Optimized Static and Dynamic Driving Forces for Removing Flux Residue under Flush Mounted Chip Caps

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Abstract

Removal of flux residue under highly dense chip caps presents a difficult cleaning challenge. Chip caps are flush mounted to the circuit card. Upon reflow, flux residue fills the gap under the chip cap. Cleaning fluids must wet, dissolve, penetrate the flux dam, and flow under the component to adequately remove all flux residues. Increased board density, miniaturization, and Pb-free soldering magnify this problem. To address this problem, process parameters in the form of cleaning temperature, time, cleaning chemistry concentration, and impingement energy must be considered. This paper presents the results from a designed experiment of an advanced cleaning fluid combined with an optimized inline spray-cleaning machine for removing flux residue under flush mounted chip caps.

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 under flush mounted chip caps, 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 designed experiment is to determine optimize chemical and mechanical forces required to remove flux residue under flush mounted chips caps.

Problem Statement

Chip caps, flush mounted to the board, 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. Devices placed in tightly packed arrays further increase the cleaning difficulty, as there is very limited access for the cleaning fluid to reach the contaminant. 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 difficulty, some ingredients used to improve cleaning speed can darken or etch solder joints or affect part markings and labels. The mechanical driving forces require optimization in nozzle design, selection and positioning to address difficult cleaning challenges on the board. Even with improved chemical and mechanical forces, time is a critical factor. 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 and 2 illustrate examples of flush mounted chip caps. 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. Chip caps positioned in series may increase the difficulty of the cleaning fluid to penetrate under the chip cap. The number of reflow cycles or increased reflow temperatures, such as those used for Pb-free increase cleaning difficulty. The thickness of solder paste increases the level of flux residue under the chip cap, which creates a more difficult cleaning challenge (Figure 2)

Figure 1: Chip caps in Series

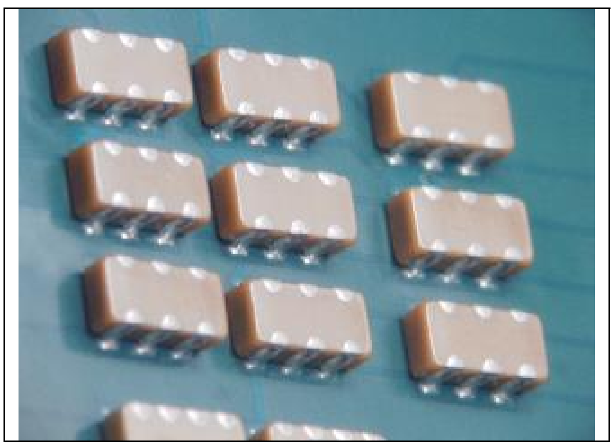
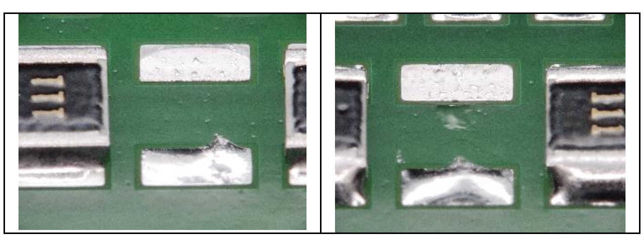


Figure 2: Solder Paste Thickness



Normal Print Heavy Print

Literature Review

Inline and batch spray-in-air cleaning systems reduce the time to clean printed 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.

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, cleaning becomes more difficult. The standoff height of flush mounted chip caps is typically less than one mil. 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 removal 100% of residue. Lower dynamic surface tension allows cleaning fluids to penetrate and dissolve the flux at a faster rate, which decreases time to achieve breakthrough.

Once cleaning fluids start to penetrate the gap under the chip cap, experiments reveal one of two possible mechanisms occurs. For hardened flux residues, concentric cleaning removes the flux residue in ever-increasing diameters driven by dissolution of the flux in the cleaning solvent (Figure 3). Softer flux residue cleans at a faster rate through channeling where the cleaning fluid penetrates in rapidly developing channel inside the reflowed flux mass (Figure 4). Several variables point to the degree of difficulty for cleaning flux residue. Higher reflow temperatures harden the flux resins, increasing cleaning difficulty. Time after reflow increases cleaning difficulty to a point. Conversely, boards reflowed in nitrogen leave the flux residue soft and improve the cleaning rate. Additionally, boards cleaned soon after reflow improves the cleaning rate.

Figure 3: Concentric Cleaning (Hard Residue)

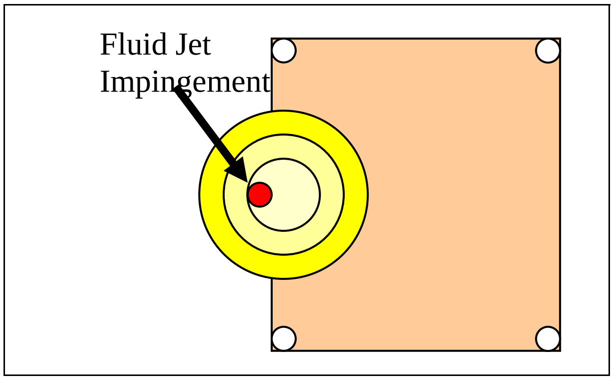
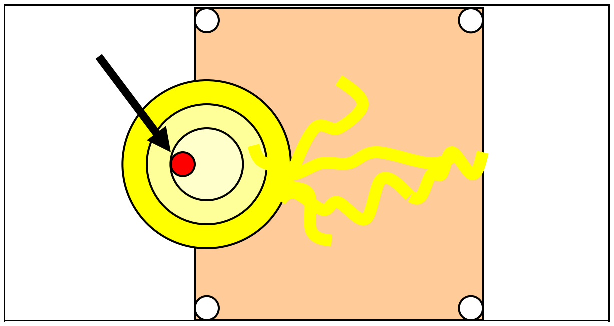
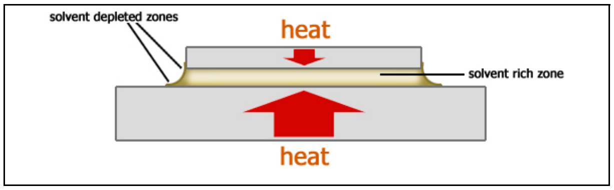


Figure 4: Channeling (Soft Residue)



The middle of the flux is softer and more easily breached by pressurized cleaning solvent (Figure 3). The soldering process causes the heat to drive the solvent molecules toward the center of the flux creating a solvent rich zone. This solvent rich zone is softer and more easily penetrated and dissolved. Conversely, a solvent depleted zone is created next to the heated and exposed surfaces. When a zone is solvent depleted it becomes harder and more crystalline and thereby significantly more difficult for cleaning agents to soften and dissolve.

Figure 5: Flux Degassing



Static Cleaning Fluid Design

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 clean under chip caps, critical design features must improve the static cleaning rate, wetting, low surface tension, low foam, and protection of the alloys, labels and other board components.

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 open the process window and allow uses 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 tension can be thought of as a balloon of sorts surrounding the cleaning. Surface-active agents create a thin and weak droplet that improves capillary action needed to wet under 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.

Foam is a critical parameter when using high impingement sources. Foam increases surface tension and allows millions of air bubbles to entrain within the cleaning fluid. Foam causes pumps to cavitate and kills cleaning effectiveness under tight standoffs. Foam can also be concentration dependent. When cleaning under chip caps, users must understand the foaming characteristics of the cleaning fluid. Does the cleaning fluid foam at low concentrations? Cleaning fluids that generate no foam at low or high concentrations are the best choice when cleaning under low standoffs.

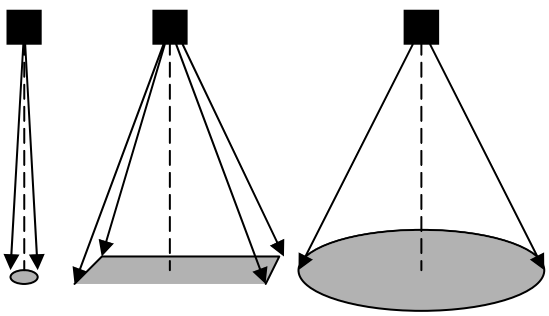
Saponification is a common method of cleaning flux residue. Alkaline materials react with the resin structure to form a water-soluble soap. Most aqueous cleaning fluids use some form of saponification. To protect the alloy and other soft metals, minor ingredients help to prevent alkaline attack to the alloy. Dull solder joints occur when the cleaning fluid leaches Sn/Pb from the surface of the solder. Properly designed materials produce solder joints that are not attacked and render a bright and shinny solder joint.

Mechanical Cleaning Design

Nozzles are used in air spray systems to create jets that carry the energy to the surface of the part to be cleaned. The kinetic energy of the jet at the surface of the board is determined by the nozzle type (see figure 6) driving pressure (manifold pressure), position (distance and angle of the Jet relative to the most distant surface to be cleaned) and the type of nozzle used.

Conical and fan nozzles spread the spray to cover larger areas at the expense of reducing the mass per unit and velocity of the jet. Coherent jets hold together longer and thus deliver more energy over a greater distance.

Figure 6: Comparison of Fluid Jets
Coherent, Fan, and Conical Jets



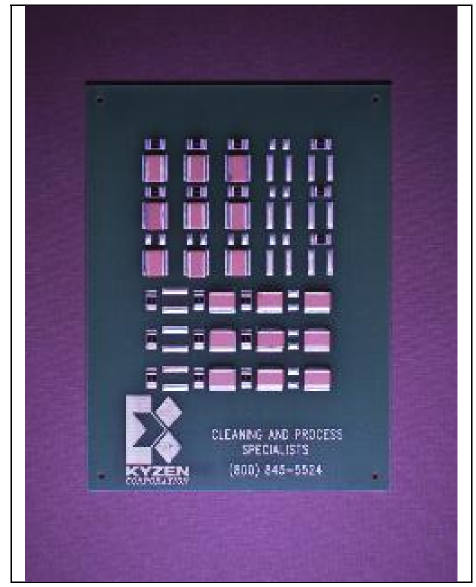
All jets will break-up and slow down over distance in air. Coherent jets hold together longer giving the maximum energy transfer per unit area at greater distances. Overlapping jets can be an effective strategy for increasing surface energy density as long as the splash at the surface does not dampen the impact force.

The inline cleaner design used for testing utilized two banks of overlapping Delta Fan Jets set at a 15 degree angle followed by three banks of vertical 0.060" Coherent Jets on 0.5" centers. The manifold was set 4.0 inches off the belt. The manifold pressure was set to 40 lbs/ in.^{2}.

Methodology

The objective of the designed experiment is to understand the time in the wash section of the cleaning machine required to clean 1210 and 1825 chip caps on the Kyzen test card (Figure 6). Six solder pastes will be evaluated, three eutectic and three Pb-free. The solder pastes are industry standard materials use by many Class 3 and Class 2 board designs. After cleaning, the components will be removed from the test board and the percentage of flux level under the component will be graded. The data will be analyzed quantitatively.

Figure 6: Test Board Design



The components were reflowed using a standard eutectic Sn/Pb solder profile for the eutectic solder pastes and a ramp-to-spike Pb-free profile for the Pb-free solder pastes. The component placement positions component where the leading and trailing gap is sandwiched in between two, chips, one chip, and no chips. This variable will not be broke out during the data analysis.

The design matrix (Figure 7) outlines the process variables used to run the designed experiment. The cleaning temperature for this experiment was fixed at 150°F. Six boards were run for each solder paste in the matrix. The cleaning fluid time, which correlates to soak and impingement in the wash section, represents the variable studied in this experiment. Previous designed experiments found that the critical variable for cleaning under flux mounted chip correlates positively to soak and impingement time in the wash. The times studies were 2 minutes, 3 minutes, 4 minutes, 6 minutes, and 8 minutes, which represents soak and impingement time in the wash section. This variable measures the importance of soak and impingement time to achieve 100% cleaning under all chip caps on the board. The experiment also studied the static cleaning rate to understand the correlation that impingement spray pressure contributes to the cleaning process. The board was immersed in the wash tank for 10 minutes and run through the rinse and dry section in the inline. This data point determines the level of cleaning with no impingement applied from the wash section.

The test matrix fixed the cleaning fluid at 15% concentration and wash temperature of 150ºF. Data from previous designed experiments suggests that higher cleaning concentration marginally improves cleaning performance. For example, if the concentration were elevated to 20% concentration, the data suggests that cleaning will improve, but the improvement will not significantly reduce wash soak and impingement time. The temperature was set at 150ºF since previous designed experiments correlate higher temperature with improved cleaning under flush mounted chip caps.

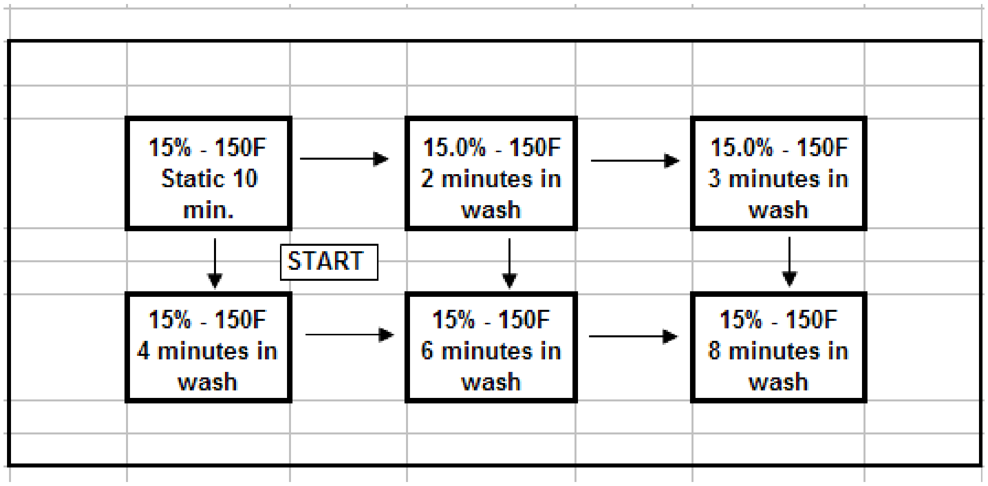
The chip caps were placed on the test board in a horizontal and vertical direction. Two sides of the chip caps were sealed, which allow the fluid to penetrate from either the vertical position or the horizontal position. Coherent nozzles were used in the wash section, which form a circular pattern upon contact. When using coherent nozzles, we would hypothesize that component place would have no affect on cleaning results. There are nine 1210 and 1825 chip caps placed in both the vertical and horizontal directions.

The research hypotheses:

H_1: The time in the wash zone correlates to improve cleaning under flush mounted chip caps.

H_2: Component placement in the vertical or horizontal position exhibits a weak correlation to improved cleaning from vertical or horizontal direction.

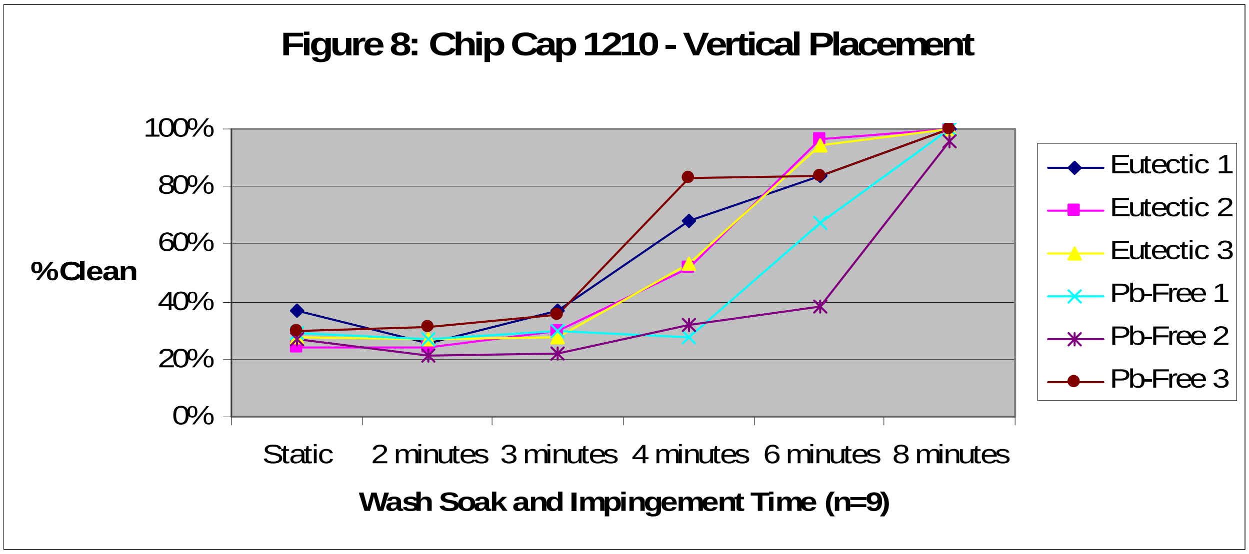
Figure 7: Test Matrix



Data Analysis

The data reports the mean percentage of flux residue remaining under nine 1210 and nine 1825 chips in the vertical and horizontal positions. The designed experiment tests the hypothesis that longer time in the wash section shows a strong correlation to improved cleanliness. Additionally, the designed experiment tests the hypothesis that part positioning on the board shows a weak correlation to part cleanliness.

selected represent the leading eutectic and Pb-free solder pastes used by assemblers. Previous experiments suggest that Pb-free cleaning is more challenging to clean but the data shows similar performance characteristics. To achieve 100% flux residue removal, the part requires roughly eight minutes in the wash section. The data support hypothesis one that infers that longer time in the wash is needed to achieve 100% cleaning under flush mounted chip caps.



Components were removed from all test boards, and the flux residue viewed and graded by a single individual, to score the percentage flux residue under the chip cap. The data reports the mean value for nine sites on both the 1210 and 1825 chip cap in the vertical and horizontal position for the six test conditions (Figure 7).

Figure 8 illustrates the test data for the 1210 chip cap placed in the vertical position. The data suggests a positive correlation for improved cleaning from increased time in the wash section. The solder pastes

Figure 9 reports the data for the 1210 chip cap placed in the horizontal position. The data shows a weak correlation to improved cleaning from component positioning. The supports hypothesis two that infers that cleaning will performance at a similar rate regardless of positioning when using coherent nozzles. The circular pattern of the nozzle suggests that the directional spread of the cleaning fluid will be equally dispersed over the surface of circuit card. The data shows remarkable consistency to the level of flux residue found under the chip caps.

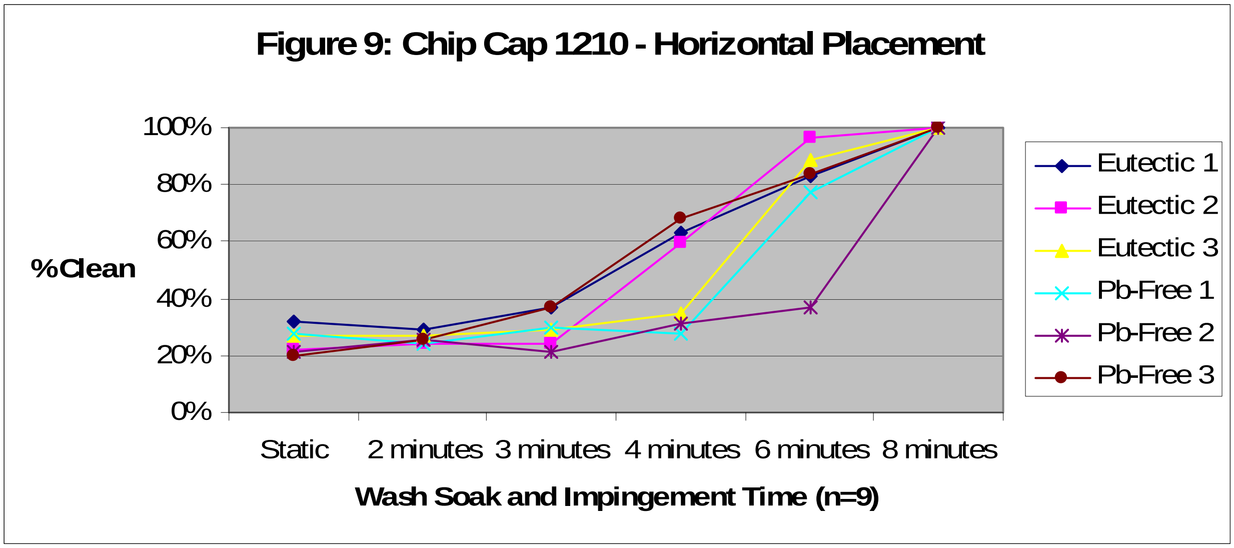


Figure 9: Chip Cap 1210 - Horizontal Placement
100%
80%
60%
40%
20%
0%
%Clean
Static
2 minutes
3 minutes
4 minutes
6 minutes
8 minutes
Wash Soak and Impingement Time (n=9)
Eutectic 1
Eutectic 2
Eutectic 3
Pb-Free 1
Pb-Free 2
Pb-Free 3

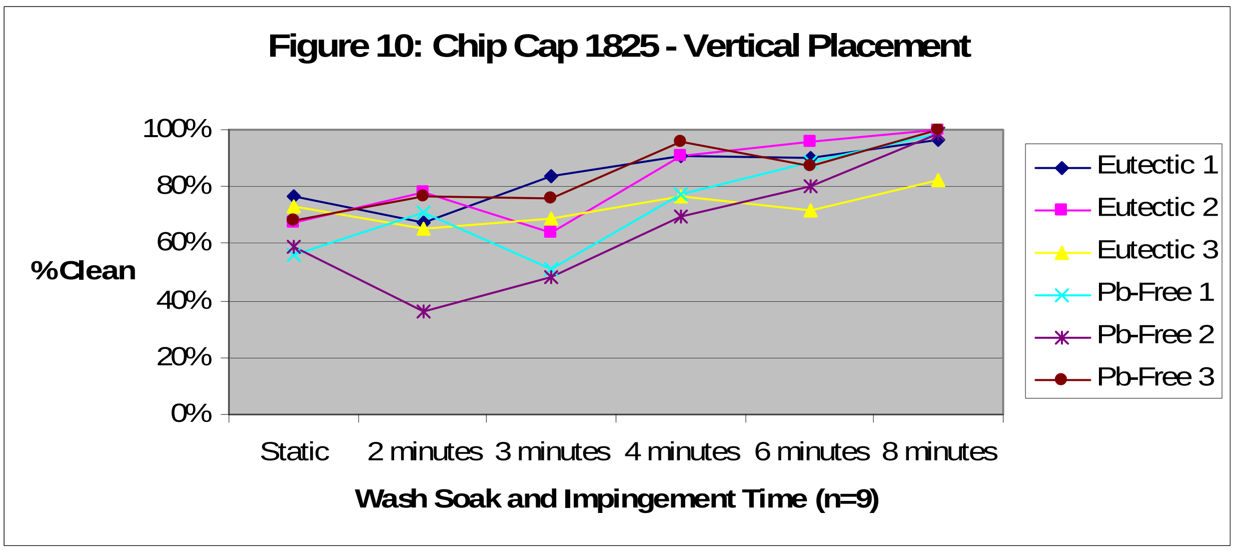


Figure 10: Chip Cap 1825 - Vertical Placement
100%
80%
60%
40%
20%
0%
%Clean
Static
2 minutes
3 minutes
4 minutes
6 minutes
8 minutes
Wash Soak and Impingement Time (n=9)
Eutectic 1
Eutectic 2
Eutectic 3
Pb-Free 1
Pb-Free 2
Pb-Free 3

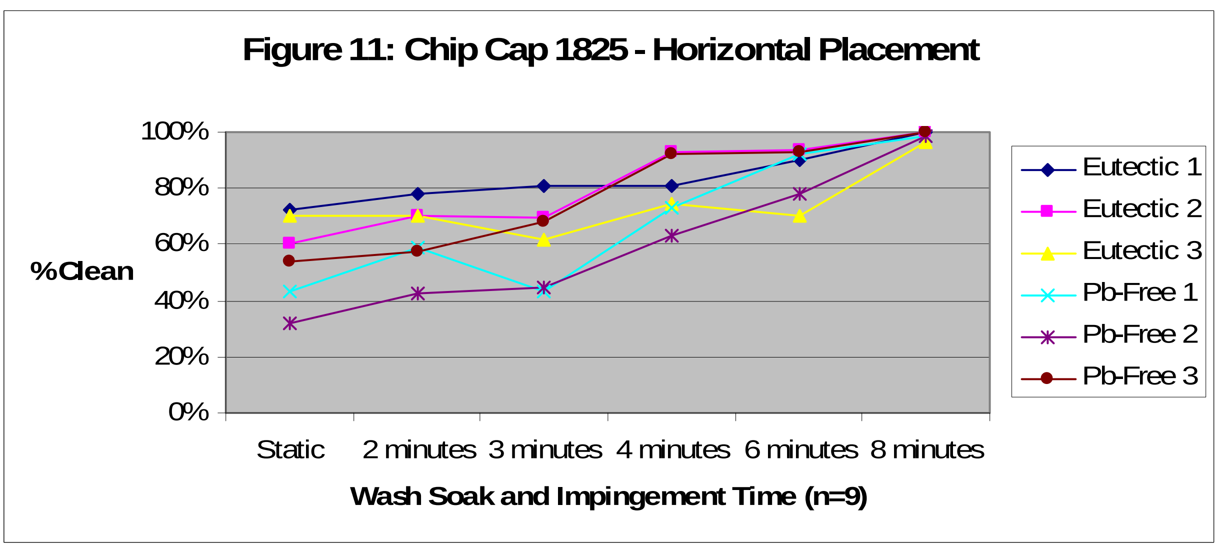


Figure 11: Chip Cap 1825 - Horizontal Placement
100%
80%
60%
40%
20%
0%
%Clean
Static
2 minutes
3 minutes
4 minutes
6 minutes
8 minutes
Wash Soak and Impingement Time (n=9)
Eutectic 1
Eutectic 2
Eutectic 3
Pb-Free 1
Pb-Free 2
Pb-Free 3

Figures 10 and 11 illustrate the data for the 1825 chip cap, which represents the larger chip cap on the Kyzen test board. Similar to the 1210 chip cap, cleaning showed a strong correlation with the length of time in the wash section. The data suggests a slight cleaning improvement from parts cleaned in the vertical position. Additionally, the data suggests a higher percentage of flux residue removed at shorter wash times but a lower percentage of flux residue removed at the eight minute time window. The residue remaining under the 1825 chip cap was near the solder filet, which we believe is due to flux degassing (see Figure 5).

The 1825's cleaned faster than the 1210's. This could be due the larger volume of flux deposited, however previous testing suggest this could be due to a higher degree of de-gassing associated with the smaller flux volume. In small volumes of flux they loose the solvents faster and can thus require additional softening time to begin active cleaning.

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 military and medical assemblers, who require 100% of the flux residue removed. When total flux removal under chip caps is a requirement, the authors recommend that assemblers specify longer wash sections when using inline-cleaning equipment. For batch cleaning designs, longer wash cycles address the issue of time. Inline cleaning machines wash sections range from 18" to 60" in length. A machine with an 18" section requires an extremely slow belt speed to achieve eight minutes in the wash section. To assure 100% cleanliness, longer wash sections should be specified from the inline cleaning Machine Company.

The data suggests that nozzle section improves cleaning under flush mounted chip caps. This experiment tested coherent nozzles for two reasons. The impingement force to the board is greater with coherent jets, Secondly; coherent jets provide a circular direction that provides impingement from all directions on the circuit card. Past experiments also find success with high flow delta fan nozzles. Delta fan-jets direct the fluid on a perpendicular direction to the board surface. This could reduce cleaning effectiveness on parts positioned in the vertical direction. To address this concern, higher flow nozzles are recommended when using delta fan-jets. Past data suggests that the flooding action onto the board surface improves penetration under flush mounted parts. Additionally, past data suggests that a 10-15 degree manifold angle at the entrance and exit side of the machine improves cleaning efficacy.

When selecting an engineered cleaning fluid, multiple functionality is needed. The cleaning fluid should exhibit a high static cleaning rate, which correlates with the cleaning fluids ability to rapidly dissolve flux residue. For cleaning under flush mounted chip caps, low surface tension and capillary action are needed to penetrate the gap at a more rapid rate. The cleaning fluid must not foam, as this will increase surface tension and reduce cleaning efficacy. The cleaning fluid should not aggressively attack and dull solder joints. Chemical attack onto the solder joint leaches small levels of the solder alloy from the surface of the solder.

When cleaning under flush mounted chip caps, cleaning temperature must be considered. Many of the advanced cleaning fluids operate at lower operating temperature, which reduces cleaning chemistry usage. When cleaning under flush mounted chip caps, higher processing temperatures softens the flux residue and cause the residue to expand. This allows the cleaning fluid to dissolve the residue at a more rapid rate, which reduces the time required in the wash section.

Conclusion

Removal of flux residue from under flush mounted chips caps is a difficult cleaning challenge. The designed experiment tested cleaning efficacy as a function of time and directional placement for removing flux residue from under flush mounted chip chips. The data suggests a strong correlation to time in the wash section to achieve 100% cleaning of multiple chip caps placed onto a printed circuit assembly. The data also suggests that coherent jets cleaning well and offer flexibility in placement of chip caps onto the board surface.

An optimized cleaning process requires the right balance of static and dynamic cleaning forces. When using inline-cleaning equipment, the length of 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 eight minutes 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 surface tension effects of the cleaning fluid to part cleanliness. Does lower surface tension equate to improve cleaning under the chip cap? A designed experiment of similar cleaning fluids that vary in surface tension affects adds to the body of data and knowledge currently known on surface wetting.

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?

Additional testing of temperature affects is needed to determine the cleaning temperatures that remove 100% of the flux residue under flush mounted chip caps. This experiment fixed the temperature at 150ºF. Would a lower temperature achieve similar results? This is an important question since lower cleaning fluid temperature improves cost of ownership.

Following on testing of nozzle design and flow is needed. Does a Delta fan jet at high flow better than a coherent jet? Do nozzle angles improve cleaning under flush mounted chip caps? There is very little published data studying this issue.

Authors

Mike Bixenman is the CTO of Kyzen Corporation. Kyzen is the world market leader for engineered cleaning targeted at electronic assembly and advanced packaging process cleaning. Mr. Bixenman has over 16 years field experience in the design and processing of cleaning fluids within high technology manufacturing environments.

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This paper is the third in a series of papers the studied advanced processing of cleaning fluids. For copies of previous submissions, please email either Kyzen (mike_bix@kyzen.com) or Austin American Technology (stevestach@aat-corp.com)