Critical Cleaning of Highly Densed Electronic Assemblies in the Lead Free

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ABSTRACT

An important development in high reliability electronics is the convergence of circuit board and advanced packaging technologies. This combination enhances the best attributes of each technology to achieve higher performing devices. These emerging technologies drive the need for critical cleaning, which requires continued innovation to meet cleanliness requirements. Additionally, the move to Pb-free alloys creates new demands from a cleaning process perspective. To meet the reliability standards for smaller, lighter, and highly dense electronic assemblies, cleaning process integration between mechanical and chemical driving forces require consideration. Research studies suggest that removal of flux residue from under die packaging technologies reduces voiding and improves reliability. The purpose of this research investigates new mechanical impingement designs and reports the correlation of Pb-free flux removal efficacy using design of experiment testing.

INTRODUCTION

An optimized cleaning process delivers the necessary chemical and mechanical energy to clean the most difficult and sensitive areas of the part being cleaned. Understanding the balance between static chemical and mechanical driving forces is fundamental to predicting and optimizing process variables. The timing and sequence of events in a cleaning process are critical. Each section or step in the process requires careful thought and understanding. As the gap from the board surface to the bottom of the component decreases, experience tells us that cleaning becomes more difficult.

Cleaning highly dense electronic assemblies, with narrow spacing, represents a difficult cleaning challenge. Many variables influence the process-cleaning rate. Research data suggests four critical variables when cleaning electronic circuit assemblies. Higher cleaning chemistry concentration typically increases static cleaning (rate at which the cleaning fluid dissolves flux residue without agitation). Increased cleaning temperature typically improves the dissolution rate. Increased time allows the cleaning fluid to dissolve flux under tight standoffs until break-through occurs, which allows the fluid to flow under the part and dissolve remaining flux residue. Mechanical impingement creates a driving force that increases penetration rates and reduces the time needed to clean under the component. A fifth variable must be considered when cleaning under tight standoffs – surface tension and capillary action. Lower surface tension improves capillary action, which allows the cleaning fluid to wet and penetrate at a faster rate.

The purpose of this research study is to build from previous work that studied the cleaning efficacy of highly dense electronic assemblies. The pressures of economics and competition drive standardized interfaces for electronic assembly and advanced packaging designs. Open standards provide a roadmap for designers as they develop new designs that move away from leaded solders. This quantitative research study investigates new mechanical impingement designs and reports the correlation of Pb-free flux removal efficacy using design of experiment testing.

BACKGROUND TO THE PROBLEM

The platform for high reliability electronic assemblies is developed from industry standards that ensure that the logic follows prescribed design rules. Electronic assembly and advanced packing industry standards provide a common interface that allows production to be outsourced to multiple companies, while exploiting the economies of scale and specialization. Standardization of electronic assembly manufacturing platforms is componentized in terms of product parts and materials of construction. Componentizing design standards enables key processes to integrate across a common platform.

As design engineers study lead-free soldering materials, new solder material innovations must be considered. The platform for high reliability electronic assemblies prescribes the removal of residues which could contribute to electromigration and result in current leakage between circuitry. End-product classes have been established to reflect differences in producibility, complexity, functional performance requirements, and verification frequency. Class III high performance electronic products includes products where continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems.

The flux chemistry is driven by the soldering alloy, solderability, surface finish, component and board design, soldering process, test methods, and upstream processes such as underfill and conformal coating. Lead-free alloys of choice contain high levels of tin. Solderability of high tin alloys requires flux materials that do not decompose at higher reflow process temperatures. Additionally, the flux compositions must remove the oxide film to allow the alloys to wet, bond and flow. Cleaning test data finds the Pb-free flux compositions that support high reliability designs to be more difficult to clean.

A number of designed experiments using common cleaning equipment and cleaning fluid designs find difficulty in removing all flux residue from under highly dense components. To address this concern, cleaning chemistry designers have worked to innovate new cleaning fluid designs that improve the static cleaning rate. Additionally, cleaning equipment companies have also studied nozzle designs, directional forces, and pressure, time and temperature effects. This study reports data findings from designed experiments on wash manifold configurations with the objective of opening the process window and improving cleaning efficacy.

PROBLEM STATEMENT

Testing data finds Pb-free flux residues are more difficult to clean as a result of high molecular weight resins and polymers, higher reflow temperatures, and higher levels of flux residue left from the soldering process. Flux residues under area array components and chip caps create a flux dam under the component during reflow. The flux dam seals the underside of the component with a thick resinous material that is difficult to completely remove.

This design challenge requires both improved chemical and mechanical technology. The chemical driving forces can be improved by adding materials to increase the speed of cleaning and by improving the wet-ability of the material to penetrate under flush mounted devices. The mechanical driving forces require optimization in nozzle design, number of spray manifolds, pressure and selection and positioning to address difficult cleaning challenges on the board. Even with improved chemical and mechanical forces, data from previous experiments find that part exposure to time in the wash section to be a critical factor. Supporting data finds the time the board is exposed to the cleaning material (wash time), along with the time between re-flow and cleaning (aging time) are very important variables.

Figures 1 illustrates an example of a highly dense circuit assembly. Part positing on the board, number of reflow cycles before cleaning, peak reflow temperature, and the thickness of the solder paste all affect cleaning efficacy. Area array components and chip caps positioned in series and adjacent to other components may increase the difficulty of the cleaning fluid to penetrate under the component gap. The number of reflow cycles and increased Pb-free reflow temperatures may increase cleaning difficulty. The thickness of solder paste and the percentage of flux in the paste may increase the level of flux residue under the component, which creates a more difficult cleaning challenge. Additionally, components sealed on two sides, such as chip caps, form a capillary action under the component during reflow, which completely seals the underside of the part with flux residue.

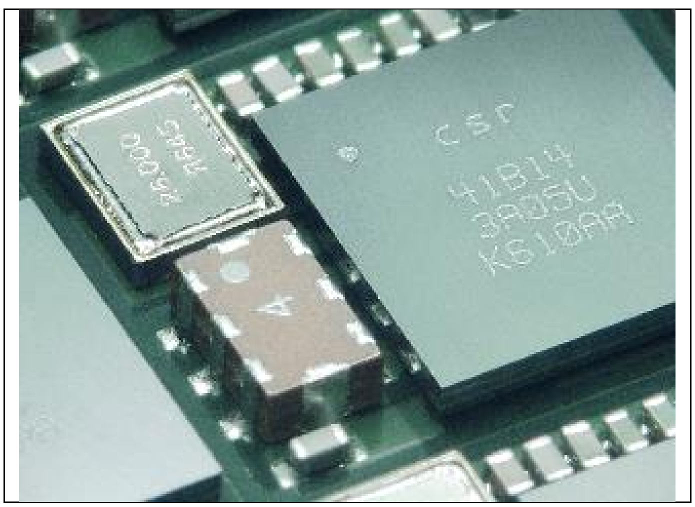


Figure 1 - Highly Dense Circuit Assembly

DISPLACEMENT ENERGY

Inline and batch spray-in-air cleaning systems reduce the time to clean highly dense circuit assemblies. Fluid mechanics suggests that the energy delivered to the surface is equal to the mass times the velocity squared. Impingement pressure at the cleaning surface is dependent on the nozzle type and distance from the nozzle manifolds to the surface of the part. Maximizing the physical energy delivered at the gap under the component requires optimal pressure that reduces bounce and improves penetration.

Pb-free flux residues clean at different rates based on the flux make-up, time after reflow, reflow temperature, and the cleaning fluid design. Water-soluble flux residues typically clean at a faster rate than do rosin flux residues, which typically clean at a faster rate than low solids synthetic flux residues. Flux residue becomes more difficult to clean with the passage of time after reflow. Higher reflow temperatures allow the lower molecular weight solvent molecules to evaporate at a faster rate, leaving higher molecular weight resin molecules, which increases the difficulty of cleaning the residue. Cleaning fluid designs either dissolve or react with the flux soil, which influences the static cleaning rate.

As the gap from the board surface to the bottom of the component decrease, the data finds cleaning to be more difficult. The standoff height of area array components decrease as the number of interconnects increase. Past research studies find longer cleaning time is required to wet, dissolve and breakthrough the underside of the component. The longer time to achieve breakthrough correlates with lower belt speeds and longer time under wash manifolds to remove 100% of the flux residue. Research data find lower dynamic surface tension allows cleaning fluids to penetrate and dissolve the flux at a faster rate, which decreases time to achieve breakthrough.

ELECTRONIC ASSEMBLY CLEANING FLUIDS

Cleaning fluids vary in their design based on solvency, saponification, wetting (surfactancy), inhibition, and defoaming characteristics. The best cleaning fluids optimize and build performance characteristics that effectively accomplish several tasks in combination. To improve cleaning efficacy of Pb-free flux residue from under area array components and chip caps, past designed experiments tested the hypotheses that lower surface tension and wetting improves cleaning efficacy.

The static cleaning rate requires materials that rapidly soften and solubilize the flux soils soon after contact. The challenge is to create a universal formulation that works well on many flux residue types. There are well over 200 commercial solder pastes, paste flux and wave flux materials used by industry. Although the flux characteristics do have commonality, there are differences that vary the static cleaning rate. Cleaning chemistry design firms who study the many soil types, and design universal cleaning fluids work to open the process window, allow users to select different flux types without a major impact on the cleaning process.

Wetting and surface tension effects occur through surface treatment that reduces the droplet size and allow the cleaning fluid to move easily in and out of tight spaces. Surface-active agents create a thin and weak droplet that improves capillary action needed to wet under area array components and chip caps at a more rapid rate. Surfactant free cleaning agents form a large droplet, which facilitates initial wetting of tight spaces. Once the fluid makes its way under the component, high surface tension affect cause the cleaning solution to repel and prevents rapid movement under tight spaces.

Past designed experiments find that cleaning fluids that exhibit low dynamic surface tension improve cleaning under highly dense area array and chip cap components. Two important findings continue to show up in the data. First, ingredients within the cleaning fluids that split and form a solvent / water layer increase the droplet size and increase surface tension, which reduces cleaning efficacy under the part. Second, surface active materials, at low levels, improve wetting, which allow the cleaning fluid reach the soil at a more rapid rate.

METHODOLOGY

The purpose of this quantitative research study investigates new mechanical impingement designs and reports the correlation of Pb-free flux removal efficacy using design of experiment testing. The designed experiment evaluates the time required to remove all flux residue under 1210 and 1825 chip caps on the Kyzen test card (Figure 2). Cleaning efficacy under the chip caps of six L^0R^0 Pb-free solder pastes was tested. The Pb-free solder pastes are industry standard materials from leading solder paste material suppliers.

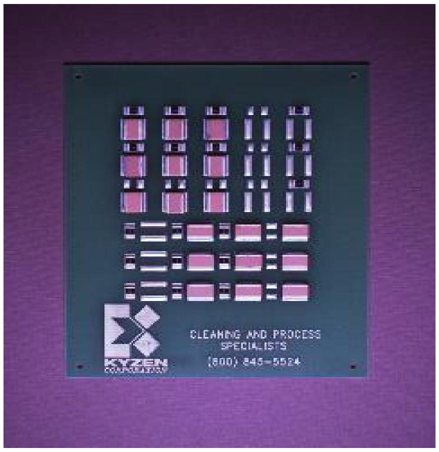


Figure 2 - Test Board Design

The components were reflowed using a soak Pb-free profile (Figure 3). The positioning of the components place the chip caps where the leading and trailing gap is sandwiched in between two, chips, one chip, and no chips. After cleaning, the components will be removed from the test board and the mean level of flux level under the components will be reported. The data will be analyzed quantitatively.

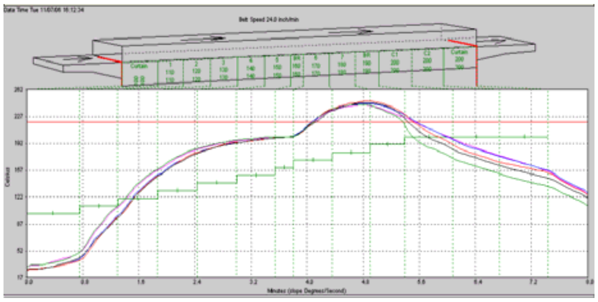


Figure 3 - Pb-Free Soak Profile

The boards were prepared using a Pb-free soak profile. Using the soak profile, the Pb-free alloy degasses for roughly 3 minutes near liquidus. The time above liquidus was roughly 90 seconds. The increased soak time, and 30-40°C higher peak reflow temperature as compared to eutectic Sn/Pb, hardens the residue. Figure 4 illustrates the peak, rising and falling slopes, and time above liquidus.

	Peak	Min	Max Rising Slope	Max Falling Slope	Total Time Above 219
1	241.5	32.5	1.80	-0.67	87.57
2	243.5	27.7	1.80	-0.78	90.23
3	246.3	27.5	1.80	-0.96	86.56
4	244.5	27.8	1.72	-1.05	80.08
5	241.8	32.7	1.84	-1.16	77.18

Figure 4 - Reflow Profile Statistics

MECHANICAL IMPINGEMENT DESIGNS

Wash Spray Manifold Design #1

The aqueous inline cleaning machine design studied has a standard wash manifold that uses two spray headers - hurricane jet – two spray headers (Figure 5). The spray manifolds can be configured to use delta fan or coherent jets. The spray pattern impinges upon the circuit card followed by a soak, impingement from the next spray manifold, soak, impingement from the hurricane jet and so on.

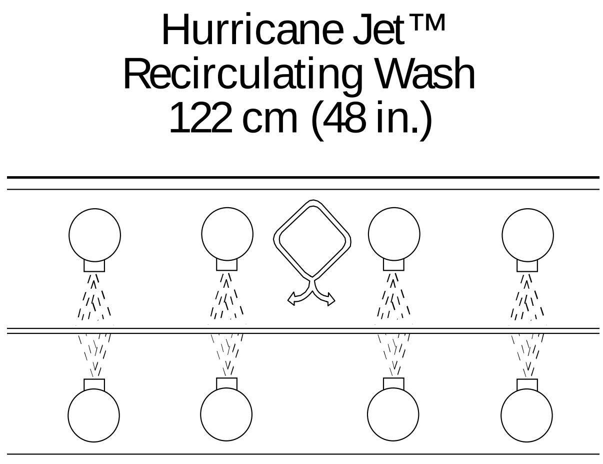


Figure 5 - Wash Spray Manifold Design #1

Designed manifold # 1 is housed in a 4 foot wash section. From a previous designed experiment, Figure 6 illustrates the mean level of Pb-free flux residue under 1210 chip caps when run at a belt speed of 1.5 feet per minute, cleaning fluid concentration of 15%, and wash temperature of 150°F using the design manifold #1. At these process conditions, the data finds insufficient cleaning under the 1210 chip caps. To improve this condition, a number of follow on designed experiments tested alternative cleaning fluid designs, cleaning fluid concentrations, different spray manifold configurations, different nozzle types, different conveyor belt speeds and different processing temperatures. The data findings continued to confirm the increased difficulty in removing Pb-free flux residues from low standoff components.

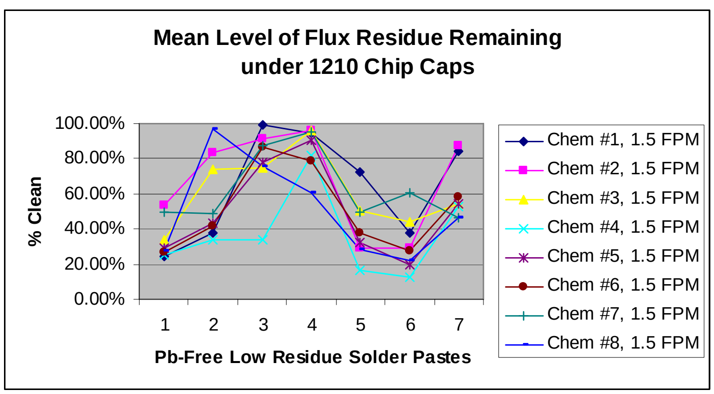


Figure 6 - Cleaning Data from Wash Spray Manifold #1

Wash Spray Manifold Design #2

The first manifold design provides for soak time after each spray manifold before reaching the next spray manifold. Wash spray manifold design #2 added four additional spray manifolds, two before the hurricane nozzle and two after the hurricane nozzle. This manifold design increases the direct impingement time onto the board surface while decreasing the soak time (Figure 7). The objective was to determine if added direct spray time onto the board surface improved cleaning performance under low standoff components.

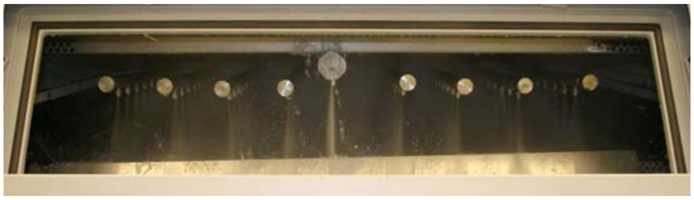


Figure 7 - Wash Spray Manifold Design #2

From a previous designed experiment, Figure 8 illustrates the mean level of Pb-free flux residue under 1210 chip caps using spray manifold design #2. This experiment tested parts reflowed in nitrogen and air environments. The data finds improved cleaning using more spray manifolds with other factors such as paste selection and belt speed being factors.

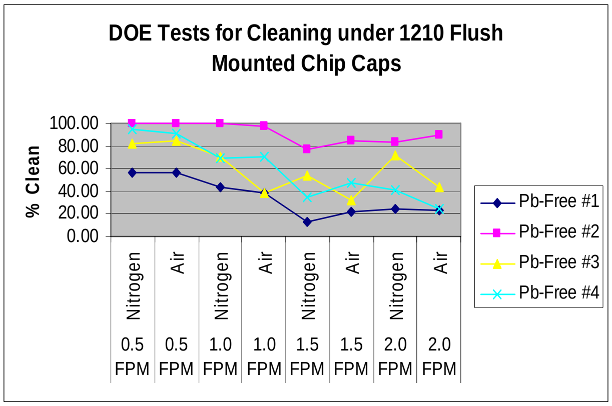


Figure 8 - 1210 Cleaning Data from Spray Manifold #2

Wash Spray Manifold Design #3

The data reported for wash spray manifold design #1 and design #2 were run from previous designed experiments. The data finds a direct correlation to improved cleaning by increasing the number of spray manifolds in the wash section. Based on these findings, eight addition wash spray headers were added to the wash manifold design (Figures 9 & 10).

Figure 9 - Wash Spray Manifold #3

Figure 10 - Wash Spray Manifold #3

To test the correlation of cleaning Pb-free flux residues under low standoff components using wash spray manifold #3, the design matrix in Figure 11 outlines the process variables used to run the designed experiment.

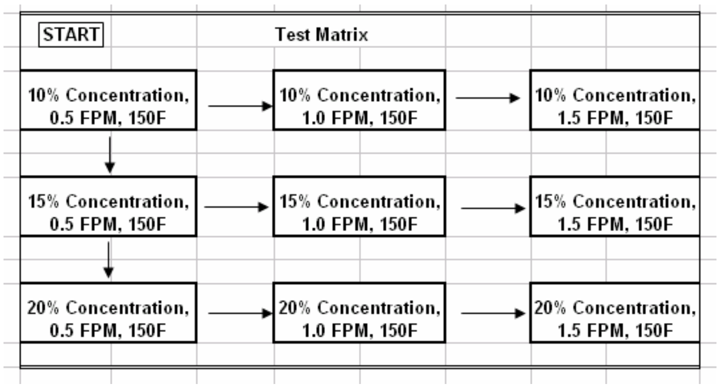
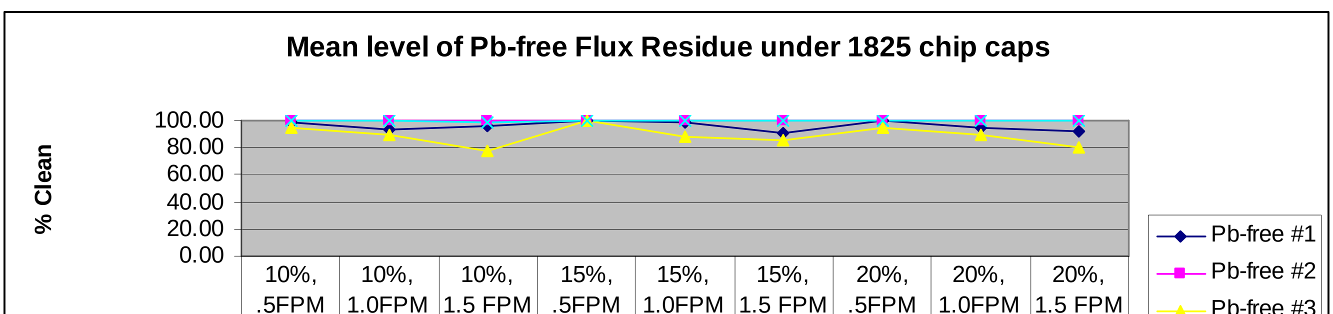


Figure 11 - DOE Test Matrix

The cleaning temperature for this experiment was fixed at 150°F. Nine boards were run for each solder paste and test condition in the matrix. Three cleaning fluid concentrations were run at 10%, 15%, and 20%. The belt speed was run at 0.5, 1.0, and 1.5 feet per minute.

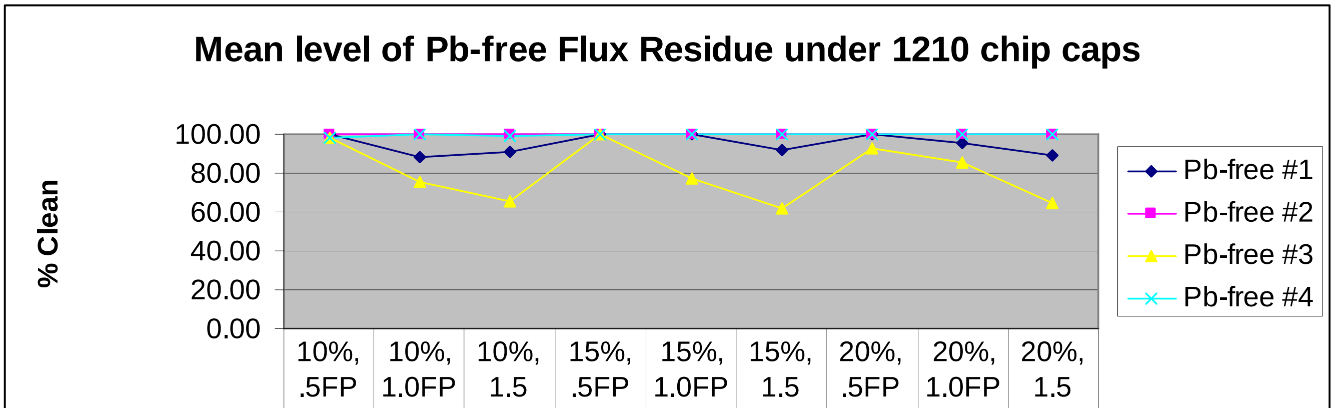
DATA FINDINGS

Figures 12 and 13 report the data findings from four Pb-free synthetic based formulations.



	10%, .5FPM	10%, 1.0FPM	10%, 1.5 FPM	15%, .5FPM	15%, 1.0FPM	15%, 1.5 FPM	20%, .5FPM	20%, 1.0FPM	20%, 1.5 FPM
Pb-free #1	98.33	93.00	96.50	100.00	99.33	90.83	100.00	94.17	91.67
Pb-free #2	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Pb-free #3	94.17	90.00	77.50	100.00	88.33	85.83	95.00	89.17	80.00
Pb-free #4	100.00	100.00	98.33	100.00	100.00	100.00	100.00	100.00	100.00

Figure 12 - Cleaning Data from Spray Manifold #3



	10%, .5FP	10%, 1.0FP	10%, 1.5	15%, .5FP	15%, 1.0FP	15%, 1.5	20%, .5FP	20%, 1.0FP	20%, 1.5
Pb-free #1	100.00	88.33	90.83	100.00	100.00	91.67	100.00	95.83	89.17
Pb-free #2	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Pb-free #3	98.33	75.83	65.83	100.00	77.50	61.67	92.50	85.00	65.00
Pb-free #4	98.33	100.00	99.33	100.00	100.00	100.00	100.00	100.00	100.00

Figure 13 - 1825 Cleaning Data from Wash Manifold #3

DATA ANALYSIS

The data reports the mean percentage of flux residue remaining under six 1210 and six 1825 chips in the vertical and horizontal positions. The designed experiment tests the hypothesis that increased spray headers in the wash section correlates to improved cleanliness under low standoff components.

Components were removed from all test boards, and the flux residue was viewed and graded by a single individual, to score the percentage flux residue under each chip cap. The data reports the mean value for six sites on both the 1210 and 1825 chip cap in the vertical and horizontal position for the nine test conditions.

The data findings suggest a number of factors worth consideration. First, the data shows a strong correlation to improved cleaning efficacy under low standoff components with longer direct impingement time in the wash section. When removing flux residue under low standoff components, impingement at the leading edge of the die/component force cleaning fluid to the source of residue. The additional manifolds added to the wash section find direct impingement verses soak correlates to improved cleaning efficacy.

The data findings suggest a difference in the cleaning rate from different solder paste formulations. Solder paste #3 cleaned well at lower conveyor belt speeds but cleaning tailed off as the conveyor belt speed increased. For this the static cleaning rate may improve or open the process particular residue, a different cleaning fluid that improves window. Previous designed experiments find that wash time has a direct correlation to cleaning efficacy. The data from these experiments find a conveyor belt speed of 0.5 feet per minute is the maximum throughput to achieve high levels of cleaning efficacy. The data from this experiment find that the process window for conveyor belt speed is dramatically improved from the additional spray wash headers added to the wash section.

Limitations from the data findings rely on previous designed experiments conducted using wash manifolds #1 and #2. Since these designed experiments were run using slightly different factors, the data findings may be slightly different.

RECOMMENDATIONS

The data suggests that cleaning under flush mounted chip caps is a difficult challenge. Many assemblers use low residue no-clean flux and only inspect for flux residue on the exterior of the chip cap. This is not the case for Class 3 high reliability assemblers, who require 100% of the flux residue removed.

The data suggests that increased direct impingement time in the wash section correlates to improved cleaning efficacy. This is an important data finding that opens the process window and allows for increased throughput. When total flux removal under chip caps is a requirement, the authors recommend that assemblers test increased impingement time in the wash section.

CONCLUSION

Removal of flux residue from under low standoff components and chip caps is a difficult cleaning challenge. The designed experiment tested cleaning efficacy as a function of direct impingement time in the wash section. The data suggests a strong correlation to increasing the number the number of spray headers and direct impingement time in the wash section to achieve 100% cleaning under low standoff components and chip caps.

An optimized cleaning process requires the right balance of static and dynamic cleaning forces. When using inline-cleaning equipment, the data finds the number of spray headers in the wash section improves cleaning performance. The prewash section wets the board with the cleaning fluid by penetrating and softening the flux residue under tight standoffs. The wash impingement section must break the flux dam under the component to achieve flow under the part. The data suggest that less soak and more direct impingement in the wash section is needed to achieve a process window that produces 100% clean parts.

FOLLOW ON RESEARCH

Follow on research on a number of process variables is needed to understand driving forces. Further testing is needed to study the temperature effects of the wash solution to part cleanliness. Improved mechanical impingement designs may allow for lower processing temperatures, which reduces evaporative losses and energy. Would a lower temperature achieve similar results? This is an important question since lower cleaning fluid temperature improves cost of ownership and potentially reduces compatibility side effects.

Additional testing is needed to correlate part cleanliness to the static cleaning rate holding the dynamic cleaning rate constant. There are a number of engineered cleaning fluids on the market, which complicate the user's ability to select the best product for the application. What are the factors that make one cleaning fluid better than competing offerings? Why do these materials offer better cleaning under flush mounted chip caps?

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