Cleaning Lead Free prior to Conformal Coating? Risks and Implications

Umut Tosun, ZESTRON America

Introduction

Cleaning prior to conformal coating ensures optimal adhesion. In fact, a number of contaminations that are created during the soldering steps significantly impair the cross linkage and can be safely removed by an adequate cleaning process. Specific analytical methods are therefore highly recommended in addition to standardized cleanliness test procedures. This article sets out to reflect on the latest study conducted, highlighting for example the characterization of encountered contamination for eutectic and lead-free materials as well as their respective impact on quality and reliability. It is noteworthy to already point out that the use of lead-free products will make cleaning, prior to conformal coating, an even higher necessity.

There has been a clear and consistent increase in the demand for no-clean (eutectic as well as lead-free) products over the last few years. This trend coincides – and is likely correlated – to the growth of observed in-field service failures, particularly with coated assemblies.

Despite its potential risks and shortcomings, the no-clean concept has established itself as a dominant production process for a majority of product segments. Unfortunately, many companies have learned a difficult lesson by adopting no-clean processes that include additional production steps, such as component underfill, or applied conformal coatings.

At the same time lessons learned within the cleaning community have promoted new innovations, such as broader process windows, improved economics, higher industrial safety, and full material compatibility. These improvements have surely assisted the return of cleaning as a value added production step. It has been oftentimes said that cleaning behaves similarly to coating in that: Being introduced retroactively it severely impacts the entire assembly process assemblies and becomes unnecessarily expensive!

It is commonly accepted that the cleanliness of assemblies plays a vital part in the quality of subsequent production steps. Industry standards such as J-STD 001D item 8 have been the mostly applied and are generally accepted procedures for assessing cleanliness. Light-optical magnification for example, is used within the electronic manufacturing industry to identify visible contamination. Unfortunately, some of the critical residues are not easily visualized.

Transparent films for example are left behind by remnants of the assembly processes, such as chemical facilitators, organic greases, flux residues and surfactant based cleaning agents. The adhesion of protective coatings can be impacted and electrical failure mechanisms promoted. This conclusion is significant as it suggests the need for new definitions of evaluation sequences that are mainly based on functionality-related product aspects. Apart from the improved process reliability such new assessment criteria could even help to improve cleaning processes as quantifiable cost factors become more apparent. Compared to visual analysis for example, more quantifiable and reproducible procedures cannot only support the functionality assessment, but would also comply with stringent industry norms such as ISO 9001-2000.

Encountered Residues	Lead-free Impact	Impact of residues
Resin based as part of the flux	Increased in rosin content	Insufficient adhesion and subsequent delamination when exposed to climatic changes.
Flux activators	Increased in activator content	Unfavorable adhesion effects and danger of delamination due to hygroscopic properties
Tin-organic compounds	Possible increase on tin organic formation due to more activators	Cross-linking toxins promoting insufficient adhesion and creep underneath coatings.
Chemical facilitators for component release	Little to no impact	Impacts wetting properties. Seeds for delamination.
Oligomeric parts of substrates and solder mask interaction	Possible increase on tin organic formation due to more activators	Faulty processes result in contamination film. Similar effect as with chemical facilitators.

Ionic contamination measurement is the most widely used method currently. It quantifies the sodium chloride equivalent (NaCl) in accordance to TM650. Geometries and surface areas of populated assemblies are unfortunately not taken into consideration. In other words, the measured values are only benchmark values and not scientific cleanliness assessments. For proper statistical control for example, 3 to 5 measurements of identical PCBs are a minimal requirement.

Despite the intuitive correlation between the sodium chloride equivalent and the observed failure rates one has to clearly distinguish between essential but not sufficient conditions for safety against electrochemical migration, for example. Furthermore, it should be pointed out that due to the antiderivative measure of ionic contamination analysis, typical pools of contamination (i.e. during the reflow process) are not adequately taken into account.

One inevitable prerequisite for conformal coating processes is a small ionic contamination value for the surface in question. Any hygroscopic contamination, a direct consequence of ionic contamination, directly promotes delamination (Figure 1) and failures within only a few years of usage/field exposure.

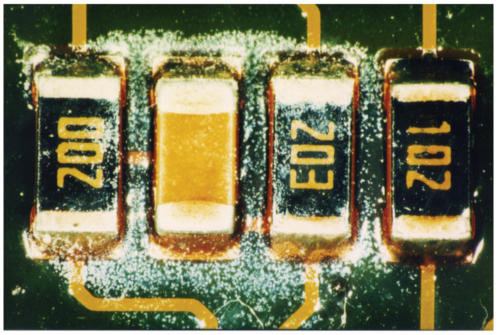
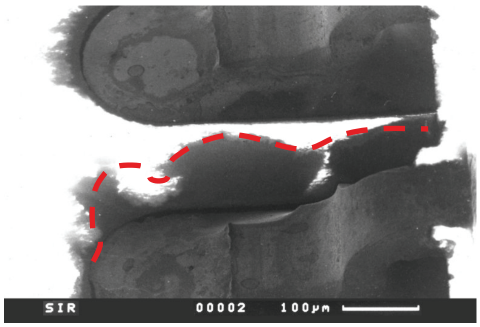


Figure 1 - Delamination of Conformal Coating due to Contamination

Current users of no-clean processes for example can attest to the very thin layered, transparent and oftentimes unrecognizable (i.e. by light optical inspection) flux-based films that remain. The latter are neither reliably authenticated via ionic contamination measurement nor can such residual contamination be cost-effectively substantiated using charge contrast measurements (SEM) (Figure 2).

Optically cleaned



Electronically contaminated

Figure 2 - SEM: Optically Clean vs. Electronically Contaminated

Innovative and simple-to-use procedures (i.e. Flux Test kits) can complement the above-mentioned shortcomings. By means of selective discoloration of residual organic acids, this test not only provides proof of their existence but also visualizes their local distribution. In addition, new innovative tests have recently attracted considerable attention. One of the most recent methods for example is called "contact angle measurement" (CAM), where surface energy values are determined to match the surface energy values of conformal coating materials directly with actual solder mask material. Furthermore, CAM enables the user to determine the actual nature of the contamination, therefore facilitating adequate cleaning process optimization. Figure 3a and 3b briefly describes this method.[1]

[1] U. Tosun, M.S.Chem.Eng., S. Chamousset "Effective Flux Removal under Stringent Environmental Limitations", SMTA - ATE, September 2005

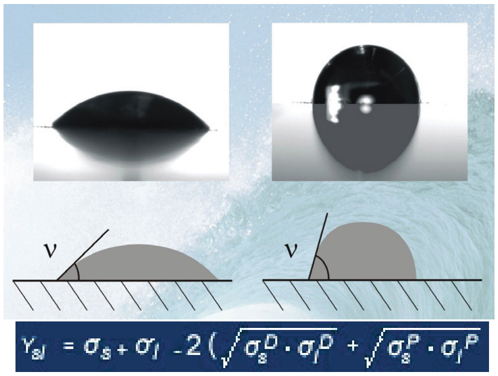


Figure 3a - CAM According to Owens-Wend Kaelble

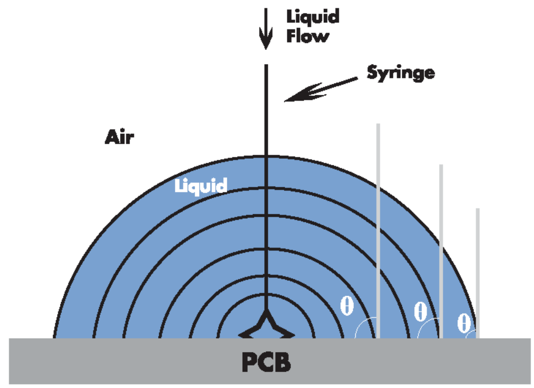


Figure 3b - Contact angle Measurement Principle on a Printed Circuit Board

As the transition to lead-free materials will be completed in 2006, more users will refer to new innovative methods such as CAM or Flux test kits. Through the emergence of new levels and types of contamination, their analytical detection becomes significantly more important than ever. With gained control over the contamination and the adequate cleaning process, users will then have to address the types of conformal coatings and their respective material properties and behaviors.

Protective Coating Demands

With the looming LF deadline, the fundamentals learned with eutectic solder now require a renewed focus on the effect of surface energies on conformal coating materials.

The authors felt compelled to not only address the nature and impact of eutectic and lead-free contamination on conformal coatings in this study, but furthermore establish a benchmark analysis across a number of different conformal coating materials that were examined. Methods ranged from mechanical testing, to permeability and absorptions tests, as well as "adhesion strength relative to contamination". An excerpt of these findings were summarized as follows:

- Water absorption tests on non-delaminated, fully hardened coatings indicate that a technically relevant influence on the insulation resistance currently is possible only for hygroscopic type contamination. Next to the bonding agent and the hardening parameters of time and temperature, the layer thickness of partially hardened coating systems also determines the water adsorption rate, because thicker layers take longer to achieve the same hardening level.

- Tests for water vapor permeability indicate a proportionality of permeability resistance in relation to the thickness the coating. However the improvement of the protective coating effect that is achieved by an increased coating thickness does not appear to be practical. This is due to the fact that the coating permeation resistance only rises by 30 percent with a given increase in coating thickness. The latter is cause by disproportionably lengthened curing times for thicker coatings.

- Mechanical Testing of partially hardened coatings result in an incomplete cohesion or material failure on EP-FR-4. Most commercial polyurethane (PU) and acrylate (AY) coatings fail on tin, primarily due to adhesion. To ensure adequate climatic protection by covering the free metal surface (i.e. leads), conformal coating adhesion strength must be higher than that of the coating on the metal surface (Figure 4). As mentioned previously, insufficient hardening of conformal coatings will result in a weakening of the cohesion strength. This in turn means that the already weak adhesion of more PU systems on tin based solders (eutectic & lead-free) is decreased even further. One way to improve such poor adhesion is cleaning prior to coating. An increase of the adhesion force by 2.5 N/mm^2 (+35%) was found with substrates (10 different SAC 305) that had been cleaned prior to be completely polymerized. (Figure 5)

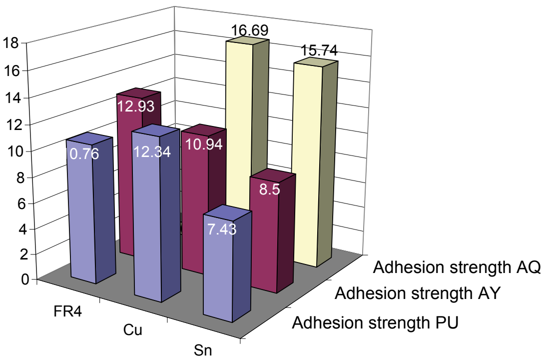


Figure 4 - Adhesion strength of Frequent Conformal Coating

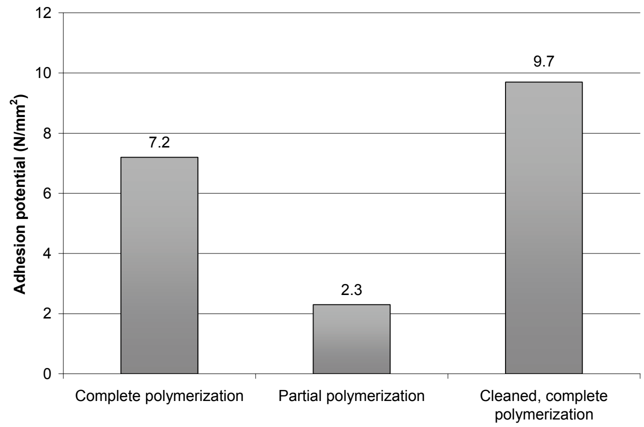


Figure 5 - How an Improvement of Conformal Coating Adhesion can be Achieved through Primer Cleaning

The Influence of Climatic Reliability

As indicated previously, the detection and analysis of contamination, especially for lead-free products will require new analytical tools. The latter are indeed needed, as numerous study have already projected an unusual failure pattern, arising mainly with silver containing lead-free alloys.

The climatic reliability of assemblies is determined in great part by the cleanliness of the circuits' surfaces and their screening against in the influences against moisture. Contamination favors moisture adsorption, and with it, electrochemical migration and corrosion induced failures (Figure 6).

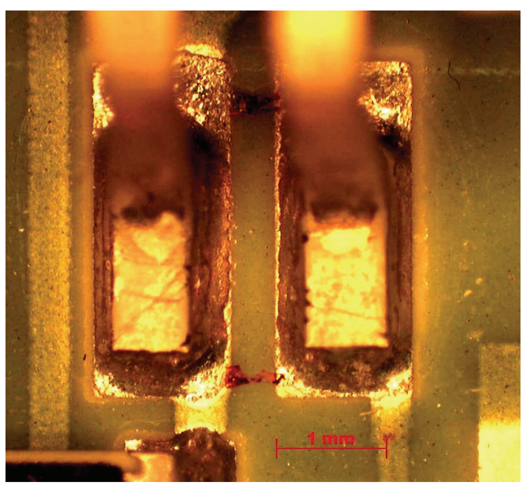


Figure 6 - Temporary Dendrites

Based on their conductivity, most production induced contamination reduces the assemblies' surface resistance:

o Flux residues change the capacitance of through-hole connection contact areas, which primarily affects the signal integrity of high density integrated and high frequency circuits.

o Dust on non-conformally coated miniaturized circuits, in conjunction with moisture, can result in the formation of so-called dust dendrites, i.e. tree-like short circuit bridges.

o Contaminants can cause long-term delamination, i.e. peeling off of the protective coatings. Both hygroscopic effects and hydrolytic processes impair the adhesion of coatings and the protection they typically provide.

In addition to the contamination present, the actual alloy also impacts the climatic reliability. For eutectic solders for example tin-organic compounds, which form between tin metals and organic residues, have become know as “cross linking agents”. Contrary to tin and lead alloys, silver containing solder (i.e. SAC 305) form hydroxides that are readily soluble in water. Formed as a result of water permeation through the conformal coating and subsequent dissociation of water, these hydroxides can be diffusible in thin moisture films. Climate resistance measurements revealed that the formation of silver based dendrites is short lived, having life spans between 10 and 15 minutes. Eutectic tin/lead solders did not exhibit such failure pattern. This phenomenon can be explained by the fact that the rate of renewed silver supplied to the surface of the solder joint is slower that the attack of electrochemical migration. This might be one of the reasons why short lived bridges never transform into predictable and repeated short circuits.

Conclusion

Whether or not cleaning is actually necessary to prevent any of the above described failure patterns has to be verified from product to product based on the expected quality requirements, i.e. product life cycles. The susceptibility of assemblies to failure can range from delamination of conformal coatings to electrochemical migration, and even the circuit design. It has been demonstrated however, that the removal of contamination prior to conformal coating provides significant improvements in the adhesion of conformal coatings and at the same time reduces the possibilities of contamination induced failures.

Furthermore, it was shown that with the onset of lead-free products, the level of contamination and its respective impact with furthermore add to the complexity of adequate process control. In light of this ongoing transition, the authors are currently extending this investigation to provide even greater insight of lead-free initiated phenomena. This in turn will lead to more adequate analytical tools for detection and complementary know how for coating materials and their respective performance.

Due to the complexity of the topic, the authors highly recommends to consult with your precision cleaning expert to avoid costly retrofits for cleaning processes or even potential product liability concerns.