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Contamination profile of Printed Circuit Board Assemblies in relation to soldering types and conformal coating

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Summary

Typical printed circuit board assemblies (PCBAs) processed by reflow, wave, or selective wave soldering were analysed for typical levels of process related residues, resulting from a specific or combination of soldering process. Typical solder flux residue distribution pattern, composition, and concentration are profiled and reported. Presence of localized flux residues were visualized using a commercial Residue RAT gel test and chemical structure was identified by FT-IR, while the concentration was measured using ion chromatography, and the electrical properties of the extracts were determined by measuring the leak current using a twin platinum electrode setup. Localized extraction of residue was carried out using a commercial C3 extraction system. Results clearly show that the amount and distribution of flux residues are a function of the soldering process, and the level can be reduced by an appropriate cleaning. Selective soldering process generates significantly higher levels of residues compared to the wave and reflow process. For conformal coated PCBAs, the contamination levels generated from the tested wave and selective soldering process are found to be enough to generate blisters under exposure to high humidity levels.

I. Introduction

Electronics manufacturing has been using no-clean flux technology today for all types of soldering process and the assumption is that the amount of residues left behind is minimal and benign. It is expected that the use of low solid content in the no-clean flux leads to almost full decomposition of the constituting components during the soldering process. However decomposition of the flux depends on number of factors, such as temperature variation over the PCBA, soldering process, amount and type of flux, flux application procedure, heating rate, decomposition temperature of chemicals etc. Therefore, in actual practice the PCBAs are contaminated with substantial amounts of flux residues [1] [2] including the activator components, mainly weak organic acids (WOA). Typical WOAs found in no-clean flux systems are di-carboxylic acids such as adipic, glutaric, succinic and malic acids, which results in ionic residues on the PCBA surface, of hygroscopic nature [3]. The combination of adsorbed moisture and ionic contaminants associated with the flux residues leads to the formation of an electrolyte which can provide a medium for leak currents leading to electrochemical migration, and therefore be a potential acceleration for corrosion [4] [5] [6].

Although it is generally known that different soldering process can introduce contamination on the PCBA surface compromising its cleanliness, no systematic work is reported investigating the relative levels of residue introduced by various soldering process and its effect on corrosion reliability. Investigations in this paper aim to show the relative difference in contamination levels introduced by soldering, investigated using a set of PCBAs, which have undergone various types of soldering process. Relevant surface conditions on actual production of PCBAs, including

distribution, composition and concentration of contaminants such as residues of fluxes used in the solder assembly process have been analysed. Localization and identification of flux residues have been done with Residues RAT gel test method, and FTIR analysis. Localized contaminations have been extracted using steam purge, with a C3 (Critical Contamination Control) equipment, and quantified by ion chromatography analysis and leakage current measurement with a platinum electrodes set up, allowing to get information about the localized WOA and NaCl equivalent concentrations. Effect of cleaning and the influence of contamination on silicone conformal coating performance were tested.

II. Materials and methods

2.1 Printed circuit board assemblies

A set of industrially processed PCBAs soldered using reflow, wave, and selective soldering process was used for investigation. All the PCBAs were soldered using no-clean flux systems, containing different flux systems but still belonging to WOA type.

2.2 Contamination profiling on PCBAs

Visualization of contamination profile on the selected PCBAs was done using a commercial test method called Residue RAT [7]. Testing includes spraying a hot gel onto the PCBA surface and observing the visual colour change at localized areas. Areas on the PCBA with flux residues will reveal a colour change from yellow to pink to reddish depending on the amount. The application by spraying combined with the high viscosity of the gel ensures that the colour change is fixed to the site where the residue was originally present and no smearing of the residues occurs. Further, infrared spectroscopy was used to identify the type of flux residue on the PCBA surface, a Nicolet iN10 MX FT-IR microscope from Thermo Scientific with ATR (Attenuated Total Reflection) mode was used for analysis directly on the surface of the PCBAs.

2.3 Localized extraction of residues and Ion chromatography

A localized cleanliness test system C3, Critical Contamination Control (Foresite Inc., USA), has been used to extract the residues from localized areas of the PCBA. The system purges steam onto a localized area (0.65 cm^2) and the condensed water with dissolved contamination (flux residue) will be extracted to a cell. An Ion chromatograph (IC) Dionex ICS 2000 was used for quantification of WOA.

2.4 Conformal coating of PCBAs and humidity exposure

Silicone coating “Dow Corning (R) Silicone RTV SE 9157 clear” has been applied by manual immersion on typical PCBAs, following by curing at room temperature for five days. The thickness of the coating was measured about $280 \mu\text{m}$. Performance of the conformal coating on PCBAs processed by various soldering methods is evaluated by observing the blisters formation, after exposure to $40 \text{ }^\circ\text{C}$ and 98% RH for a duration of 3 weeks. Optical microscopy was conducted on the exposed surfaces to analyse the blisters formation.

III. Results

3.1 Residues RAT gel test

Figure 1 shows partial images of typical PCBAs tested with Residue RAT, revealing the localized contaminations on the PCBA surface as a function of involved soldering process. The patented Residues RAT gel makes use of pH change due to the presence of acid in the flux residue to reveal the colour change in an optimized manner [7].

As shown in Fig. 1a, reflow soldered PCBAs in general did not show any red coloration indicative of the absence of residues. On the other hand, PCBAs that have undergone wave and selective soldering process have shown intense colour change including clear indication of the mark of pallet used in the case of selective soldering (Fig. 1b and 1c). The red coloration in both cases indicates the presence of high levels of flux residue.

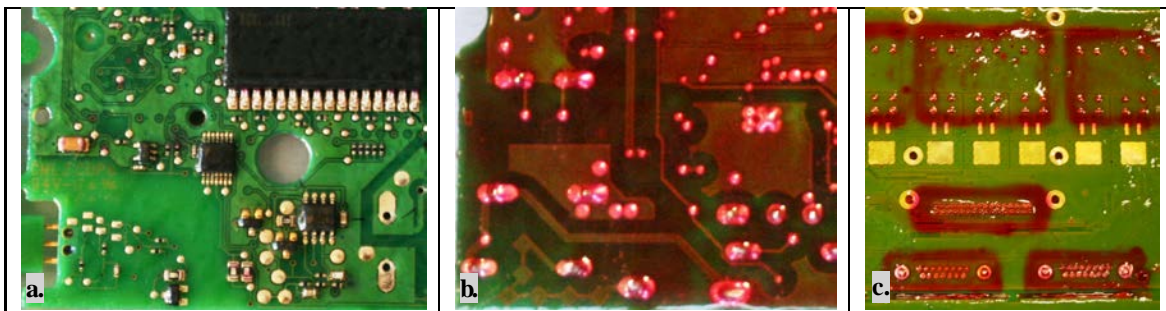


Figure 1: Residues RAT gel test on a) reflow, b) wave and c) selective wave soldered PCBs

While red coloration was seen all over the surface of the wave soldered PCBAs (Fig. 1b) (although only part of it is shown), selective soldered PCBAs showed residues only over a selected area depending on the application procedure (Fig. 1c).

The observation can be explained by the type of flux application in different soldering process.

For reflow soldering process, the use of flux in the form of paste and screen printing process limit the location of residues only to the localized areas, for example very close to or under the components.

In wave and selective soldering process, the flux is sprayed onto the bottom side of the PCBA, therefore resulting in wider distribution of flux on the surface. A large number of droplets can be left on the top of the PCBA, through via-holes, and the difference in the temperature of the top and bottom parts of the PCBA during soldering could introduce higher amounts of residue on the top part, where the temperature reaches only up to 170 °C (Figure 3 a and b).

In the case of selective wave soldering process, flux can be sweep under the pallet, and these trapped residues are not exposed to a sufficient temperature to be degraded (Figure 3 c).

Under such conditions, flux cannot be fully decomposed due to lack of thermal energy available and are more corrosive than residues heated to the appropriate soldering peak temperature of 250°C [8-9].

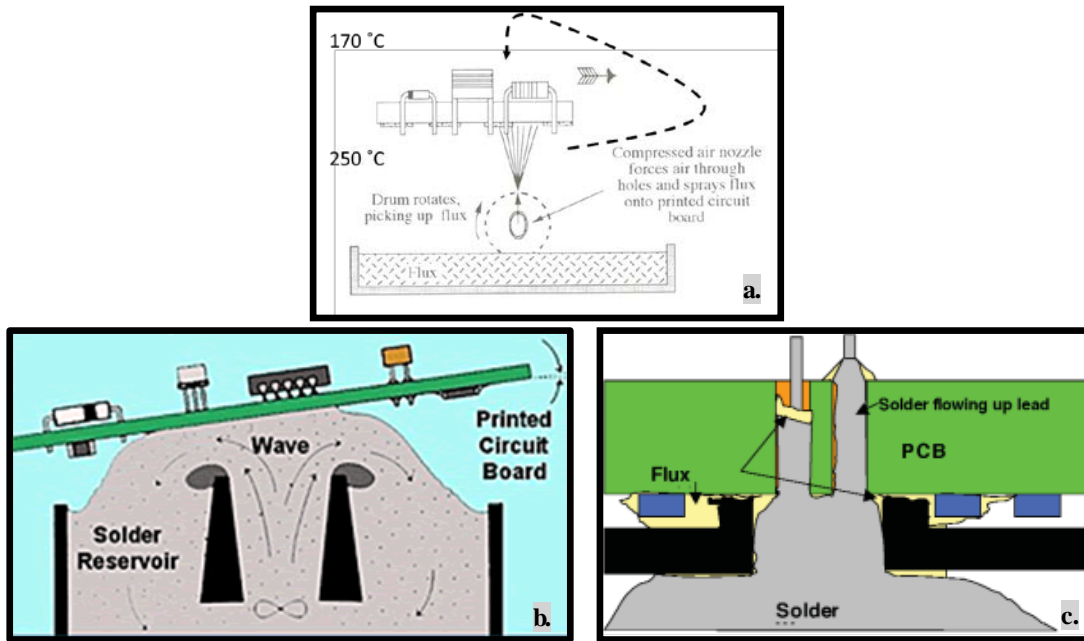


Figure 2 : Schematics of a) flux spraying at the bottom of the PCB to remove oxide on the through hole component leads and solder pad [10], b) through hole assembled PCB passing through the molten solder wave [11] and c) selective wave soldering process using a pallet [12]

Reflow soldering flux residue can be concealed initially due to the presence of the binder and the resin part of the flux, and WOA may not be immediately released [10]. Fig. 3 shows the residue RAT gel test of the reflowed PCB after five cycles of water spraying following by slow drying under an UV light in order to open up the residues. It can be seen that after this treatment a small red spot appears under the component, showing the release of WOA. The residues were found to be concealed initially and require heavy exposure to humidity for opening up [13].

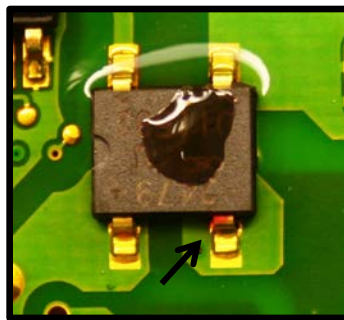


Figure 3: Residues RAT gel test on reflow soldered PCBA after severe humidity exposure

Fig. 3 shows images of Residue RAT gel test, of a typical wave and selective soldered PCBAs similar to the ones shown above in Figures 1b and 1c, however, after a simple cleaning process, by rinsing with a solution of Isopropyl alcohol and Millipore water at 3:1 ratio and scrubbing with a soft tissue, and rinsed again with the same solution to avoid any additional contaminations from the tissue. It is clearly showed that the acid residues are decreased, however little residues were found at some localized regions.

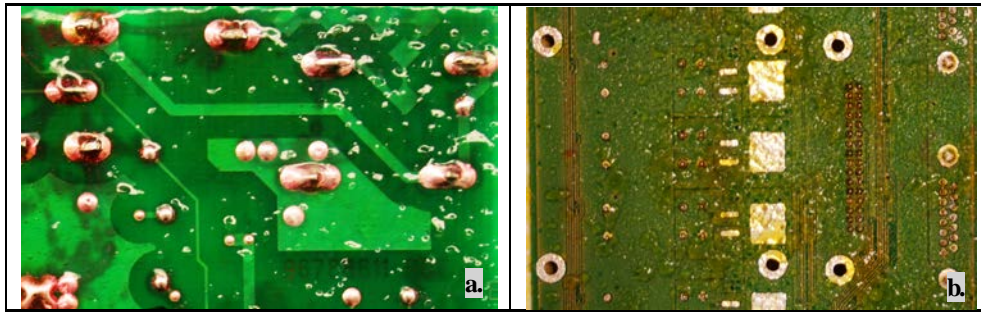


Figure 4: Residues RAT gel test on cleaned a) wave soldered PCBAs and b) selective wave soldered PCBAs

Although only few PCBAs are shown in Figure 1, the results shown here represent typical levels of residues found based on the test carried out on a large number of PCBAs with various designs and three soldering process. Therefore the results are applicable as a relative comparison between the cleanliness levels of various soldering process using no-clean flux systems.

3.2 Fourier Transform Infrared spectroscopy (FTIR)

In order to confirm that the contamination revealed by the residue RAT gel corresponds to flux residue, FTIR analysis were performed directly at the contaminated area on the PCBA surface, using a microscopic IR spectrophotometer with ATR. Typical spectra shown in Fig. 5a, clearly show that the chemistry of the contaminated area of the PCBA of the Fig. 3. a. corresponds to weak organic acid (succinic acid in this case), the active part of the flux systems. Similar evaluations of PCBAs showed such acids (Fig.5b).

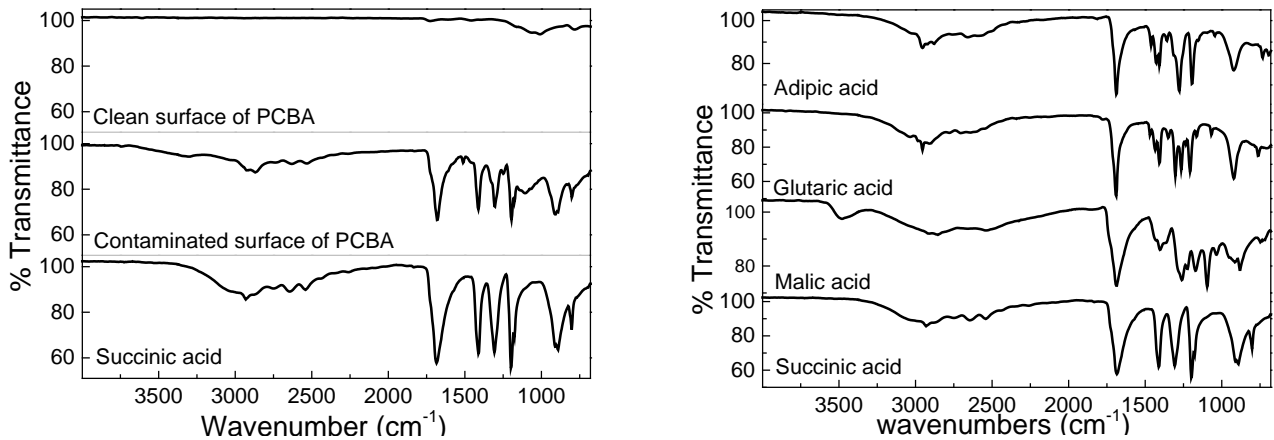


Figure 5: FTIR spectra on the surface a) of wave soldered PCBA and b) of typical contamination found on the surfaces of WOAs

3.3 Ion Chromatography

Residues were extracted from the localized areas on the PCBAs using C3 extraction set up and analysed using the IC with an aim to quantify the WOAs present in the residues. A large number of spots on the PCBAs have been identified, with and without contamination, for extraction. Although some unidentified peaks were seen, IC spectra show distinct peaks for adipic and

succinic acid (depending on the flux types on various boards). The distributions of the measured concentrations of WOA contained in all the extracted solutions are shown in Table 1.

Table 1: Range of WOA concentration values in localized extracted solutions on PCBs surfaces

Type of soldering	Reflow		Wave		Selective wave	
	As received	Cleaned	As received	Cleaned	As received	Cleaned
Process before measurement						
Range of local concentration of WOA, $\mu\text{g}\cdot\text{cm}^{-2}$	[n.a]*	[n.a]*	[0.4 - 17.2]	[1.1 - 8.4]	[1.1 - 44.1]	[2.2 -11.4]

* Below detection limit

The level of WOAs on the reflow soldered PCBAs were below detection limit, which is in agreement with the Residue Rat results. However, wave and selective soldered PCBAs showed contamination levels up to $17.2 \mu\text{g}\cdot\text{cm}^{-2}$ and $44.1 \mu\text{g}\cdot\text{cm}^{-2}$ of WOAs respectively. These concentrations were reduced to a maximum of 8.4 and $11.4 \mu\text{g}\cdot\text{cm}^{-2}$ respectively, after a carefully cleaning of the PCBAs.

3.4 Effect of contamination on the performance of conformal coating

Performance of the conformal coating on the contaminated PCBAs were evaluated by exposure to $40 \text{ }^\circ\text{C}$ and 98% RH for 3 weeks, and by observing the change in morphology of the coating due to blister formation. Only typical results before and after exposure to humidity are shown in Fig. 7-9, and for comparison of the initial level of contamination, Figure 6 consists of Residue RAT tested surface of same PCBAs with circles showing examined area for blisters. Fig. 8 and 9 also show the results for cleaned PCBAs which are conformal coated and tested.

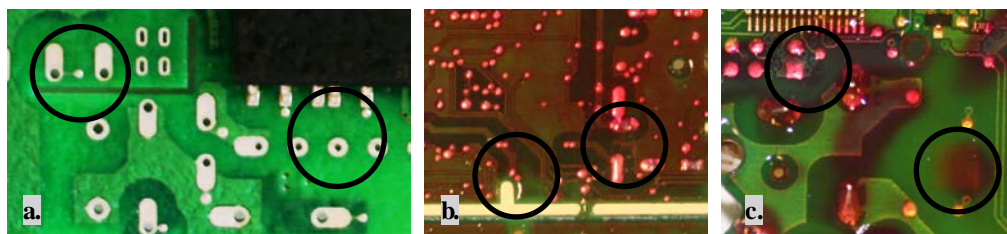


Figure 6: Selected areas for optical microscope pictures, of a) reflow b) wave and c) selective wave soldered and coated PCBs

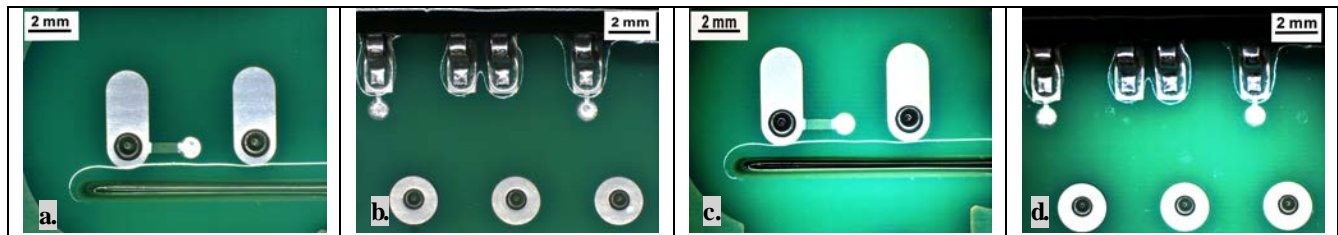


Figure 7: Optical microscope pictures of reflow soldered and coated PCB, a) b) before and c) d) after 3 weeks exposure to saturated humid

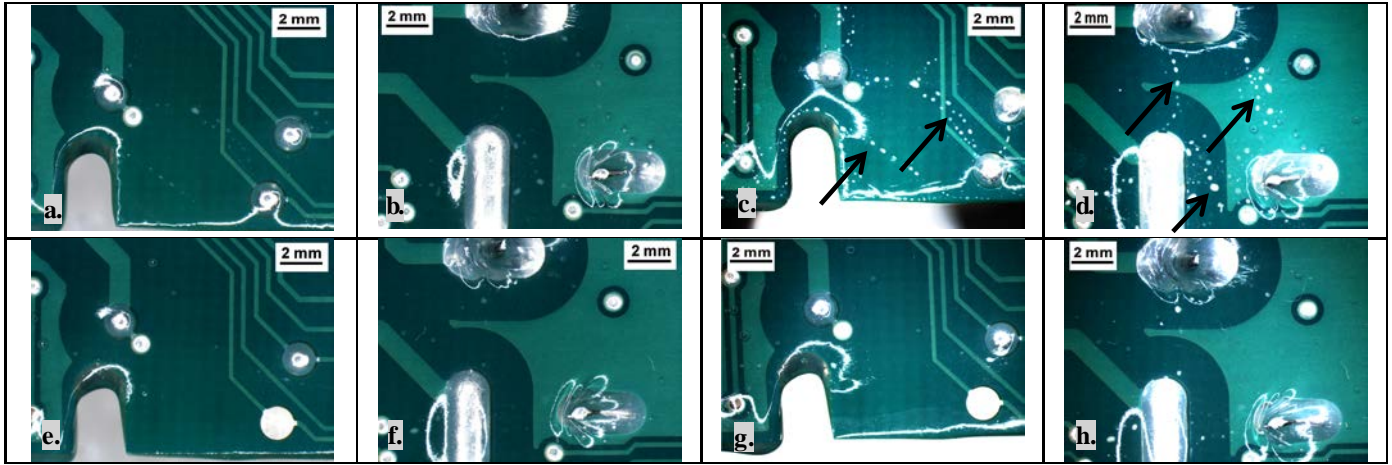


Figure 8: Optical microscope pictures of as received wave soldered and coated PCB, a) b) before and c) d) after 3 weeks exposure to saturated humid, and cleaned wave soldered and coated PCB, e) f) before and g) h) after 3 weeks exposure to saturated humid

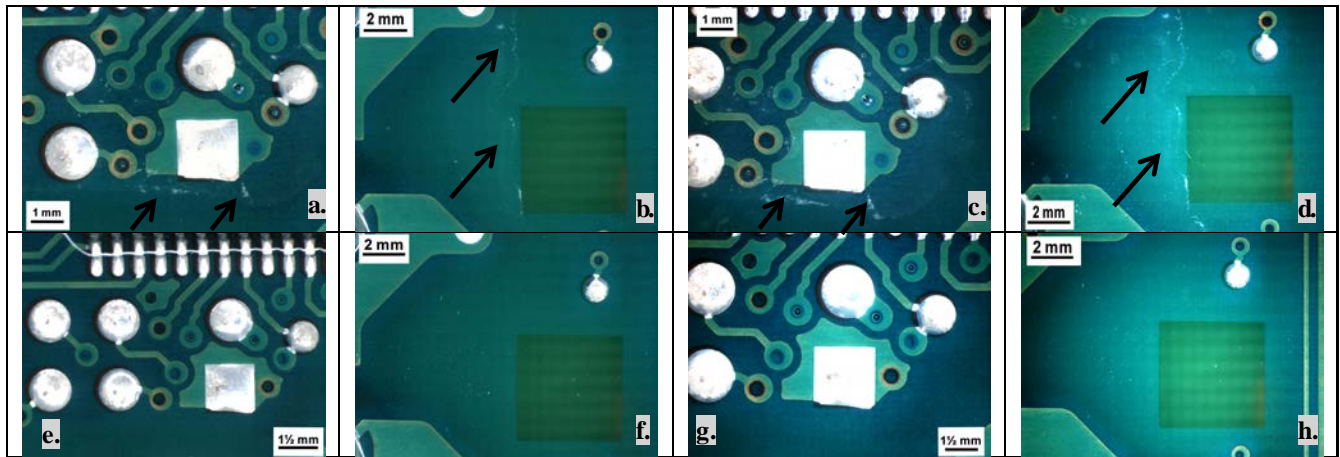


Figure 9: Optical microscope pictures of as received selective wave soldered and coated PCB a) b) before and c) d) after 3 weeks exposure to saturated humid, and cleaned selective wave soldered and coated PCB, e) f) before and g) h) after 3 weeks exposure to saturated humid

Results show that the conformal coating on reflow soldered PCBA remained unaffected during the three weeks of exposure (Fig. 7) (no blisters were found on the surface). But on wave and selective soldered PCBAs (Fig. 8 and 9), the conformal coating showed signs of deterioration and the majority of the blisters appeared at the same areas where a high level of contaminations were found by the Residue Rat testing. It clearly indicated that the excessive levels of contamination could introduce problems for conformal coating under humid conditions. This is expected, as the ionic contaminants under the coating will influence the water transport through the coating due to osmotic pressure, while the adhesion of the coating is affected by the contamination at the interface [14-16].

However, in both cases, cleaning of the PCBA has enhanced the performance of the conformal coating, indicating a direct relation between the contamination and the blister formation.

IV. Conclusion

1. Distribution and concentration of no-clean flux residues left after soldering on PCBAs are directly correlated to the type of processing. Residue RAT gel test reveals intense red coloration indicative of high levels of flux residue on wave and selective soldered PCBAs, while no red coloration was found on as processed reflow PCBAs. Selective soldered PCBAs also revealed selective mask tool's aperture region as the trapping areas.

2. Quantity of flux residues left was found to be a function of the soldering process. The activator part of the flux residue, weak organic acid, had not been detected on reflowed PCB's surfaces, but showed increased levels on wave and selective soldered PCBAs reaching a level of 17.2 and 44.1 $\mu\text{g}\cdot\text{cm}^{-2}$ for wave and selective soldering process.

3. Simple cleaning of PCBA with a solution of Isopropyl alcohol and water has reduced the maximal contamination level down to 8.4 and 11.4 $\mu\text{g}\cdot\text{cm}^{-2}$ of WOA on wave and selective wave soldered PCB's surfaces.

4. Presence of high levels of flux residues on wave and selective soldered PCBAs resulted in the degradation of the conformal coating under exposure to humidity revealed by blister formation. The distribution of the blisters after exposure corresponds to the pattern of flux residue on the PCBAs surfaces, and found to reduce by prior cleaning.

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