

This paper presented the types of defects that can occur: capillary flow, de-wetting, orange-peel, bubbles. These processes are described from their appearance to their prevention.

7. REFERENCES

[1] Sean, Horn., *6 Conformal Coating Defects (And How to Best Avoid Them),* https://blog.paryleneconformalcoating.com/6-conformal-coating-defects-and-how-to-best-avoid-them/

[2] Antonio, J., Faria, B., *Conformal Coatings Rheology and Surface Tension,* https://www.rheologylab.com/articles/electronic/conformal-coatings/

[3] Taylor P., *Comparison of conformal coating technologies for military devices with non-traditional conformal coatings*, University of Massachusetts Lowell ProQuest Dissertations Publishing, 2010.

[4] Wu, L, You B., Li D., *Synthesis and Characterization of Urethane/Acrylate Composite Latex*, Journal of Applied Polymer Science, Vol. 84, 1620–1628, 2002

[5] Watsuji, T., Katou, H., Matsumura, K., Kikuchi, K., *Flux-containing compositions for brazing aluminum, films and brazing method thereby*, PCT/JP90/01013

[6] SC Robert Bosch SRL Romania (Jucu), *Internal Documentation*, 2023.

TIPURI DE DEFECTE APARUTE LA PROCESUL DE ACOPERIRE SELECTIVA FOLOSIND UN MATERIAL 1K

Rezumat: Infrastructura sistemelor electronice de putere constă din plăci de circuite imprimate (PCB). Produsele electronice de înaltă performanță adesea folosesc materiale de acoperire pentru a proteja ansamblurile de circuite imprimante si componentele de umiditate, murdărie sau de alte medii dăunătoare, de asemenea oferă o izolație durabilă pentru a reduce stresul termic și mecanic asupra componentelor și reduce riscul de scurtcircuitare și curenți de scurgere. În acest studiu au fost examinate PCB-uri cu acoperire selectivă folosind un material 1K. O parte semnificativă a cercetărilor efectuate este concentrată în dezvoltarea metodelor specifice pentru diagnosticarea acestor acoperiri și prevenirea defectelor.

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