Methods for Choosing a Saponifier or Surfactant for Printed Circuit Board and Stencil Cleaning Applications

Ken Wilson
Flextronics International
Special Business Solutions
Charlotte, North Carolina, USA

Charles Merz & Aaron Unterborn
Flextronics International
Technology Leadership Group
Charlotte, North Carolina, USA

Abstract
This paper will discuss the technical challenges associated with the selection of chemical additive for the printed circuit board assembly (PCBA) and stencil cleaning processes. The removal of residues from lead free and tin lead fluxes are increasingly causing problems for printed circuit board (PCB) assemblers. The heat requirements of lead free chemicals have made removing the residues difficult, and all residues can cause problems with components that have decreased in size and those with increased electrical sensitivity. The problems associated with residues exist with both lead free and tin lead organic and rosin based chemicals. Residues from organic chemicals can cause corrosion or lead to electrochemical migration. Residues from rosin based no clean chemicals can cause problems with the application of conformal coatings, test connections, and high frequency components. The practice of using of high purity deionized water has been unsuccessful in removing many types of residues and can actually contribute additional problems.

For these situations, additional chemical additives, such as saponifiers and surfactants, can be used to assist in removing hard to clean residues. These additives are used in all style of cleaners such as in-line, batch style, and stencil cleaners. Because not all additives have the same formula and can be used with all cleaning processes, manufacturing locations must decide which additive can be used to clean the residues in question and meet local environmental regulations. The cost of the additive must also be considered. Since the use of chemical additives is a large investment for manufacturing facilities, the correct type and concentration must be determined to achieve the appropriate cleanliness level for the least amount of investment.

Introduction
With the majority of electronics assembled using no-clean flux systems the notion of PCBA cleaning can be considered out-dated. However there are a number of strong indications that PCBA cleaning may experience resurgence. Portions of the medical, infrastructure, industrial, aerospace and automotive markets have stringent PCBA cleanliness requirements that are likely to continue even after the transition to lead-free assembly[4]. These requirements are driven by concerns over long-term product reliability[2], RF sensitivity to flux residues, and end-use applications such as implantable medical electronics [5].

A number of technical papers have been published focused on PCBA cleaning. Topics have included the optimization of process parameters, equipment selection, the residue / reliability relationship[5], and the impact of lead-free assembly on cleaning[4,6]. Few provide details on the evaluation methods used to select a cleaning agent. The contents of this paper will focus on the selection criteria and methodologies used to evaluate cleaning agents for the misprinted PCB and assembled PCBA cleaning process. Both tin lead and lead-free assembly processes are considered.

Fluxes, Residues and Contaminants
Residues found on PCBAs are typically the by-products of the fluxing / soldering processes. The active chemistries in flux remove oxides and contaminates from the surface of the PCB and components during the soldering process. Active chemistries from solder pastes and fluxes are typically weak organic acids (WOA), halides, chlorides or other ionic species. Organic residues are considered polar (negatively charged) and can present a reliability concern and contribute to electromigration (degrading the insulation between pads) or in extreme cases, contribute to corrosion. Flux manufacturers mitigate this issue by formulating these chemistries to either suspend the oxides in a water soluble gel that will be washed away with deionized water (clean) or to physically encapsulate oxides on the surface of the solder joint in a non-polar film (no-clean). When the correct process parameters are used, both clean and no-clean flux chemistries provide robust and reliable solder interconnects. Contaminates are typically deposited on PCBAs through improper handling or storage. These include oils and sweats extruded through human skin or non-soluble debris that can be transferred to products during

handling. Most of these types of contaminates are considered to be non-polar and do not represent an electromigration risk. However, the presence of these contaminates can contribute to a decrease in wettability of soldering surfaces or leave visible traces causing a cosmetic concern. A common example is fingerprint smudges visible on organic surface protectant (OSP) coated soldering surfaces.

Cleaning Process Challenges
The difficulty associated with cleaning under low stand-off packages and large body size devices with standard purified or deionized water cleaning is well documented. Other cleaning challenges are related to the transition from tin lead to lead-free assembly processes. Lead-free solder paste and flux chemistry formulations are still relatively new and somewhat immature.

<u>Lead-free Cleaning Challenge #1:</u>
The current generations of lead-free water soluble solder pastes are difficult to clean using tin lead cleaner settings and deionized water alone. *[Image 2]* Based on recent internal lead-free water soluble solder paste study, the residue of some formulations harden during the reflow process and will not wash away during the PCBA wash process using DI water. This effect is only aggravated by the adoption of low standoff package sizes and large body sizes. *[Image 1]*

<u>Lead-free Cleaning Challenge #2:</u>
The changes in solder paste formulations also challenge the effectiveness of stencil and mis-printed board cleaning, including effectively remove reflowed residues from the 'B' side of a misprinted PCB.

<u>Lead-free Cleaning Challenge #3:</u>
Another complication involves the poor PTH vertical hole-fill provided by low-solids no-clean wave flux chemistries developed for lead-free, especially with thick or thermally massive PCBs. To meet the vertical hole-fill requirements established by IPC-610D, assemblers are considering the use of rosin based or high solids no-clean wave fluxes. While this option provides improved hole-fill it also has drawbacks including the presence of visible residues that may fail cosmetic requirements or block test point access. *[Image 3]*

For these situations, additional chemical additives, such as saponifiers and surfactants, can be used to assist in removing hard to clean residues. These additives are used in all style of cleaners such as in-line, batch style, and stencil cleaners.

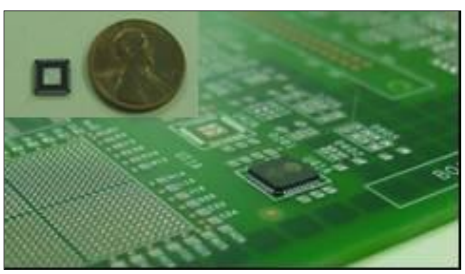


Figure 1: Leadless Package on PCB

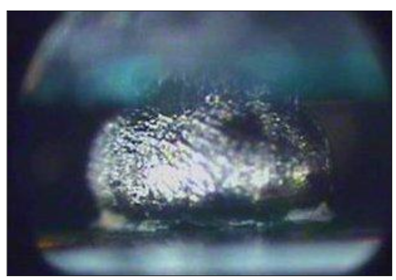


Figure 2: Residue under Solder Sphere

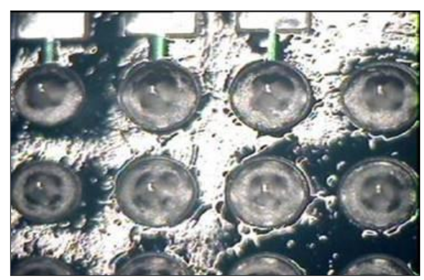


Figure 3: Rosin Wave Flux Residue

Cleaning Agents
The removal of solder paste and flux residues can be enhanced through the addition of specialized cleaning agents. Cleaning agents are generally classified in two formats: saponifiers and surfactants. The use of saponifiers and surfactants is commonplace in PCBA, misprinted PCB and stencil cleaning processes. Saponifiers are alkaline chemistries (high pH) that combine with residues and react producing a water-soluble soap. This soap solution suspends the residues enabling it to be flushed away from the surface with high purity water. Surfactants, also called detergents reduce the surface tension of the liquid medium into which it is dissolved (typically water). This allows the solution to flow into and access areas that would otherwise be too small for the water to penetrate allowing contaminates and residues to be flushed away. Materials that assist in the release of residues from the surface of the PCB are frequently included in surfactants to further aid in the cleaning process.

Selecting a Saponifier or Surfactant
Selecting the best cleaning agent greatly depends on the target residues, application and equipment set. Engineers need to be aware that not all chemical additives can be used with all cleaning processes, meet operational cost targets, or comply with local environmental regulations. In February 2007, IPC released the 'Stencil and Misprinted Board Cleaning Handbook', IPC-7526. The IPC-7526 handbook in conjunction with IPC-CH-65A, 'Guidelines for Cleaning of Printed Boards and Assemblies' provides the necessary foundation for the development or deployment of a cleaning process including a review

of the process variables, equipment sets and chemistries. The contents of this paper will focus on additional or unique selection criteria and evaluation methodologies used to evaluate cleaning agents for the misprinted PCB and assembled PCBA cleaning process.

Cleaning Agent Evaluation Process

Initially a literature search, survey of factories, suppliers, customers, and users narrowed the list of perspective cleaning agents to evaluate. Factors such as cost of acquisition, cost of ownership / use, supplier technical support capability, and product global availability were considered. The factory survey was used to collect information from operations in an effort to better understand the current and future cleaning requirements and equipment sets and solder flux residues identified or targeted for cleaning. Once the field of candidates was narrowed, a series of tests and application studies were conducted to determine the finalist.

The identification of target residues likely to be cleaned is a critical step in the evaluation of cleaning agents. Most manufacturers provide a list of target chemistries and residues that their cleaning agents can remove. Not all chemistries clean all residues and some chemistries are specially formulated to perform in cleaning machine configurations. The chemistry should also be evaluated for environmental impact. Some chemistries and residues can destroy resin tanks used to recycle deionized water and some equipment is configured to drain waste water (along with the expensive chemistries) directly to drain. Many cleaning agents are not pH neutral (alkaline or acidic) and wastestreams sent to drain may have to be treated to comply with local regulations or internal environmental policies. The pH level will also influence operational costs. Typically, if a neutral pH value additive is selected, it will require higher levels of concentration and longer wash cycle times. Another pH consideration involves the cleaning application. During the course of our investigation it was identified that cleaning agents with higher pH values (more alkaline) [pH value of 10 @ 10% concentration] will tarnish stencil frames and weaken the mesh attaching the aluminum frame to the stencil. It was also identified that lower pH values (acidic) do not attack the frame or the mesh, but will not remove all residues from PCBAs when used to remove reflowed solder residues at lower concentration levels.

Surface Insulation Resistance, Electromigration, Halides and Corrosion

After selecting the cleaning additives to test it is reasonable to ask for data on or conduct Surface Insulation Resistance (SIR), Electromigration, Halides and Copper Corrosion tests based on IPC and Telcordia protocols for each chemistry. These tests are not required by either IPC or Telcordia for process chemistries. However, a number of OEMs require this data set to demonstrate that the cleaning agent will not degrade the insulation between pads, encourage the growth of metal between traces, cause intermetallic growth or have corrosive properties, respectively. In the event that any of the candidate chemistries fail any one of these tests, it was removed from further evaluation.

Industrial Test Methods Used:

- IPC-TM-650 Section 2.6.3.3 "Surface Insulation Resistance, Fluxes,"
- Surface Insulation Resistance per Telcordia (formally Bellcore) GR-78-CORE
- Electromigration per Telcordia (formally Bellcore) GR-78-CORE
- IPC-TM-650, Section 2.3.33D, Presence of Halides in Flux, Silver Chromate Method
- IPC-TM-2.3.32 "Flux Induced Corrosion (Copper Mirror Method)
- Ion Chromatography on different concentrations of the chemistry

The IPC test methods have been developed to assess the possible negative impact solder fluxes may have on a PCB. IPC does not have a test method defined to test cleaning agents. The authors modified the test methods to simulate likely scenarios in manufacturing. For example, two different preparation methods were used for SIR and Electromigration test coupons. Coupons were coated with a 100% concentration of the cleaning agent and then air dried without rinsing. This simulates a worse case condition where a rinse cycle was not used. Coupons were also prepared by being run through the actual manufacturing cleaning process using a 25% concentration solution of the cleaning agent and rinse cycle. Both sets of coupons were tested using the required sample size and controls. All chemistries tested passed the IPC & Telcordia test standards using both methods. No significant differences were noted between or within the test results.

The method of preparing the samples for the halide test was slightly modified for use with cleaning agents. A 25% by volume concentration of chemistry in 17.5 meg-ohm deionized water. Two drops of solution placed on separate locations on a pre-cleaned copper mirror substrate. The substrate had been precleaned with a 5 gram per liter solution of EDTA in deionized water, rinsed with deionized water, rinsed with methanol, then forced air dried. A mixture of 35 grams of rosin in isopropyl alcohol was also prepared as a control solution. One drop of this solution was placed at the opposite end of the substrate. All the substrates were placed in a temperature and humidity chamber at 50% RH and 23 deg C for 24 hours. The test results indicated that the candidate chemistries passed with one exception. Ion chromatography was then used to evaluate mixtures of 5, 15, and 25% by volume of each chemistry in deionized water for the presence of a halide or other anionic contaminant. Based on these results it suspected that this false failure was the result of the inclusion of propriety ingredients or formulations that emulated the presence of halides. The supplier confirmed this to be the case.

Misprinted PCB and Stencil Cleaning Evaluation

Correct solder paste registration and volume is the foundation for reliable solder interconnects. As PCB densities, component counts, and the use of solder volume sensitive devices increase assemblers have deployed 3-D automated paste inspection (API) tools. It is widely accepted that the proper use of API within the SMT process results in an improvement in solder joint quality and interconnect reliability. However, because the automated inspection process is much more accurate than visual inspection alone, it also has the potential to increase the reject and misprinted card cleaning rates within a factory. Typically misprinted PCBs rejected from the SMT process are cleaned using manual wiping methods either at the SMT line or over a rinse sink using lint-free cloths and isopropyl alcohol (IPA). Wiping away excess solder by hand is an unreliable and inconsistent process. The IPA will breakdown most no-clean flux systems which releases ionics that can spread into vias and onto the other side of the PCB surface. Even the most diligent technician will not be able to wipe away all of the fine solder beads suspended solder paste using a manual operation. *[Image 6]* The wiping action also has the potential to smear excess solder paste across the surface of the PCB trapping solder into the edges of solder mask and forcing paste into PTH barrels and vias. [Image 4&5] Aggressive action with plastic spatulas or scrapers can damage solder mask and fine features on the PCB surface.

Figure 4: Smeared Solder Paste in Vias

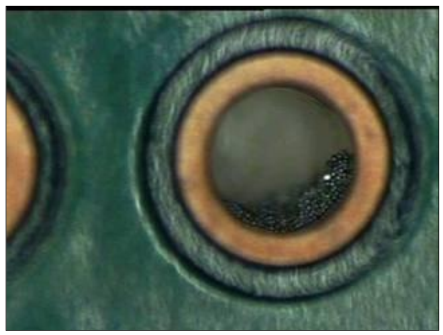


Figure 5: Solder trapped in PTH Via

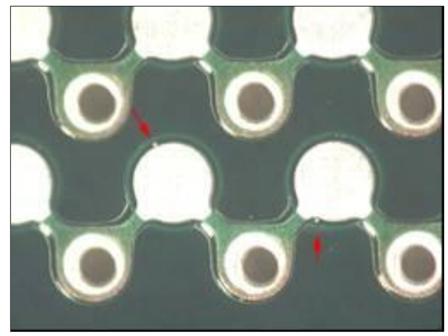


Figure 6: Solder Beads Trapped in Mask

Another factor to consider is that a PCB is most likely to be rejected for a misprint during the application of solder paste to the primary or topside surface. The primary side of the PCB typically contains the majority of the surface mount pads providing a higher opportunity for a misprint condition. When a misprint occurs on the primary side, the secondary or bottomside has already been assembled through the reflow process. This provides another challenge during the selection of a PCB misprint cleaning agent. The cleaning process will not only have to remove wet solder paste and flux from the misprinted side, it will also have to be capable of removing the hardened residues from reflowed materials on the secondary side. It is also possible that the secondary side encountered manual rework or touch-up using another series of solder chemistries including rework flux and cored wire. The industry refers to this a 'B-side' PCB cleaning. For these reasons the complete removal of wet paste and flux residues is best accomplished through the use of an automated cleaning process.

The factory survey identified common equipment configurations and processing parameters for the cleaning of misprinted PCBs. Most factories used a spray in air stencil cleaner to reclaim misprinted PCBs. For this reason this evaluation focused on spray in air stencil and misprint PCB cleaning using a chemistry capable cabinet style cleaner. A number of factories also identified the need to clean misprinted or incorrectly dispensed surface mount adhesives as well as the various combinations of tin lead and lead free solder pastes from PCBs and stencils. A series of designed experiments were performed evaluating the effectiveness of cleaning agents removing target residues from stencils (wet solder paste), misprinted PCBs (wet solder paste & SMT adhesive) and the populated backside of misprinted PCBs (reflowed & reworked solder). Combinations of target residues are listed in table 10 in the appendix section of this paper.

Stencil Cleaning DOE

A design of experiment (DOE) was used to compare the effectiveness of the cleaning agents to clean the various target residues from SMT stencils. The following variables were considered:

- *Target Residues* – Within major EMS companies it is not uncommon to find multiple solder paste chemistries within a single factory or building. Surface mount lines are flexed to maximize utilization and operational effectiveness. Consequently a single stencil cleaner and chemistry must be capable of cleaning all versions of solder paste including tin lead, lead-free, no-clean and water soluble. The topic of lead from the tin-lead stencils contaminating the wash system or lead-free product has been previously published and was not be explored in this DOE. [3] All solder pastes tested used type 3 powder size. [3]

- *Chemistry Concentration Level* – The cost of implementing a cleaning agent will increase as the concentration levels or depletion rates increase. The objective is to select an additive that will achieve the desired cleanliness results with the lowest concentration level, acquisition cost and depletion rate. (10%-25%)
- *Water Temperature* – Cleaning agents have predetermined operating temperature ranges that should be explored to understand where the temperatures are most effective. (70°F-150°F)
- *Cycle Time* – Cleaning results are improved by extending the wash cycle exposing the stencil to the chemistry and the mechanical impingement action of the water spray. However extended cleaning cycles can increase operational costs and time delays for operations.
- *Time Delays* – Cleaning agents should have the capability to remove wet and dried solder paste from difficult to clean apertures over a time delay. Time delays tested included 0, 2 and 4hrs to simulate delays in manufacturing. (75°F & 45%R.H.)
- *Stencil Design & Technology* – The stencils used during the testing should be representative of the materials and apertures that are likely to be used in production. Small apertures such as those for CSPs, QFNs, BGAs, and fine pitch QFPs.

Stencil cleanliness is typically assessed using un-assisted visual inspection targeting solders residues and flux residues. The results of this DOE were assessed using 40 x magnification using an aperture cleaning requirement of 95% to 100% clear. The combination of lead-free no-clean solder pastes in small apertures over a long time delay (4hrs) provided the greatest cleaning challenge. The cleaning cycle times and chemistry concentration levels has to be increased to a level between 15% and 20% by volume. In general it was observed that the tin-lead chemistries were less sensitive to the time delay.

Misprinted PCB Cleaning DOE

The results of the stencil cleaning DOE defined the starting point for the misprinted PCB DOE. Water temperature and wash cycle times were intentionally not altered in response to operational and energy cost pressures. Only the chemistry concentration level and process cycle times were altered. The same aperture & solder paste locations were evaluated under 40 x magnification after PCB misprinting with the target solder materials after a 0, 2 and 4hr time delay before cleaning. Two test vehicles were used. The first test vehicle (TV-1) was a singled sided PCB (3"x5"x0.063") developed for lead-free factory qualifications. *[Table 1]* The second test vehicle (TV-2) was a doubled sided PCB (5"x8"x0.063") intended to simulate B-side cleaning. *[Table 6]* Both test vehicles were tested with high temperature OSP and immersion silver surface finish. The immersion silver finish coated boards were used to assess ionic residues and the OSP boards were used to assess the % removal of finish after PCB cleaning. The evaluation of the impact of a cleaning agent on OSP survivability is an important aspect of the misprinted PCB evaluation process. The erosion of the protective finish by the cleaning agent or flux residues can influence the performance of downstream soldering operations; especially lead-free PTH wave soldering. This work will be explored further in future publications.

The test vehicle boards were screened with various solder paste chemistries and submitted to the stencil cleaning after set time intervals (0hrs, 2hrs and 4hrs). Cleanliness was assessed using visual inspection under 40x magnification. Residual ionic residues were measured using the ionigraph and ion chromatography (IC) analysis. The ionigraph solution was a room temperature mixture of 73% isopropyl alcohol and 27% deionized water. Following the manufacturers operating instructions, the samples were assessed after cleaning. A failure limit was set at a sodium chloride equivalent reading of 6.4 ug/in2. The IC analysis was performed using a local extraction technique. Seven locations per PCB were extracted; five by placing water directly on the pads and two by injecting water under a component. Extractions were performed with one milliliter portions of 80-85 deg C 17.5 meg-ohm deionized water. The contact time of the water on the board was five minutes. A Dionex DX-120 Chromatograph fitted with IonPac AS-14 columns and conductivity detection was used in the analysis. The concentration of each anion was determined and the total weight of the anion was calculated in micrograms. As of yet, IPC does not specify maximum limits for anions measured by ion chromatography. However, it is known that chloride ion and bromide ion should be controlled to less than 5.0 ug/in2 and 7.0 ug/in2 and Sulfate ion should be controlled to less than 3.0 ug/in2. Internal data has indicated that Nitrate ion under 1.0 ug/in2 is not a problem. IC measurements were taken from PCBs with immersion silver surface finish.

The misprinted PCB DOE results indicated that a stencil and misprinted PCB cleaning process using 25% concentration of a pH neutral, recoverable surfactant cleaning agent and deionized water solution at 78°F provided the best performance with the lowest total cost of operation and environmental impact. The spray in air cleaning cycle time (wash/rinse/dry) was 21 minutes with a wash time was about 8.4 minutes. Optimal results will be dependent on the target residues, the equipment and chemistries used. [1,3]

Table 1: Misprinted PCB Cleaning Test Vehicle (TV-1)

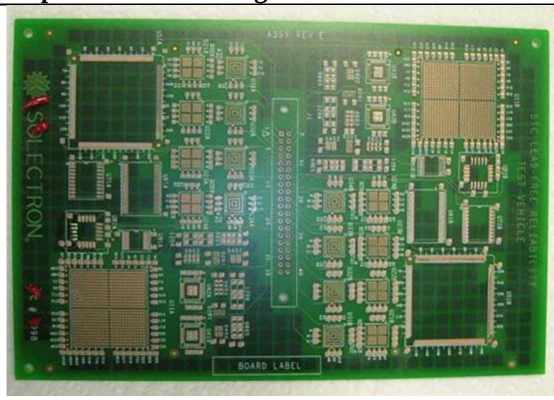
	Misprint PCB Cleaning Test Vehicles	Description of Testing
Test Vehicle 1 (TV-1)	 **Single Sided SMT PCB**	Processing: • Misprinted Solder Paste • Wet SMT Adhesive • B-side Cleaning – Non-pop Reflowed Residues Non-pop ○ Paste ○ Flux ○ Cored Wire Assessment: • Visual Inspection 40x • Ionigraph measurements • Ion Chromatography

Table 2: Misprint PCB & 'B'-Side Cleaning Test Results (SnPb Water Soluble)

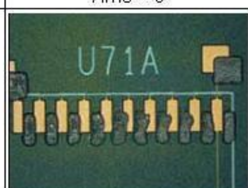
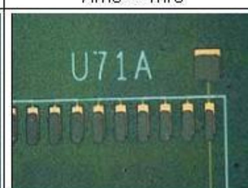
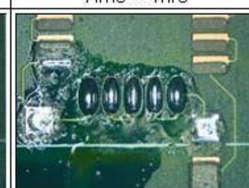
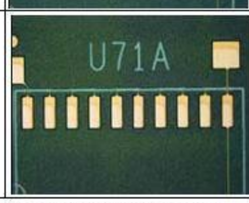
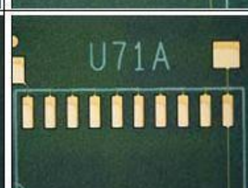
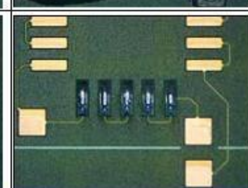
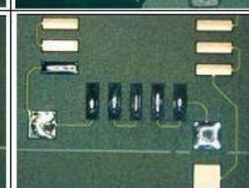
<table>
<tr><th colspan="5">Tin Lead Water Soluble Chemistry Set</th></tr>
<tr><td rowspan="2"></td><td colspan="2">Wet Solder Paste</td><td colspan="2">Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire</td></tr>
<tr><td>Time = 0</td><td>Time = 4hrs</td><td>Time = 0</td><td>Time = 4hrs</td></tr>
<tr><td>Before Cleaning</td><td></td><td></td><td></td><td></td></tr>
<tr><td>After Cleaning</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Ion Chromatography Test Results:
(2 boards tested per combination)
Internal IC Thresholds:
- Organic Acids < 25.0 μg/in²
- Chloride Ion < 5.0 μg/in²
- Sulfate Ion < 3.0 μg/in²</td><td>Weak Organic Acid
[μg/in² equivalent]</td><td></td><td>9.61 / 10.3</td><td>8.28 / 10.51</td></tr>
<tr><td>Chloride
[μg/in² equivalent]</td><td></td><td>0.00 / 0.00</td><td>0.00 / 0.00</td></tr>
<tr><td>Sulfate
[μg/in² equivalent]</td><td></td><td>1.90 / 1.74</td><td>1.33 / 1.72</td></tr>
</table>

Table 3: Misprint PCB & 'B'-side Cleaning Test Results (Lead-free Water Soluble)

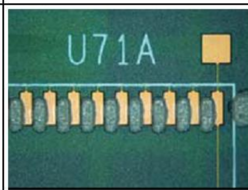
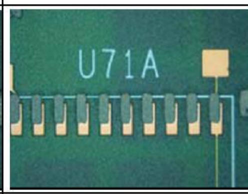
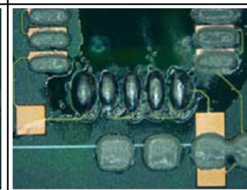
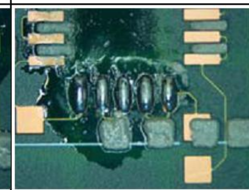
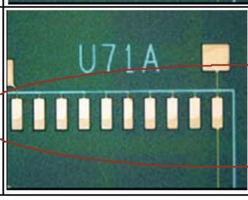
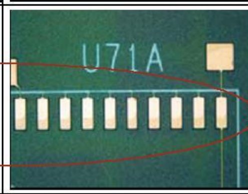
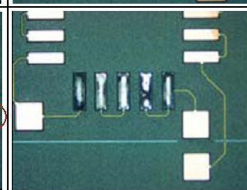
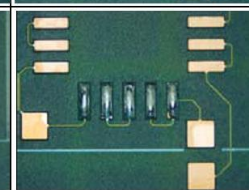
RoHS Compliant Water Soluble Chemistry Set				
	Wet Solder Paste		Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire	
	Time = 0	*Time = 4hrs*	*Time = 0*	*Time = 4hrs*
Before Cleaning				
After Cleaning				
Ion Chromatography Test Results: (2 boards tested per combination) <u>*Internal IC Thresholds:*</u> *- Organic Acids < 25.0 µg/in^2* *- Chloride Ion < 5.0 µg/in^2* *- Sulfate Ion < 3.0 µg/in^2*	**Weak Organic Acid** *[µg/in^2 equivalent]*		9.54 / 8.98	5.55 / 7.43
	Chloride *[µg/in^2 equivalent]*		0.04 / 0.11	0.00 / 0.04
	Sulfate *[µg/in^2 equivalent]*		1.90 / 1.99	1.12 / 1.47

Table 4: Misprint PCB & 'B'-Side Cleaning Test Results (SnPb No-Clean)

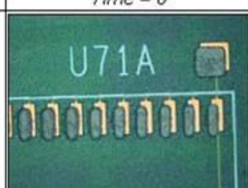
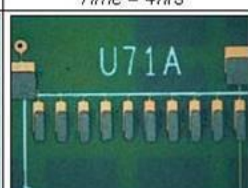
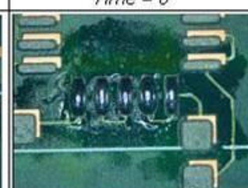
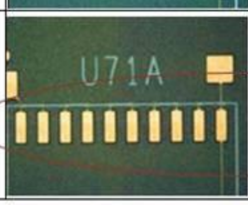
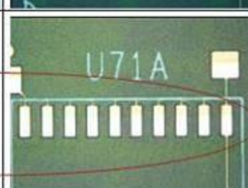
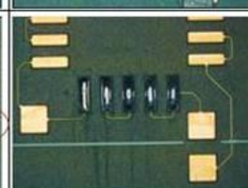
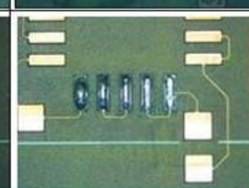
Tin Lead No-Clean Chemistry Set				
	Wet Solder Paste		Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire	
	Time = 0	*Time = 4hrs*	*Time = 0*	*Time = 4hrs*
Before Cleaning				
After Cleaning				
Ion Chromatography Test Results: (2 boards tested per combination) <u>*Internal IC Thresholds:*</u> *- Organic Acids < 25.0 µg/in^2* *- Chloride Ion < 5.0 µg/in^2* *- Sulfate Ion < 3.0 µg/in^2*	**Weak Organic Acid** *[µg/in^2 equivalent]*		9.53 / 9.37	8.58 / 8.63
	Chloride *[µg/in^2 equivalent]*		0.03 / 0.00	0.00 / 0.00
	Sulfate *[µg/in^2 equivalent]*		1.99 / 1.80	1.84 / 1.73

Table 5: Misprint PCB & 'B'-Side Cleaning Test Results (Lead-free No-Clean)

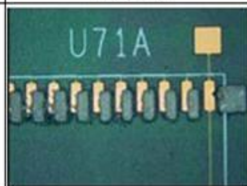
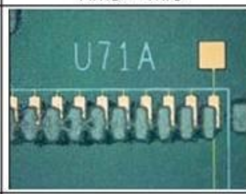
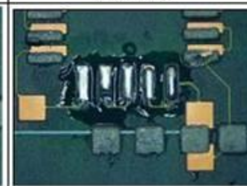
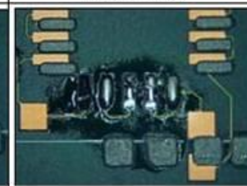
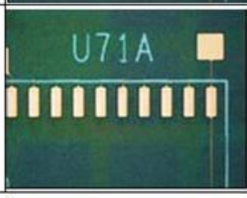
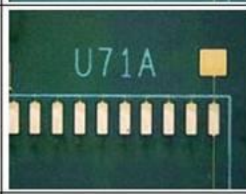
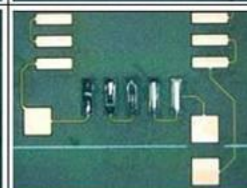
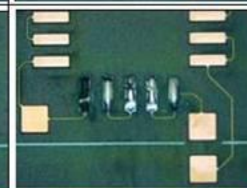
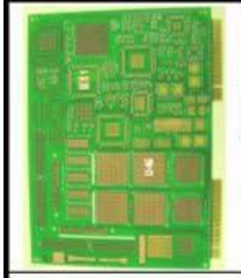
RoHS Compliant No-Clean Chemistry Set				
	Wet Solder Paste		Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire	
	Time = 0	*Time = 4hrs*	*Time = 0*	*Time = 4hrs*
Before Cleaning				
After Cleaning				
Ion Chromatography Test Results: (2 boards tested per combination)		**Weak Organic Acid** *[µg/in² equivalent]*	10.55 / 10.05	7.28 / 6.69
Internal IC Thresholds: - *Organic Acids < 25.0 µg/in²*		**Chloride** *[µg/in² equivalent]*	0.12 / 0.76	0.07 / 0.00
- *Chloride Ion < 5.0 µg/in²* - *Sulfate Ion < 3.0 µg/in²*		**Sulfate** *[µg/in² equivalent]*	1.51 / 1.91	1.22 / 1.93

Table 6: Misprinted PCB Cleaning Test Vehicle (TV-2)

	Misprint PCB & B-side Cleaning Test Vehicle	Description of Testing
Test Vehicle 2 (TV-2)	 **Double sided SMT PCB**	<u>Processing:</u> • Misprinted Solder Paste • B-side Cleaning – Populated & B-side Cleaning – Non-pop Reflowed Residues ○ Paste ○ Flux ○ Cored Wire <u>Assessment:</u> • Visual Inspection 40x • Ionigraph measurements • Ion Chromatography

Table 7: Misprinted PCB ‘B’-Side Ion Chromatography Results

	Location	Device Placed?	Chloride (ug/in^2)	Bromide (ug/in^2)	Nitrate (ug/in^2)	Sulfate (ug/in^2)	Extracted Area (in^2)	Results
	U4 - top side QFP208SQ-20 mil	Yes	0.38	< 0.10	0.16	1.31	1.56	PASS
	U6 - top side QFP256SQ -16mil	Yes	0.42	0.13	0.14	1.52	1.56	PASS
	U8 - top side QFP168SQ -12mil	No	0.23	< 0.10	< 0.10	0.52	0.563	PASS
	U11-bottom side PLCC84SQ	No	< 0.10	< 0.10	< 0.10	0.26	1.56	PASS
	U43-top side PBGA	No	0.24	1.04	0.10	1.15	1.00	PASS
	U45-bottom side CBGA	No	0.26	1.28	0.10	1.15	1.00	PASS
	U49-top side QFP256SQ-16mil	No	0.12	< 0.10	< 0.10	0.38	1.56	PASS
Established IC Limits: *Chloride Ion < 5.0 ug/in2, Bromide Ion < 7.0 ug/ in2, Nitrate Ion < 1.0 ug/ in2, Sulfate Ion < 3.0 ug/ in2*								

PCBA in-line cleaning evaluation

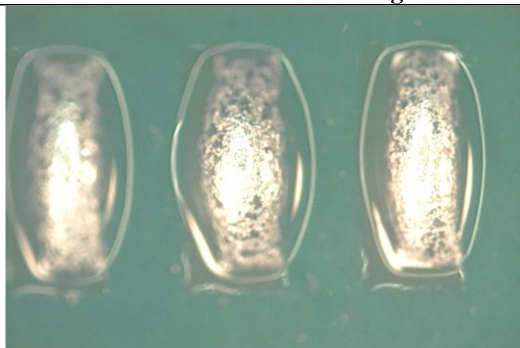
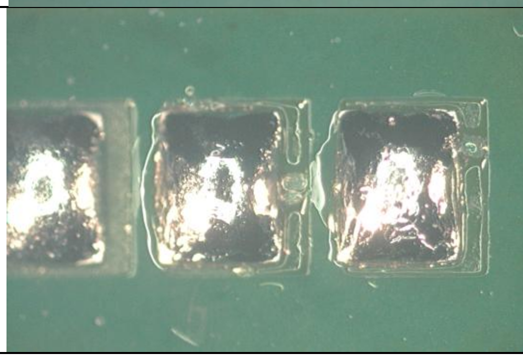
The evaluation process involved with the selection of a cleaning chemistry for in-line PCBA cleaning is very similar to that used during the misprinted PCB and B-side cleaning evaluation with the exception being that the cleaning process will not have to address wet solder paste and unactivated flux materials. The cleaning agent formulations for use with a contained in-line cleaning system are specially designed for that application. While it may be possible to use a single cleaning agent for both stencil / misprinted PCB cleaning and in-line PCBA cleaning, it is not likely to be cost effective. Stand-alone cabinet style stencil cleaners work differently than in-line wash systems. Although there are common elements such as spray nozzles and dryers it is the chemistry handling and recovery systems design differences that drives the need to use different cleaning agents.

The same series target residues were used during the in-line cleaner evaluation and the same series of IPC and Telcordia tests were performed with the candidate chemistries. The focus of this evaluation was to identify a cleaning agent for future use in response to the proliferation of the use of low stand off components with water soluble chemistry sets as well as prepare a process to clean no-clean residues including high % solids rosin based no-clean wave fluxes. Two test vehicles were used to evaluate process variables and cleaning agents. Test vehicle 1 (TV-1) was again used to measure cleanliness under QFN and CSP low stand-off devices. A separate study was conducted to evaluate the cleaning agents’ capability to clean no-clean PTH wave solder flux residues. The evaluation was replicated on two in-line cleaners, one polymer based cleaner with a on-board chemical isolation chamber and one stand-alone chemical wash chamber followed by a multi-zone high pressure stainless-steel DI cleaner. The latter configuration was included to address the possibility of a high mix; low volume factory that may need to run both DI water cleaning and chemistry assisted cleaning in the same facility. Immediately it was obvious that wash machine set-up and configuration has a significant influence over cleaning effectiveness and cost of operation. Performing a cleaning evaluation without directly involving technical experts from the chemistry provider, equipment manufacturer and production engineering is a mistake to avoid.

Beaker Test

After passing the IPC & Telcordia tests, a simple laboratory beaker evaluation was performed on the target residues for each of the PCBA cleaning agents evaluated. Although this test will not provide the same degree of agitation and mechanical cleaning action found within an inline cleaner, it did provide a cost effective means to evaluate the performance of chemistries in a laboratory environment. Changing between cleaning or defluxing agents is a costly and time consuming proposition, the beaker test described was also used to help define the concentration levels for the PCBA cleaning DOE. The concentration level recommended by the cleaning agent manufacturer was mixed into a solution with deionized water. A total volume of 400 ml of each solution was placed in a 600 ml glass beaker fitted with magnetic stirring. The defluxer solution was equilibrated at 40 deg C while the solution was gently stirred. A simple SMT coupon processed with the target residues and suspended in the agitated solution for 90 seconds and then rinsed in deionized water. The amount of flux removed was evaluated under visual inspection. The lead free no clean solder paste and rosin based wave fluxes represented the worst-case cleaning situation and were used to initially compare the effectiveness of cleaning solution. Sample results are depicted below *[Table 8]*. The lead-free no-clean reflowed solder paste clearly represented the greatest defluxing challenge and is explored further based on the results of additional designed experiments.

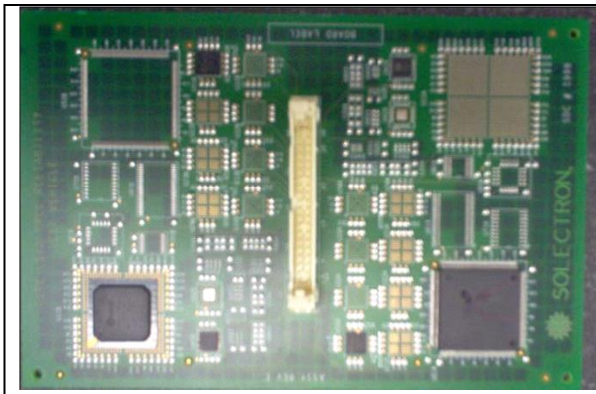
Table 8: Example of No-Clean residues after 'beaker' testing

	Residues Before 'Beaker' Cleaning	Residues After 'Beaker' Cleaning
Lead-free No-Clean Solder Paste (Reflowed)		
Lead-free No-Clean Wave Flux		

Reflowed lead-free no-clean solder paste residues represent a special cleaning challenge for a number of reasons. First, the residues were intended to exist in a process where cleaning was not required. The flux system becomes hard and difficult to remove by design. Second, partial removal of no-clean flux (as shown in the beaker samples) can leave behind acids and other ionic residues on the surface of the PCB. The beaker test results clearly indicated that defluxing reflowed solder paste flux residue depends on solution agitation, mechanical impingement force (spray) as well as the chemical reaction of a cleaning agent. Understanding these limitations, the DOE focused on the defluxing of no-clean lead-free low stand-off and low profile devices. Test Vehicle 1 (TV-1) *[Table 1]* was populated and sent through various combinations of inline cleaning processes and chemistries (surfactants). To minimize the impact to production, much of this work was completed offsite in collaboration with the equipment and cleaning chemistry supply base. Equipment settings (water temperature, pressure, belt speed, etc...) were set within a range used for in-line deionized water cleaning. Only the defluxing agent and concentration level (10%, 15%, 20%) was changed. In-line cleaner settings: Belt Speed: 2ft/min, Water Pressure for Pre Wash and Wash Section: (Top/Bottom) 60/50 PSI, Chemical Isolation: (Top/Bottom) 18/13 PSI, Rinse: (Top/Bottom) 120/20 PSI, Final Rinse: (Top/Bottom) 12/12 PSI, Water Temperature: 125°F.

Once again immersion silver finished test vehicles (TV-1) *[Table 1]* were assembled using the solder paste manufacturers reflow requirements without the use of a nitrogen atmosphere. The test vehicle was assembled with an assortment of SMT devices including a number of difficult to clean packages *[Table 9]*. Each board was assembled using solder paste and wave flux, and then certain components were repaired using liquid touch up flux, tacky flux, and solder core wire. Only similar chemistry sets were used, cross sampling between chemistry families was not performed. *[Table 10]* After SMT assembly & forced rework, the PCBAs were sealed with nitrogen into ESD vacuum bags and shipped to the equipment supplier location(s). All samples were cleaned within 5 days of reflow. Post-cleaned PCBAs were once again sealed in new ESD bags and shipped back to an internal analytical laboratory for examination using the ion chromatography test methods as described in IPC-TM-650 Section 2.3.28 using a solution of deionized water and 10% isopropyl alcohol as well as IPC610D class II visual cleanliness standards. Pass/Fail criteria was defined according to internal limits of weak organic acids, chloride, bromide, nitrate, nitrite, sulfate and phosphate ions identical to those used during the misprinted PCB cleaning DOE.

Table 9: PCBA Cleaning DOE – Populated SMT Components



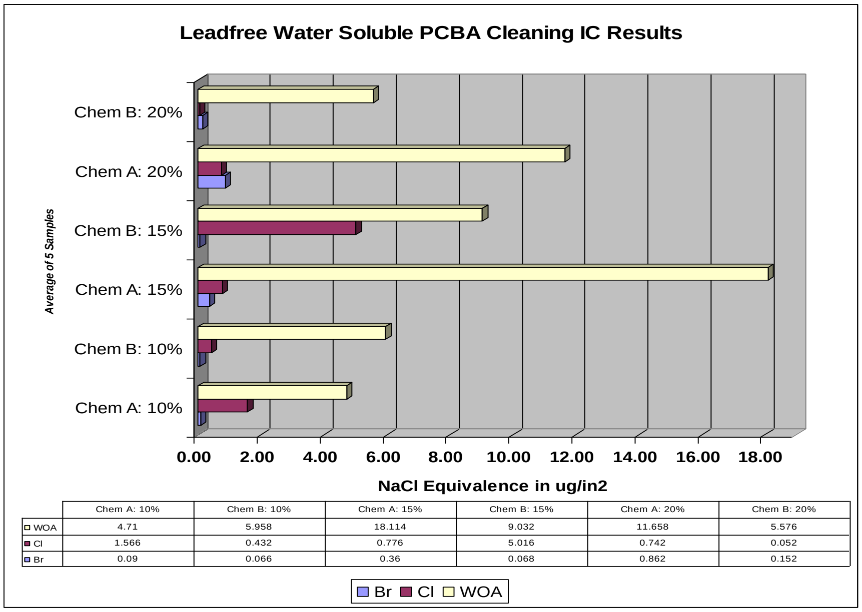
PCBA Cleaning DOE – SMT Components Tested			
Component Type	**Component Length**	**Component Width**	**Lead / Pad Pitch**
PBGA	0.91mm	0.91mm	1.27mm
QFN 44	0.26mm	0.26mm	0.5mm
CSP 84	0.31mm	0.31mm	0.8mm
QFP 256	1.28mm	1.28mm	0.020”
CSP 64	0.28mm	0.28mm	0.5mm

Table 10: Process Chemistry Combinations Evaluated for PCB & PCBA Cleaning

Combinations of Process Chemistries Tested (WS) = Water Soluble (NC) = No Clean (SnPb) = Tin Lead (LF) = Lead-free		‘Wet’ Paste					Reflowed / Heated Paste & Flux									
		SnPb NC Paste	SnPb WS Paste	LF NC Paste	LF WS Paste	SMT Adhesive	SnPb NC Paste	SnPb WS Paste	LF NC Paste	LF WS Paste	NC Rework Flux	WS Rework Flux	NC Core Wire	WS Core Wire	NC Wave Flux	WS Wave Flux
‘Wet’ Paste	SnPb NC Paste	●														
	SnPb WS Paste		●													
	LF NC Paste			●												
	LF WS Paste				●											
	SMT Adhesive	●	●	●	●	●										
Reflowed / Heated Paste & Flux	SnPb NC Paste	◆					◆									
	SnPb WS Paste		◆					◆								
	LF NC Paste			◆					◆							
	LF WS Paste				◆					◆						
	NC Rework Flux	◆		◆			◆		◆		◆					
	WS Rework Flux		◆		◆			◆		◆		◆				
	NC Core Wire	◆		◆			◆		◆		◆		◆			
	WS Core Wire		◆		◆			◆		◆		◆		◆		
	NC Wave Flux						◆		◆		◆		◆		◆	
	WS Wave Flux							◆		◆		◆		◆		◆

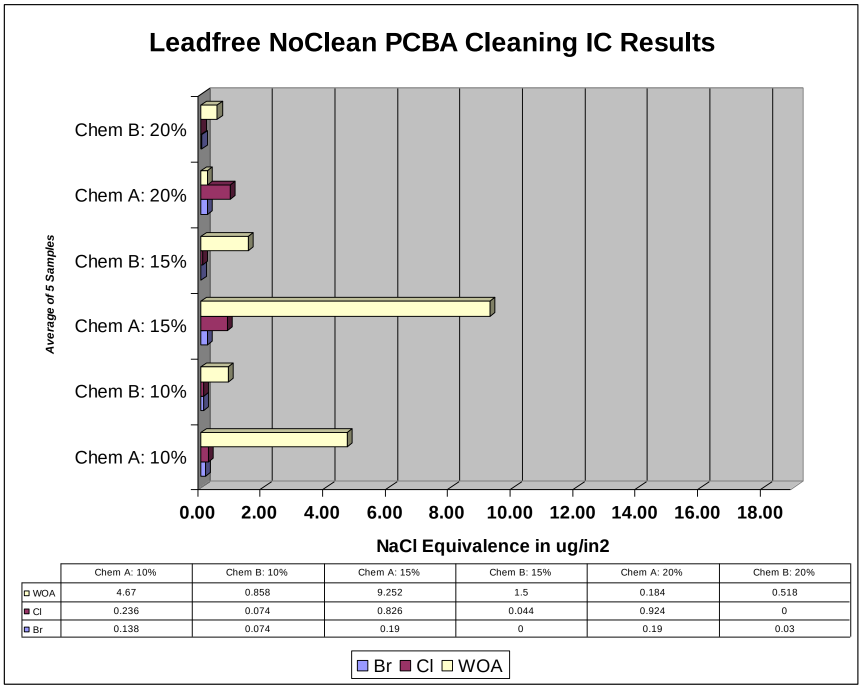
Color Key: ● Misprint PCB Cleaning ◆ PCBA & B-side Cleaning

The beaker test indicated that lead-free no-clean materials, specifically those under the low stand-off packages would be the most difficult to clean followed. The results of the IC analysis were surprising. The tin-lead chemistry sets and the lead-free no clean passed local IC extraction testing on all five SMT device locations for both cleaning agents at 15% or greater concentration levels. *[Figure 1]* The lead-free water soluble chemistry set failed the local IC testing for both chemistries at the 20% concentration level. *[Figure 2]* The lead-free water soluble solder paste used was a new formulation specially developed for a on-going solder paste evaluation. Additional studies were performed confirming that the solder paste had cleanability issues and the solder paste supplier was alerted. The product was removed from the solder paste evaluation and is not used in production. The results of the DOE identified that both cleaning chemistries provided acceptable results between 15% and 20% concentration levels. Final assessments were made based on total cost of ownership calculations [1]. Unfortunately it was not possible to economically use a single chemistry for both stencil, PCB and PCBA cleaning.



	Chem A: 10%	Chem B: 10%	Chem A: 15%	Chem B: 15%	Chem A: 20%	Chem B: 20%
WOA	4.71	5.958	18.114	9.032	11.658	5.576
Cl	1.566	0.432	0.776	5.016	0.742	0.052
Br	0.09	0.066	0.36	0.068	0.862	0.152

Figure 7: Ion Chromatography Results for the Lead Free Water Soluble Chemistry Set



	Chem A: 10%	Chem B: 10%	Chem A: 15%	Chem B: 15%	Chem A: 20%	Chem B: 20%
WOA	4.67	0.858	9.252	1.5	0.184	0.518
Cl	0.236	0.074	0.826	0.044	0.924	0
Br	0.138	0.074	0.19	0	0.19	0.03

Figure 8: Ion Chromatography Results for the Lead-free No-Clean Chemistry Set

Conclusion

Although there are a number of resources and guidelines to reference when initiating a cleaning process chemistry evaluation, it is important to listen to the needs of the customer and modify or define new tests to meet critical requirements such as cleaning no-clean or reliability. Using the available IPC cleaning reference documents (IPC-7526 & IPC-CH-65A) as a foundation it was possible to evaluate, compare and define processes using modern cleaning chemistries for the cleaning of misprinted PCBs, stencils and assembled PCBAs for tin-lead and lead-free products. Cleaning processes continue to be used by a number of products with low or no residue requirements in a variety of market segments and will drive the need for chemistry based cleaning well into the next generation of lead-free conversions.

Acknowledgments

The authors would like to thank the technical staff of the respective chemistry and equipment suppliers who provided critical materials and information on the nuances of PCBA cleaning. Considerable credit should be extended to the following Flextronics (Solectron) engineers who provided their expertise, time and energy into numerous technical reports supporting this paper including: Jenny Porter, Andres Turrbiates and George Oxx.

References

[1] Bixenman, M., Gervascio, T., and Lasky, R., "Using Six Sigma Techniques to Optimize Cleaning in Class III Electronics," Proceedings of SMTA International 2007.

[2] Lee, D., "A Comparative Analysis of Aqueous Based Cleaning Chemistries on High Reliability Electronic Assemblies," Proceedings of SMTA International 2007.

[3] Tosun, U., Afshari, S., Ellis, D., "Defluxing of Eutectic and Lead-free Assemblies in a Single Cleaning Process." Proceedings of SMTA International 2006.

[4] Forsythe, T., "Cleaning Issues Associated with Lead Free Soldering Materials Phase II", Proceedings of Pan Pacific Symposium 2006.

[5] Borgensen, P., Cotts, E., "Implantable Medical Electronics Assembly – Quality and Reliability Considerations," Proceedings from SMTA 2004 Medical Electronics Symposium.

[4] Bixenman, M., Ellis, D., Owens, S., "Lead-Free Soldering: DOE Study to Understand its Affect on Electronic Assembly Defluxing," Presented at IPC Printed Circuits Expo SMEMA Council APEX Designers Summit 2004.

METHODS FOR CHOOSING A SAPONIFIER OR SURFACTANT FOR PRINTED CIRCUIT BOARD AND STENCIL CLEANING APPLICATIONS

Aaron Unterborn, Ken Wilson & Charles Merz (ret.)

FLEXTRONICS

PCBA Cleaning Processes

Automated Stencil Cleaning

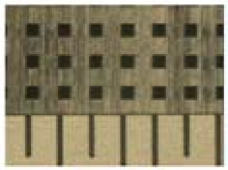


Figure 1. 1mm BGA, Alpha WS609

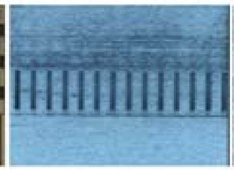


Figure 2. 20mil, Indium NC-SMQ92J


Figure 3. BGA, Kester HM531


Figure 4. 20mil, Alpha R520A

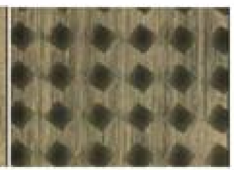
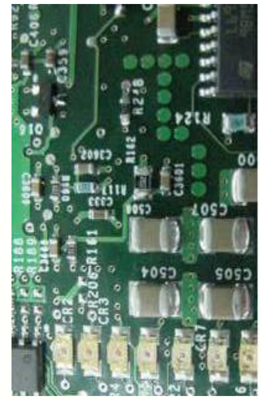
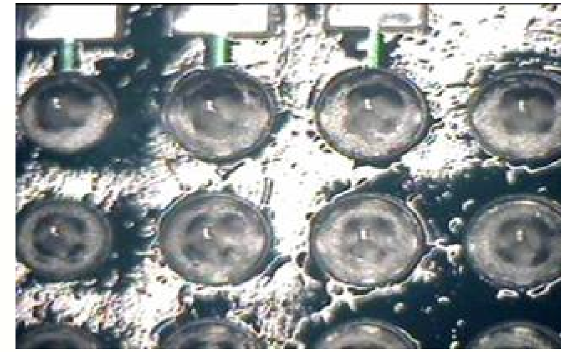


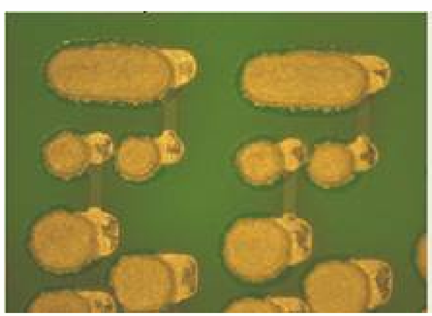
Figure 5. BGA, Senju GRN-360

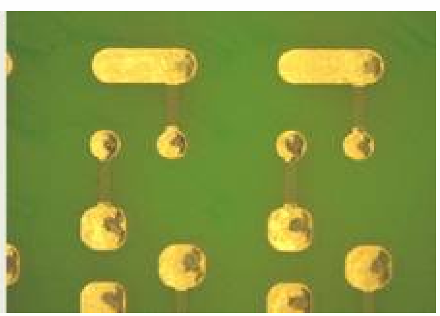
Assembled PCBA Cleaning





Mis-printed PCB Cleaning





Manual Post Rework Cleaning

Cleaning Agents

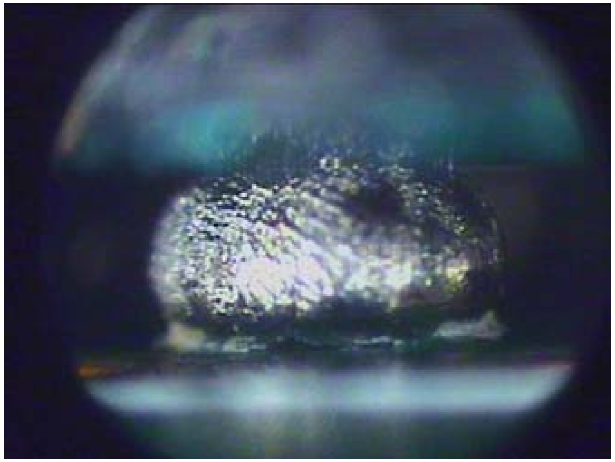
Basic Cleaning Agent Categories:

- **Saponifiers** are alkaline chemistries (high pH) that combine with residues and react producing a water-soluble soap. This soap solution suspends the residues enabling it to be flushed away from the surface with high purity water.
- **Surfactants**, also called detergents reduce the surface tension of the liquid medium into which it is dissolved (typically water). This allows the solution to flow into and access areas that would otherwise be too small for the water to penetrate allowing contaminates and residues to be flushed away. Materials that assist in the release of residues from the surface of the PCB are frequently included in surfactants to further aid in the cleaning process.

Traditional uses of cleaning agents during PCB assembly:

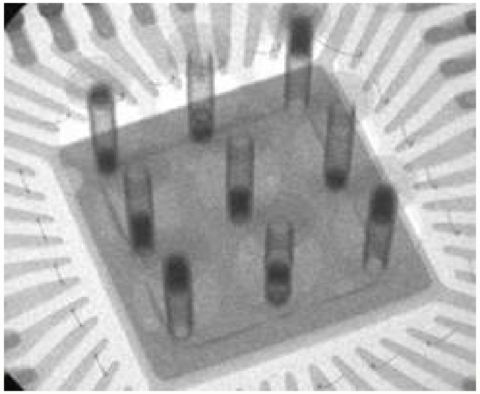
- Cleaning mis-printed PCBs and SMT stencils (offline)
- Cleaning products with special cleanliness requirements to meet market requirements or applications.
  (Aerospace, Medical, Automotive

Cleaning Challenges Facing the PCBA Industry

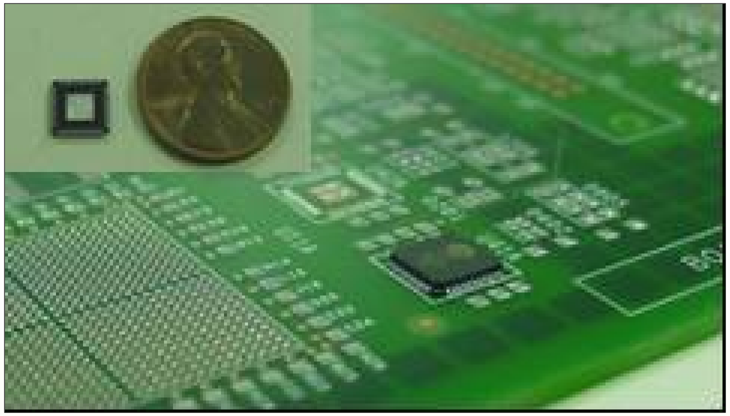


Lead-free Water Soluble Pastes

Lead-free Rosin Based Flux Residues (Cleaning of No-Clean)



Trapped Flux Residue in Open Vias



Low / No Standoff Devices

PCBA Cleaning Industrial References

- **IPC 610D Acceptability for Electronic Assemblies Section 10.4: 'Cleanliness'**
- **ANSI/IPC-CH-65A Guidelines for Cleaning of Printed Boards and Assemblies**
  - Generic PCBA cleaning / washing guidelines
- **IPC-7526 Stencil and Misprinted Board Cleaning Handbook**
  - Stencil & Misprint cleaning information
- **ANSI/IPC-AC-62A Post Solder Aqueous Cleaning Handbook**
  - Water wash guidelines
- **ANSI/IPC-SA-62A Post Solder Semiaquous Cleaning Handbook**
  - Water + Chemistry cleaning guidelines
- **ASTM D-19 Standard Guide for Electronic Grade Water**
  - Typically type E-III or E-II depending on line spacing.

Literature Samples

A sample of recent cleaning documents that also serve as paper references:

• Bixenman, M., Gervascio, T., and Lasky, R., "Using Six Sigma Techniques to Optimize Cleaning in Class III Electronics," Proceedings of SMTA International 2007.

• Lee, D., "A Comparative Analysis of Aqueous Based Cleaning Chemistries on High Reliability Electronic Assemblies," Proceedings of SMTA International 2007.

• Tosun, U., Afshari, S., Ellis, D., "Defluxing of Eutectic and Lead-free Assemblies in a Single Cleaning Process." Proceedings of SMTA International 2006.

• Forsythe, T., "Cleaning Issues Associated with Lead Free Soldering Materials Phase II", Proceedings of Pan Pacific Symposium 2006.

• Borgensen, P., Cotts, E., "Implantable Medical Electronics Assembly – Quality and Reliability Considerations," Proceedings from SMTA 2004 Medical Electronics Symposium.

Key Points: Considerations when Selecting Cleaning Agents

Cleaning Agent must have the Ability to Clean Target Residues
- Understand the various types of residue combinations (ie: pastes & fluxes)
- Wet paste, reflowed flux, rework wire, SMD adhesive

Cleaning Agent should be compatible with the Equipment Set
- Maintenance, Monitoring, Corrosion, Tarnish, pH levels (acidic or alkaline)
- Found that pH levels >10 @10% (alkaline) tarnished or damaged stencil frames

Cleaning Agent should not damage the DI Water Treatment System
- Observed Decreased DI filtration system life with some chemistries

Cleaning Agent should comply with Applicable Environmental Regulations
- Drain & sewage controls

Cleaning Agent should not pose a reliability concern - Product Compatibility
- Compatibility testing including SIR & EM
- Process sensitive components (solvent sensitive devices)

Internal:

Total Cost of Ownership Factors
- Supplier support, material costs, bath life, concentration level, etc

Cleaning Agent should be developed for the Cleaning Application
- Not all cleaning agents are designed for all processes & applications (TCO)
- Stencils, PCBs, B-side, In-line, Time Delay, Concentration levels, etc…

Evaluation of Cleaning Agents using a 6 step process

Phase 1: Stencil Cleaning

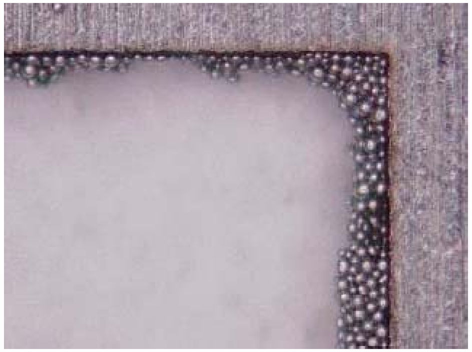
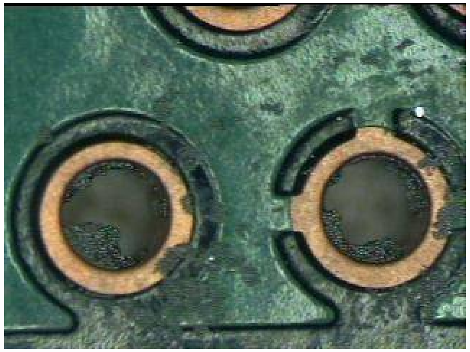
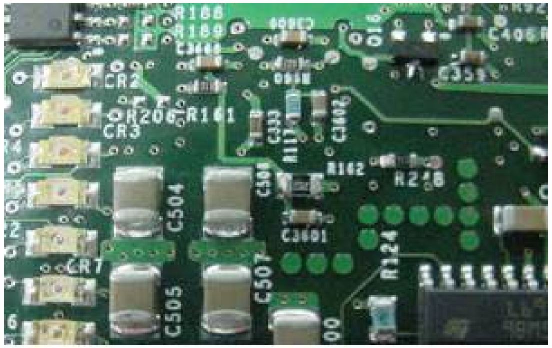
Phase 2: Misprinted PCB Cleaning

Phase 3: In-line PCBA Cleaning

1. Literature search (standards & papers)
2. Internal factory survey to understand current capabilities and technical requirements.
3. 'Paper' Evaluation of suppliers based on service, global footprint and total cost of ownership.
4. Laboratory tests.
5. Test Vehicle evaluations.
6. Validation in production.

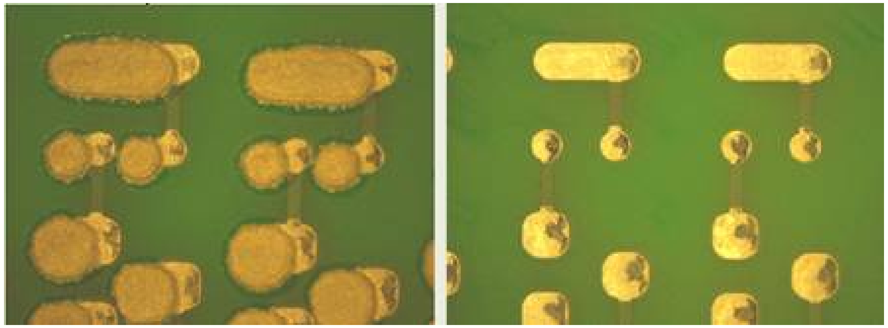
General Factory Survey Results

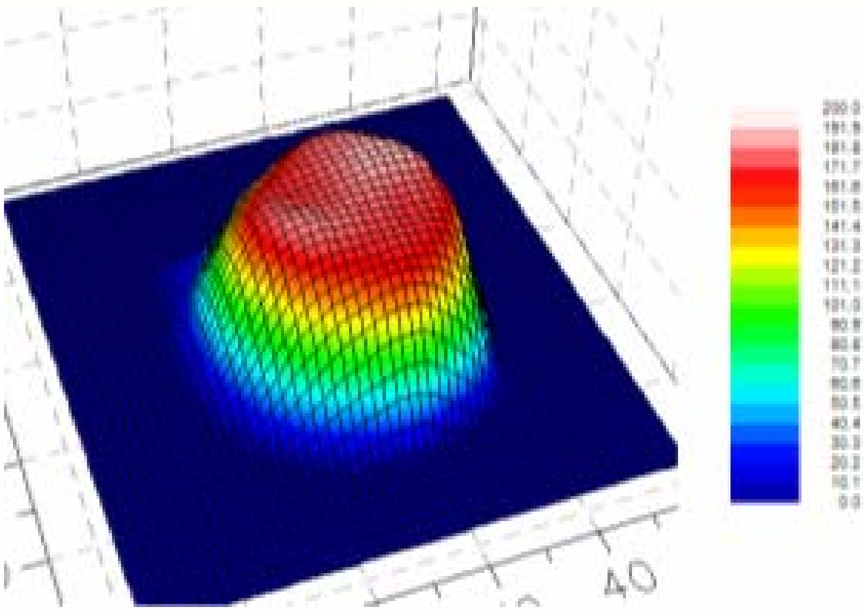
- Provided details on the current equipment set, setpoints, chemistry, applications and technical needs.

STENCIL CLEANINING	MISPRINTED PCB CLEANING	IN-LINE PCBA CLEANING
• On board or manual wiping used for in-line maintenance. • Off line cleaning performed by a cabinet style spray in air, immersion spray or ultrasonic cleaner	• Automated misprinted PCB cleaning is preferred. • Process typically uses a cabinet style spray in air or immersion spray process with DI water and chemistry.	• Majority of factories 100% no-clean. • Aqueous solder processes used for some infrastructure, server and ATE customers (still SnPb) • Stainless Steel & Poly Cleaners
		

Objective was to use existing / common process conditions

Example of Evaluation Process: Misprinted PCB Cleaning





A number of industry trends have placed pressure on the misprinted PCB cleaning process.

– Continued adoption of 100% solder paste inspection tools.

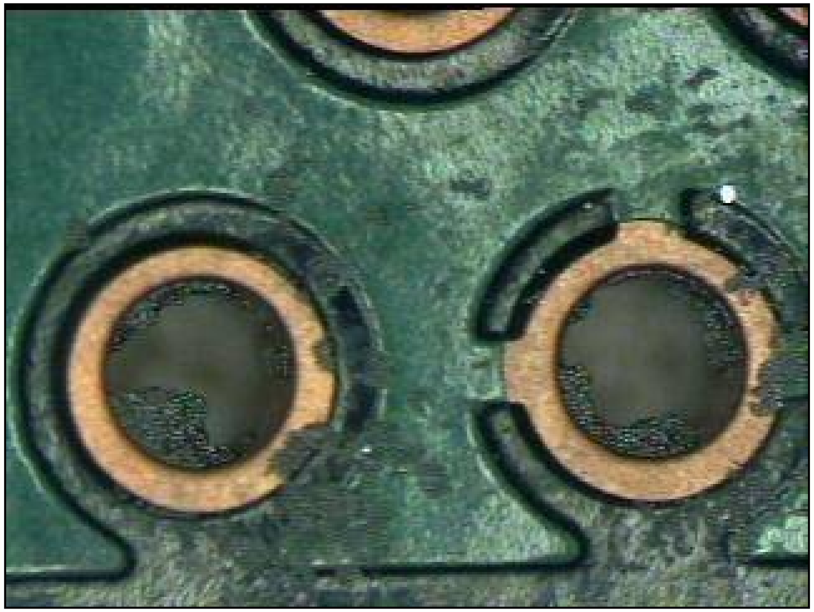
– Increasing PCB size & density.

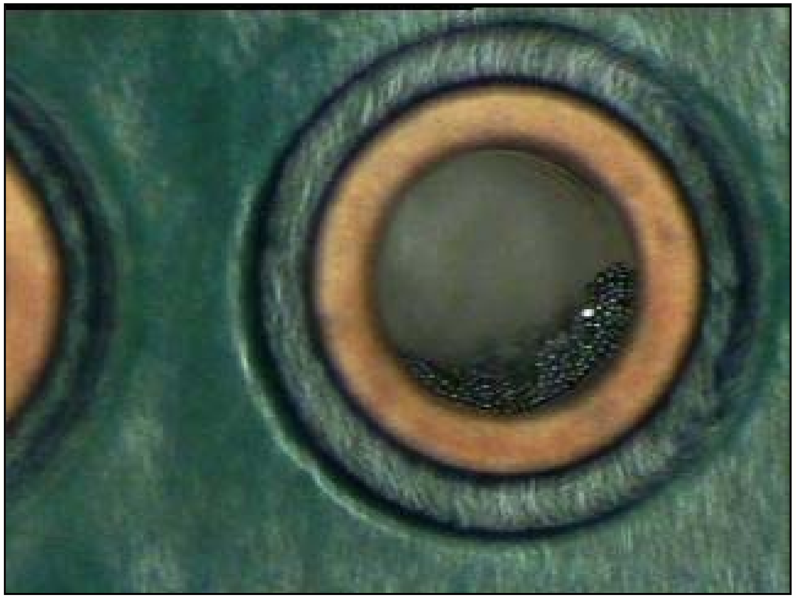
– Increase in area array body sizes & IO count.

– No / low standoff devices on the A-side of the PCB.

– Shrinkage of part to pad spacing.

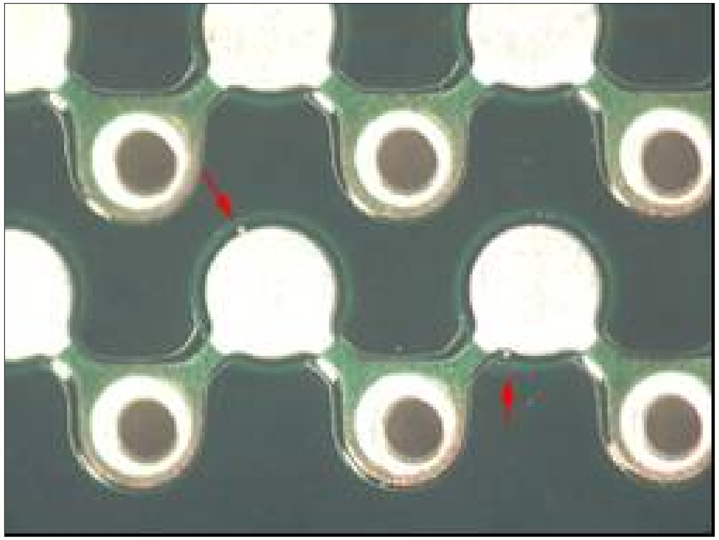
Solder fines in PTH holes after hand cleaning of misprint





Improper misprint cleaning cause solder balling, shorts or poor stencil gasketing.

The process should be automated and use chemistry that allows for the highest degree of flexibility



Evaluation Plan: Test Worse Case Conditions

Test for SIR & EM.

- In many cases the CM is responsible for the selection of assembly process materials.
- It is reasonable to test a cleaning chemistry designed to come into direct contact with PCBAs using modified version of IPC and Telcordia test methods developed for solder pastes and fluxes.
  - IPC-TM-650 Section 2.6.3.3 “Surface Insulation Resistance, Fluxes,”
  - Surface Insulation Resistance per Telcordia (formally Bellcore) GR-78-CORE
  - Electromigration per Telcordia (formally Bellcore) GR-78-CORE
  - IPC-TM-650, Section 2.3.33D, Presence of Halides in Flux, Silver Chromate Method
  - IPC-TM-2.3.32 “Flux Induced Corrosion (Copper Mirror Method)
  - Ion Chromatography on different concentrations of the chemistry

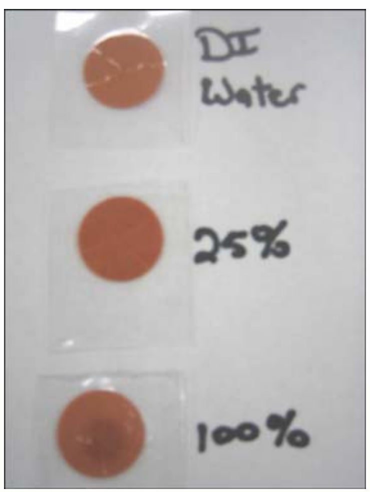
- Samples were prepared for each test using the ‘typical’ and ‘worse case’ conditions.
  - 25% concentration using full rinse & dry cycles
    (25% was previously identified as the maximum concentration level)
  - 100% concentration + air dry (no rinse)

Evaluation Plan: Halides & Copper Corrosion

Silver Chromate Test:

Used to determine if halides were present in the cleaning chemistries. (60 sec immersion).
A change to off-white or yellow white can indicate the presence of chlorides or bromides.

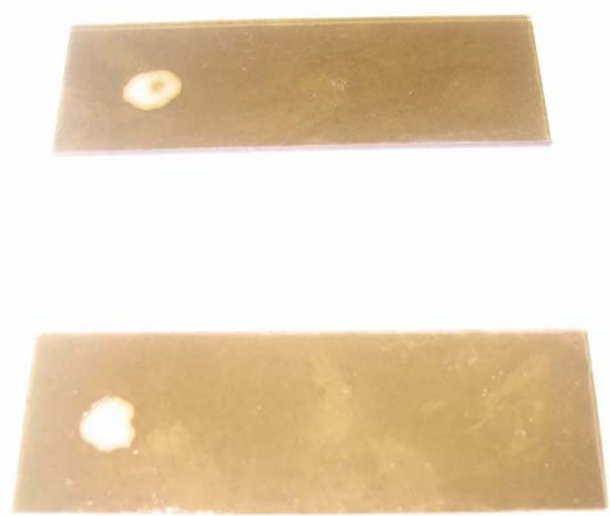
- DI water control
- 25% concentration in DI water
- 100% concentration in DI water



Copper Mirror Test:

Used to determine what effect the solution had on copper. Two drops of solution were placed at separate locations on two pre-cleaned copper mirror substrates and aged at 50% RH and 23 deg C for 24 hrs.

- Isopropyl alcohol control
- 25% concentration in DI water



Chemistry Reliability Testing Methods

Accelerating test environment: temperature, humidity & bias

Electronic Industrial Test Standards

IPC TM 650
Surface Insulation Resistance (SIR)

Test Conditions:
85+/-2C
85+/-2%RH
45 to 50 VDC
168 hours

Measurements:
-100V DC at
24, 96, 168 hrs

Telcordia GR78
Surface Insulation Resistance (SIR)

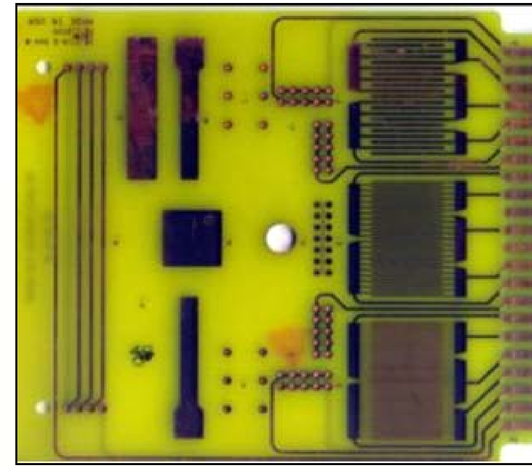
Test Conditions:
35+/-2C
85%RH min
45 to 50 VDC
96 hours

Measurements:
-100V DC at
24, 96 hrs

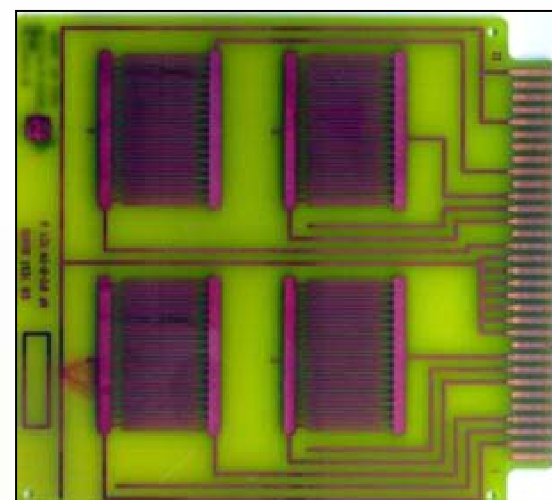
Telcordia GR78
Electro-migration (EM)

Test Conditions:
65+/-2C
85%RH min
10 VDC
500 hours

Measurements:
45 to 100V at
96 and 500 hrs

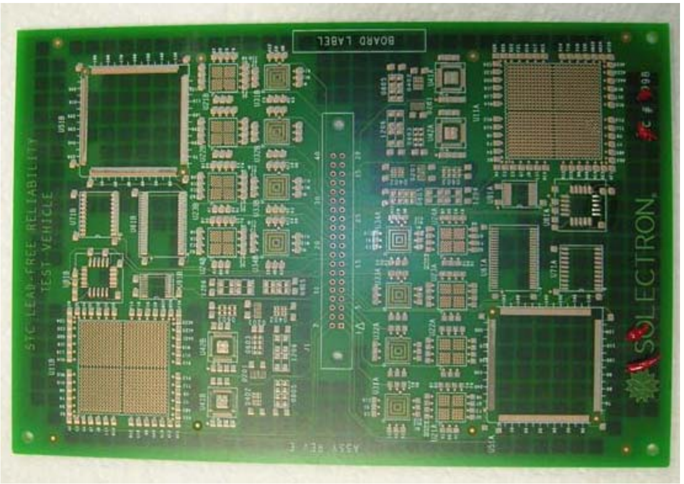


TOP: Double-sided IPC-B-25 test board for BellCore SIR and ECM tests

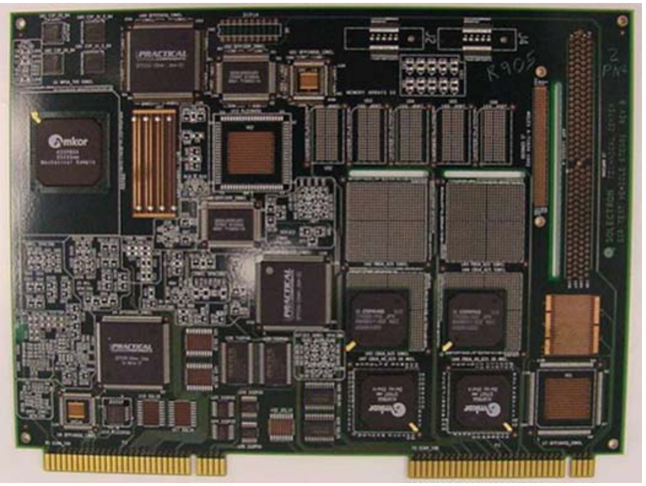


BOTTOM: Single sided IPC-B-24 test board for J-Standard SIR tests

Misprinted Board Cleaning Test Vehicles



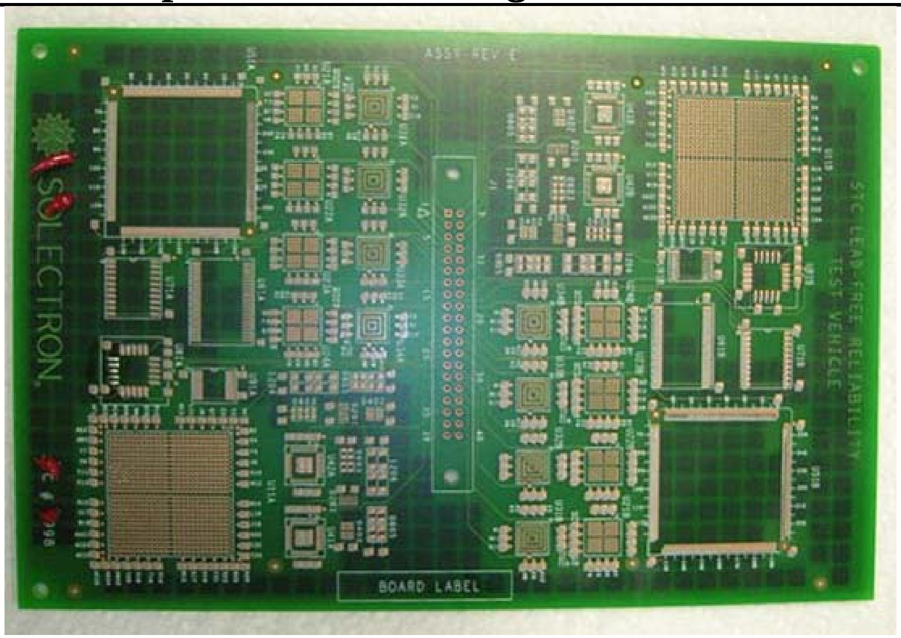
TV-1



TV-2

- Both Test Vehicles were used to simulate A-side and B-side assembly processes using various combinations of reflowed and wet process chemistries.
- All Ion Chromatography samples were taken from Immersion Ag finish PCBs. (NOTE: OSP finishes may provide false IC failures)
- Visual Inspection Performed at 40x.

Misprint Experiment 1: Lead-free No-Clean (Wet)

<table>
<tr><th></th><th>Misprint PCB Cleaning Test Vehicles</th><th>Description of Testing</th></tr>
<tr><td>Test Vehicle 1 (TV-1)</td><td>

Single Sided SMT PCB</td><td><u>Processing:</u>
• Misprinted Solder Paste
• Wet SMT Adhesive
• B-side Cleaning – Non-pop

Reflowed Residues Non-pop
o Paste
o Flux
o Cored Wire

<u>Assessment:</u>
• Visual Inspection 40x
• Ionigraph measurements
• Ion Chromatography</td></tr>
</table>

No-clean solder paste was considered the most difficult paste / flux system to remove and was used to define the starting condition for the B-side testing.

Time delays were included to simulate conditions within the factories.

Stencil Cleaner Chemistry Evaluation – Visual Inspection Results (40x)

	Chemistry # 2 @ 10% Concentration			**Chemistry # 2 @ 15% Concentration**			**Chemistry # 2 @ 20% Concentration**			**Chemistry # 2 @ 25% Concentration**		
Solder Paste Type	5 min	2 Hrs	4 Hrs	5 min	2 Hrs	4 Hrs	5 min	2 Hrs	4 Hrs	5 min	2 Hrs	4 Hrs
SnAgCu NoClean	PASS	FAIL	FAIL	PASS	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS
SnPb NoClean	PASS	FAIL	FAIL	PASS	FAIL	FAIL	PASS	PASS	PASS	PASS	PASS	PASS

20% - 25% Concentration was defined as the starting point for the B-side cleaning DOE for Chemistry #2

Misprint Cleaning B-Side Considerations

- When a misprint occurs on the primary side, the secondary or bottomside has already been assembled through the reflow process.

- The the cleaning process will be required to:
  - Clean the remove wet solder paste and flux from the misprinted side
  - Removing the hardened residues from reflowed materials on the secondary side
  - Clean residues from a possible rework operation on the secondary side including rework flux and cored wire.

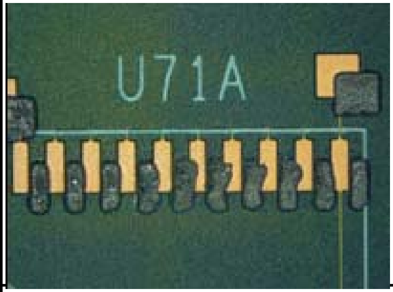
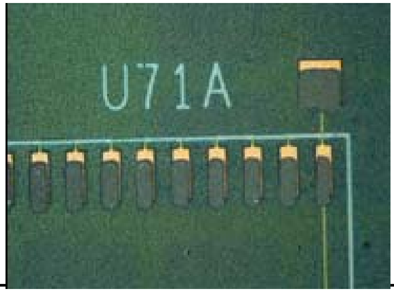
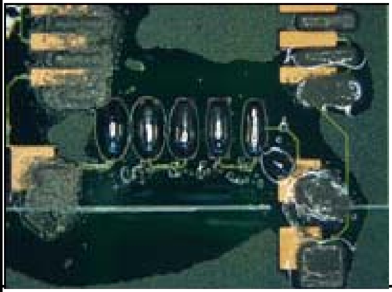
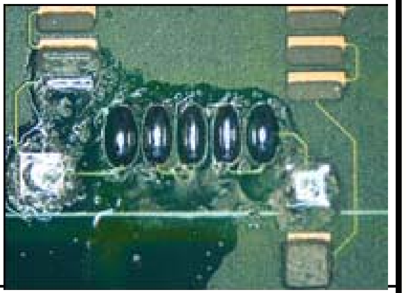
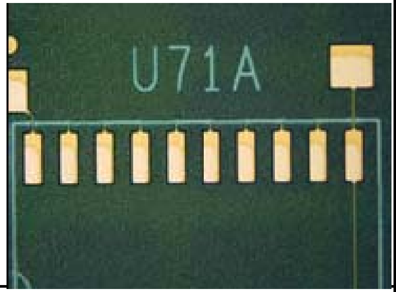
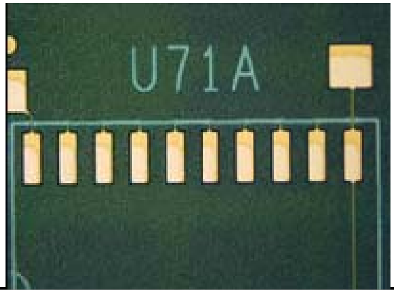
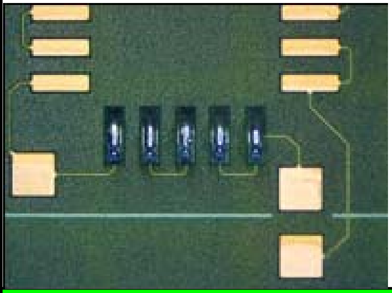
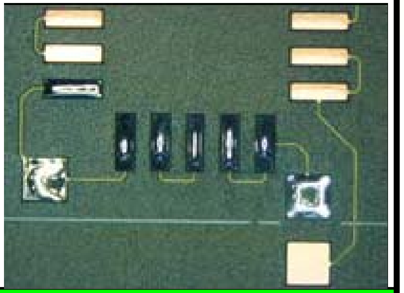
Misprinted Board Cleaning Test Regimen on TV1 (B-Side)

- Spray in Air Cleaner (Cabinet)
- Existing Cleaning Cycle (50-175°C)
- ~7min cleaning cycle (same as stencils)
- 2 Chemistries @ supplier recommended levels (chemistry #2 @ 25% shown)
- Combinations of SnPb & SnAgCu Soldering Chemistries including solder paste, liquid rework flux, cored rework wire and SMT adhesive.

- Residue combinations included SnPb & lead-free systems:
  - Wet paste time 0hrs
  - Wet paste time +4hrs
  - Reflowed paste time 0hrs
  - Reflowed paste time +4hrs
  - Reflowed paste + Rework +4hrs
  - Wet SMD Adhesive 0hrs
  - Wet SMD Adhesive +4hrs

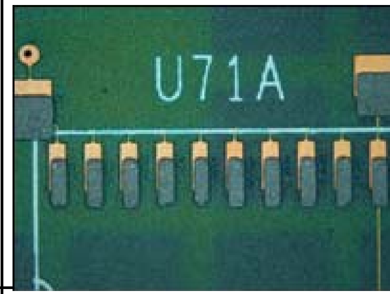
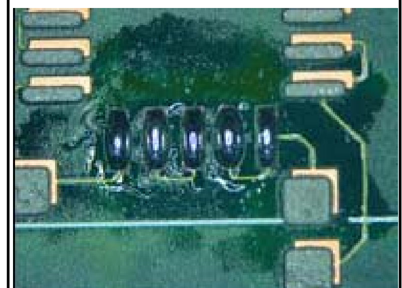
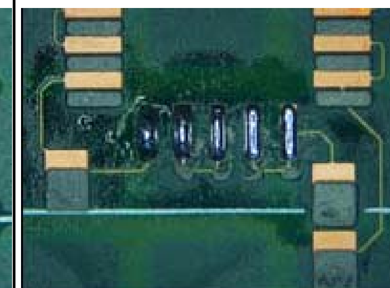
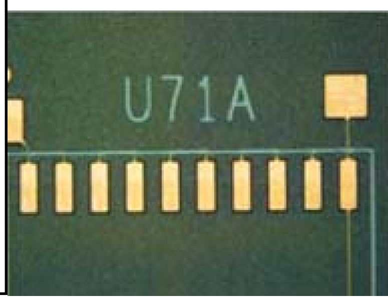
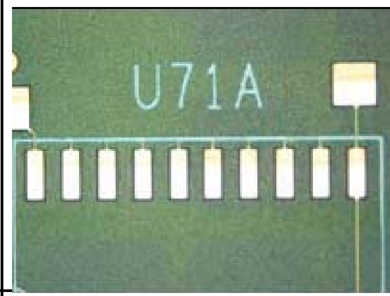
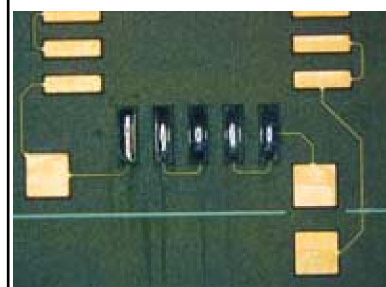
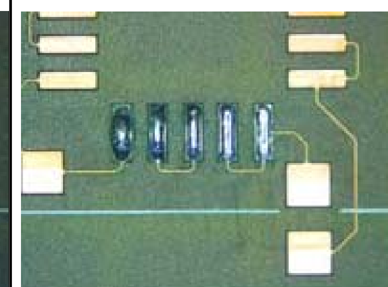
  (All delay samples in 75°F & 45% R.H.)

Misprinted Card Cleaning Inspection Results
(Chemistry #2 @25%)

Tin Lead Water Soluble Chemistry Set				
	Wet Solder Paste		**Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire**	
	Time = 0	*Time = 4hrs*	*Time = 0*	*Time = 4hrs*
Before Cleaning				
After Cleaning				
Ion Chromatography Test Results: (2 boards tested per combination) <u>*Internal IC Thresholds:*</u> *- Organic Acids < 25.0 µg/in²* *- Chloride Ion < 5.0 µg/in²* *- Sulfate Ion < 3.0 µg/in²*	**Weak Organic Acid** *[µg/in² equivalent]*		9.61 / 10.3	8.28 / 10.51
	Chloride *[µg/in² equivalent]*		0.00 / 0.00	0.00 / 0.00
	Sulfate *[µg/in² equivalent]*		1.90 / 1.74	1.33 / 1.72

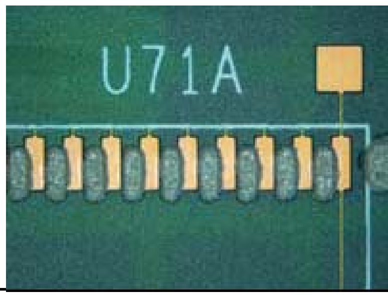
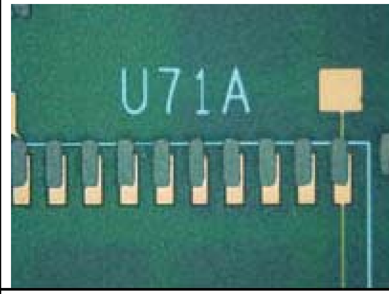
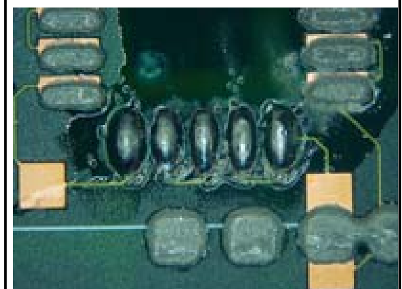
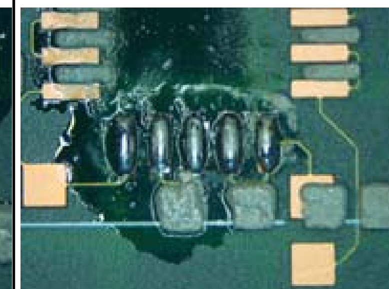
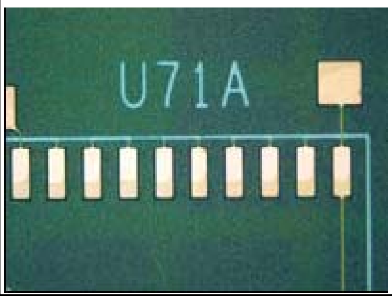
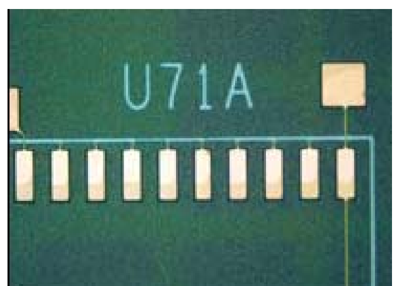
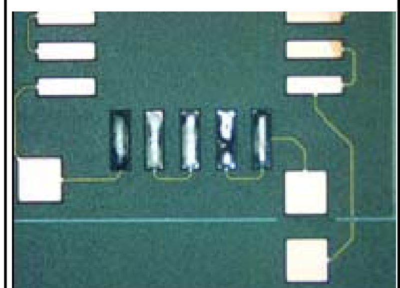
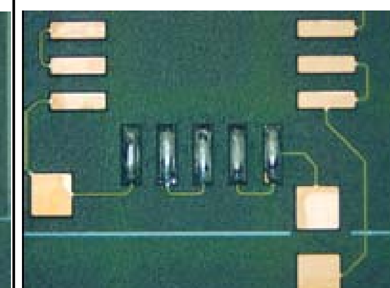
Visual Inspection found some discoloration on the solder mask and the removal of oxidation from pads covered with mis-screened pasted.

Misprinted Card Cleaning Inspection Results
(Chemistry #2 @25%)

Tin Lead No-Clean Chemistry Set				
	Wet Solder Paste		**Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire**	
	Time = 0	*Time = 4hrs*	*Time = 0*	*Time = 4hrs*
Before Cleaning				
After Cleaning				
Ion Chromatography Test Results: (2 boards tested per combination) *Internal IC Thresholds:* *- Organic Acids < 25.0 µg/in²* *- Chloride Ion < 5.0 µg/in²* *- Sulfate Ion < 3.0 µg/in²*		**Weak Organic Acid** *[µg/in² equivalent]*	9.53 / 9.37	8.58 / 8.63
		Chloride *[µg/in² equivalent]*	0.03 / 0.00	0.00 / 0.00
		Sulfate *[µg/in² equivalent]*	1.99 / 1.80	1.84 / 1.73

Visual Inspection found some discoloration on the solder mask and the removal of oxidation from pads covered with mis-screened pasted.

Misprinted Card Cleaning Inspection Results (Chemistry #2 @25%)

<table>
<tr><th colspan="5">RoHS Compliant Water Soluble Chemistry Set</th></tr>
<tr><th rowspan="2"></th><th colspan="2">Wet Solder Paste</th><th colspan="2">Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire</th></tr>
<tr><th>Time = 0</th><th>Time = 4hrs</th><th>Time = 0</th><th>Time = 4hrs</th></tr>
<tr><td>Before Cleaning</td><td></td><td></td><td></td><td></td></tr>
<tr><td>After Cleaning</td><td></td><td></td><td></td><td></td></tr>
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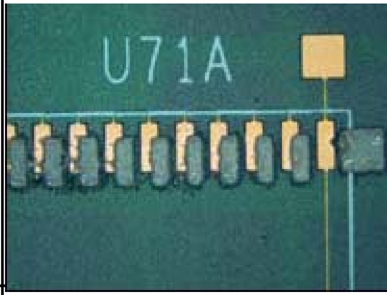
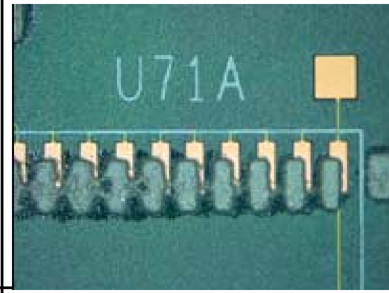
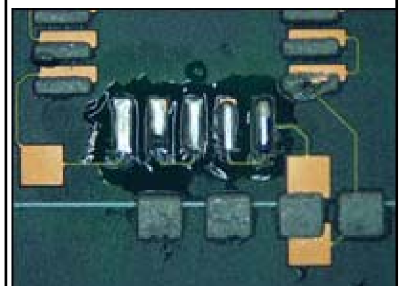
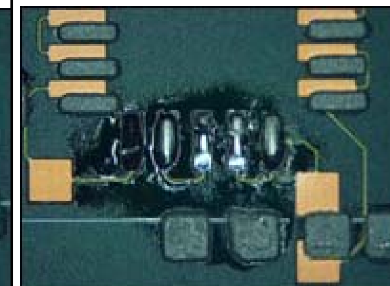
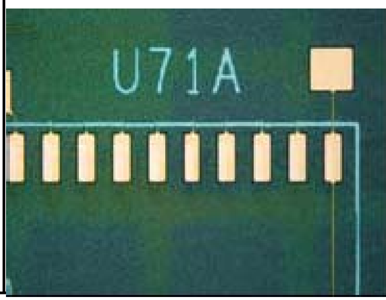
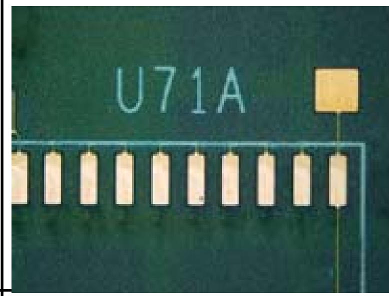
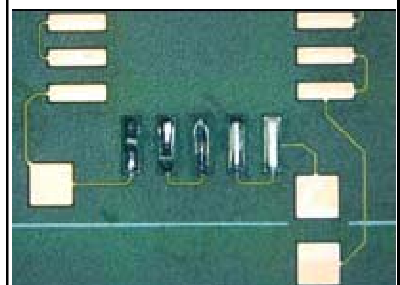
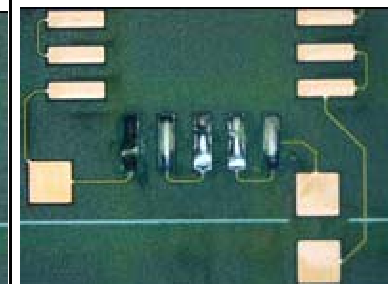
- Chloride Ion < 5.0 µg/in²
- Sulfate Ion < 3.0 µg/in²</td><td>Weak Organic Acid
[µg/in² equivalent]</td><td>9.54 / 8.98</td><td>5.55 / 7.43</td></tr>
<tr><td>Chloride
[µg/in² equivalent]</td><td>0.04 / 0.11</td><td>0.00 / 0.04</td></tr>
<tr><td>Sulfate
[µg/in² equivalent]</td><td>1.90 / 1.99</td><td>1.12 / 1.47</td></tr>
</table>

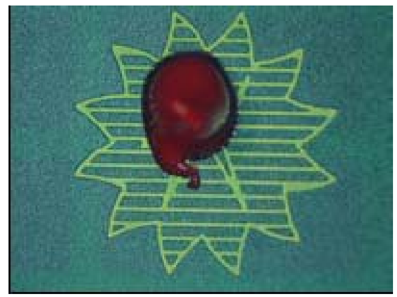
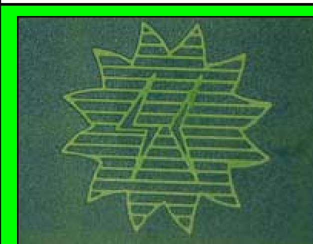
Noted light oxidation of OSP pads after wet paste removal. No visual defects observed

Misprinted Card Cleaning Inspection Results (Chemistry #2 @25%)

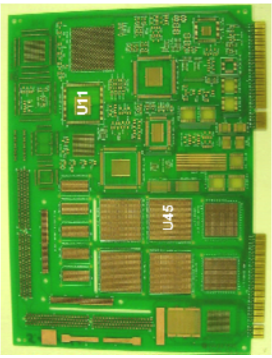
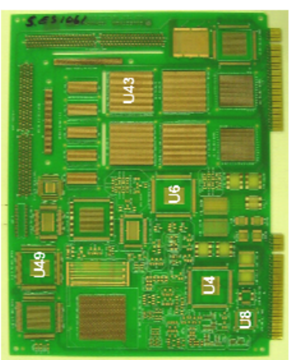
RoHS Compliant No-Clean Chemistry Set				
	Wet Solder Paste		**Reflowed Solder Paste + Rework Flux + Wave Flux + Cored Wire**	
	Time = 0	*Time = 4hrs*	*Time = 0*	*Time = 4hrs*
Before Cleaning				
After Cleaning				
Ion Chromatography Test Results: (2 boards tested per combination) <u>*Internal IC Thresholds:*</u> *- Organic Acids < 25.0 µg/in²* *- Chloride Ion < 5.0 µg/in²* *- Sulfate Ion < 3.0 µg/in²*		**Weak Organic Acid** *[µg/in² equivalent]*	10.55 / 10.05	7.28 / 6.69
		Chloride *[µg/in² equivalent]*	0.12 / 0.76	0.07 / 0.00
		Sulfate *[µg/in² equivalent]*	1.51 / 1.91	1.22 / 1.93

Solder Balls identified after wet paste w/ 4hr delay… .

Misprinted Card Cleaning Inspection Results
(Chemistry #2 @25%)

		Before Cleaning	After Cleaning t = 0	After Cleaning t = 4hrs
Surface Mount Adhesive 'A'	*Manually Wiped prior to cleaning*			
	Not Wiped prior to cleaning			Not Tested
Surface Mount Adhesive 'B'	*Manually Wiped prior to cleaning*			
	Not Wiped prior to cleaning			Not Tested

TV 2 – Verified Concentration Levels using IC
(Lead-free No-clean Wet Paste – Chemistry #2 @25% shown)

	Location	Device Placed ?	Chloride (ug/in^2)	Bromide (ug/in^2)	Nitrate (ug/in^2)	Sulfate (ug/in^2)	Extracted Area (in^2)	Results
	U4 - top side **QFP208SQ-20 mil**	Yes	0.38	< 0.10	0.16	1.31	1.56	**PASS**
	U6 - top side **QFP256SQ - 16mil**	Yes	0.42	0.13	0.14	1.52	1.56	**PASS**
	U8 - top side **QFP168SQ - 12mil**	No	0.23	< 0.10	< 0.10	0.52	0.563	**PASS**
	U11-bottom side **PLCC84SQ**	No	< 0.10	< 0.10	< 0.10	0.26	1.56	**PASS**
	U43-top side **PBGA**	No	0.24	1.04	0.10	1.15	1.00	**PASS**
	U45-bottom side **CBGA**	No	0.26	1.28	0.10	1.15	1.00	**PASS**
	U49-top side **QFP256SQ-16mil**	No	0.12	< 0.10	< 0.10	0.38	1.56	**PASS**

Established IC Limits: *Chloride Ion < 5.0 ug/in2, Bromide Ion < 7.0 ug/ in2, Nitrate Ion < 1.0 ug/ in2, Sulfate Ion < 3.0 ug/ in2*

Misprinted PCB Cleaning Agent Evaluation Results

- Chemistry #2 at 25% concentration proved to be successful at removing the target residues without causing harm to the PCBA.
- An identical series of tests were performed to verify stencil cleaning performance.
- Similar tests were performed to define the cleaning agent for in-line PCBA flux removal operations.

- Future work includes:
  – A detailed look into the ionic residue levels of area array modules and low-standoff devices using the same chemistry set and processing parameters
  – Additional TCO investigations into the cost of energy for heated DI water compared to the cost of using unheated water at higher concentration levels. (cost / performance)

Conclusion

Using the available IPC cleaning reference documents (IPC-7526 & IPC-CH-65A) as a foundation it was possible to evaluate, compare and define processes using modern cleaning chemistries for the cleaning of misprinted PCBs, stencils and assembled PCBAs for tin-lead and lead-free products.

Cleaning processes continue to be used by a number of products with low or no residue requirements in a variety of market segments and will drive the need for chemistry based cleaning well into the next generation of lead-free conversions.

Acknowledgements

- The technical staff of the respective chemistry and equipment suppliers - who provided critical materials and information on the nuances of PCBA cleaning.
- Flextronics engineers who provided expertise, time and energy into numerous technical projects supporting this paper including:
  - Jenny Porter (Flextronics SBS Charlotte)
  - Andres Turrbiates (Flextronics Guadalajara-South)
  - George Oxx (Flextronics SBS Charlotte)

Thank you

Aaron Unterborn

Senior Manager

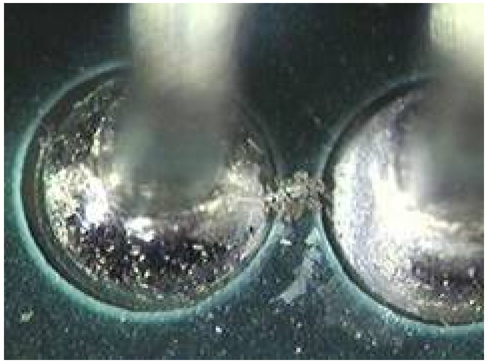
Technology Leadership Group

Flextronics International

Aaron.Unterborn@Flextronics.com

Cleaning: The Removal of Residues

Ionic contamination is an industry documented source of test and field failures by contributing towards corrosion, electromigration and current leakage.



INTERNAL IONIC FAILURE LIMITS USING ION CHROMATOGRAPHY:

Organic Acids < 25.0 ug/in2
Chloride Ion < 5.0 ug/in2
Bromide Ion < 7.0 ug/ in2

(measurements in equivalent ug of NaCl)

Common Ionics found within the PCBA process include:

- Weak Organic Acids (WOA): Mostly found in residues from solder paste.
- Chloride Ions: Typically found in SMT & Wave flux residues. Chlorides absorbs moisture and can cause corrosion.
- Bromide Ions: Found in some flux residues or is generated during reflow when bromine compounds are heated to decomposition.

PCBA Cleaning Terminology

- **Wash or Washing – The primary cleaning op0eration that removes undesirable impurities (contaminants) from surfaces by chemical and physical effect.**

•Rinse or Rinsing – A Cleaning operation (usually following the wash step) where fresh cleaning medium replaces any residual contamination, leaving surfaces wet with pure cleaning medium.

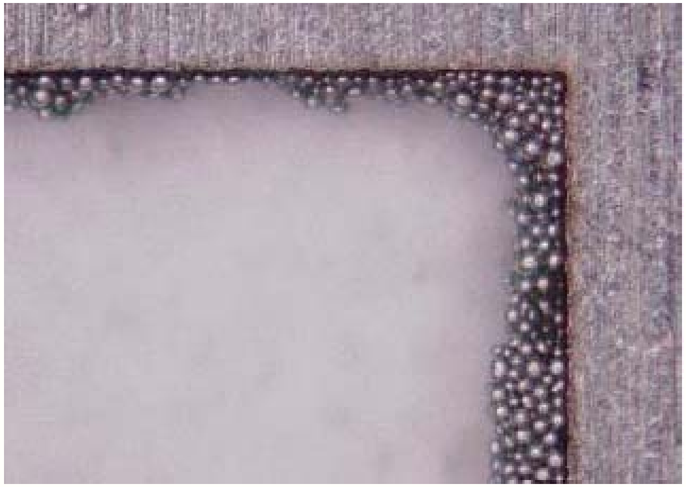
•Dry or Drying – The process of removing and residual cleaning medium on the surface of the washed and rinsed parts.

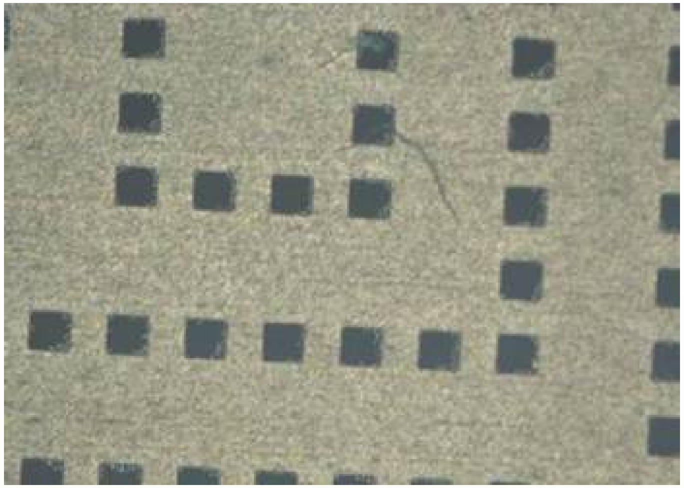
•Solvent Cleaning – The removal of organic & inorganic soils using a blend of polar & nonpolar organic solvents.

•Surfactants - Chemicals that reduce the surface tension of printed circuit boards to help with the removal of fluxes, pastes, adhesives, industrial soils, and greases.

•Saponifiers - Chemicals that react to break down fats, oils, and other contaminates.

Stencil Cleaning





Essential PCBA Assembly Process

- Ensures proper stencil life & print condition (paste release)

Manual (wipe with lint-free cloth & solvent)

- Acceptable for minor in-process cleaning.

Semi-manual (assisted clean)

- Examples include:
- Ultrasonic paddle
- Water & chemistry @ spray sink

Automated cleaner (offline)

- Ideal process can handle stencils and mis-printed PCBA with a common process.
- Segregation of solder paste chemistries or alloys not required.
- Spray in Air and Ultrasonic cleaners are available.

In-Line Cleaner Systems

Used for the Cleaning of Assembled PCBAs (post-SMT & post-Wave)

- Aqueous Cleaners:
  - Large stainless steel multi-zone cleaners
    - Stainless-steel allows higher water temps (>150°C)
    - Limited to Deionized Water Only (no chemistry containment)
      - Acceptable range of resistivity is 1.3MΩ to 2 MΩ.
      - DI Water supplied through a filtration system.
- Semiaqueous Cleaners:
  - Large multi-zone poly cleaners
    - Polymer materials resist chemical corrosion
    - Available with chemical isolation chamber option
  - Supplimental chemistry isolation unit
    - Stand-alone chemical chamber placed in front of DI water cleaner (sst or poly) to allow for mixed use or low volume semiaqueous cleaning.