Optimizing Batch Cleaning Process Parameters for Removing Lead-Free Flux Residues on Populated Circuit Assemblies

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ABSTRACT

Electronic assembly cleaning processes are becoming increasingly more complex because of global environmental mandates and customer driven product performance requirements. Manufacturing strategies today require process equivalence. That is to say, if a product is made or modified in different locations or processes around the world, the result should be the same. If cleaning is a requirement, will existing electronic assembly cleaning processes meet the challenge? Innovative cleaning fluid and cleaning equipment designs provide improved functionality in both batch and continuous inline cleaning processes. The purpose of this designed experiment is to report optimized cleaning process parameters for removing lead-free flux residues on populated circuit assemblies using innovative cleaning fluid and batch cleaning equipment designs.

INTRODUCTION

High growth electronic products require performance on demand and miniaturization accelerating the need for thinner and highly dense circuitry. Miniaturization is constantly imposing new criteria and challenges on the cleaning process. One such challenge is the removal of all soldering residues adjacent to fine pitch components and under Z-axis area array, leadless chip carriers, and chip cap components.

Aqueous inline spray-in-air in combination with engineered cleaning materials creates a path for removing surface and Z-axis residues from the populated circuit assembly. The problem is that not all manufacturing operations have the capacity, utilities, or floor space to support an aqueous inline cleaning process. Process Equivalence (the ability for spot cleaning, batch, and inline cleaning equivalence) is a core need within electronic assembly manufacturing operations. The focus of this research is to develop process variables that provide process equivalence between aqueous inline and batch cleaning processes for cleaning flux residues under the Z-axis.

ARTICLE SUMMARY

The Research in Brief – the core research: With the advent of SMT in the 1980's, a need arose to clean gaps of less than 5 mils that were fully filled with flux (Figures 1&2). The core research of this paper focuses on this cleaning challenge because it is considered one of the most difficult cleaning challenges faced by manufacturing engineers when designing cleaning processes that achieve the demands of building today's circuit designs.

Figure 1: Heavily populated with Leadless Chip Carriers (one removed to show flux residue)

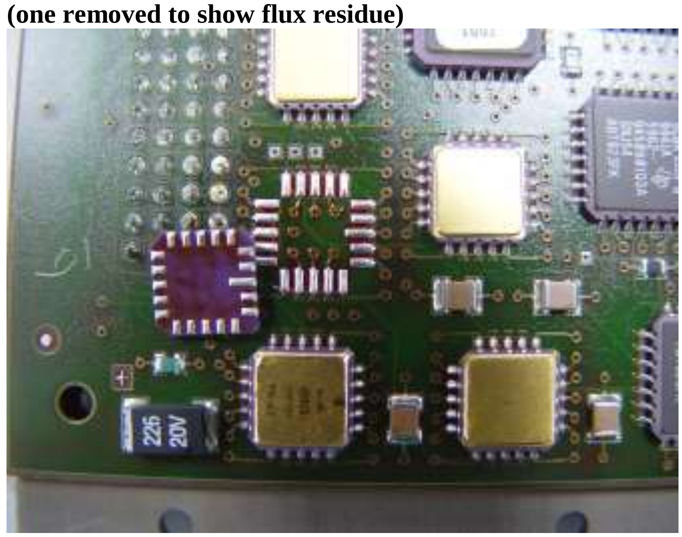
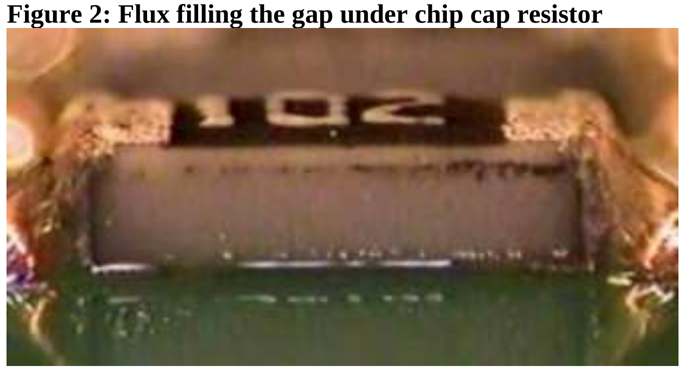


Figure 2: Flux filling the gap under chip cap resistor



Test boards were built and populated with 1210 and 1825 chip cap resistors using one eutectic and five lead-free solder pastes. The solder pastes represent leading low residue, and in some applications, eutectic and lead-free no-clean soldering materials. The research studied process variables needed to remove flux residues under the Z-axis using an aqueous batch dishwasher style cleaning equipment.

The Research in Practice – applying the data findings:
Inspection standards are designed around what we can see or what we can dissolve. If the flux remains trapped under tightly spaced components, we probably will not see it, and we may not measure it on a cleanliness test. In reality, an assembly could meet the IPC "ROSE" cleanliness test and the visual inspection standards with significant quantities of flux remaining under surface resistors, capacitors, transistors, LCC's, and other tightly spaced "leadless" components. In this study, components were removed both physically and with de-soldering tools to grade the flux remaining.

High energy in-line cleaners have typically been successful in removing flux in filled gaps at belt speeds of 0.6fpm[1] to 1.5fpm[2]. Batch cleaners typically have not proven as successful[3] due to an inherent lower level of physical cleaning energy in comparison to in-line cleaners.

Establishing "process equivalence" between in-line cleaners and batch cleaners assures an equal result in both cleaning processes. This is highly desirable if a company is manufacturing in multiple assembly locations or with different contract manufacturers. This leap in batch process performance requires rethinking the cleaning rate fundamentals.

The data findings indicate the benefit of increased wash temperature and time. Increasing wash temperature approaches rosin and resin melting points. Approaching rosin and resin softening points expands the residue under the Z-axis. Surface tension and temperature effects create a set of forces that allow the flux to seep out from under the component. The cleaning material rapidly dissolves and penetrates the Z-axis in the absence of high impingement energy. These forces combine to clean flux residues under the Z-axis when processed in batch style dishwasher cleaning equipment.

PROCESS CLEANING RATE

The inferences from the cleaning rate theory[4] predict two parts to the total cleaning rate; one component is the static rate, the other is the dynamic rate. The static rate plus the dynamic rate equals the process cleaning rate. This relationship is expressed in Equation 1.

Equation 1: Process cleaning rate equation: $R_p = R_s + R_d$
Where;
Process cleaning rate = R_p
Static cleaning rate = R_s
Dynamic cleaning rate = R_d

The static cleaning rate is the rate at which the cleaning material dissolves flux residues in the absence of impingement energy. The static rate is determined by placing the test assemblies in an uncirculated dip tank and calculating the time required to dissolve surface flux residues. The static rate depends upon the residue and the cleaning agent being used. It is influenced by temperature and, in aqueous solutions, the engineered cleaning fluid composition and in-use concentration.

The cleaning fluid design influences the static cleaning rate. Aqueous engineered cleaning materials are formulated with solvating materials, builders that soften or react with the flux residue, wetting agents that drop surface tension, and minor ingredients to control foam and protect metal alloys. Cleaning material design influences the dissolution rate, saponification, foam propagation, material compatibility, bath life, and metal inhibition. Best in class cleaning materials dissolve all types of flux residues including polymerized and charred residues; penetrate and wet under low standoffs; offer a wide compatibility window on materials of construction; break surface foam at rate greater than foam build; low in toxicity and odor; and protect metal alloys during the cleaning process.

The dynamic rate is the energy forces applied from the machine and its fluid delivery system. The dynamic cleaning component is directly related to fluid flow, fluid pressure at the board surface, and directional forces delivered to the surfaces and gaps to be cleaned.

Spray-in-air inline cleaning equipment provides a platform delivering spray impingement perpendicular or angled to the circuit board being cleaned. Batch cleaning designs use both spray impingement, spray under immersion, and ultrasonic energy forces. The batch cleaning machine dynamic rate commonly applies less energy forces over the surface of the circuit board than does the inline cleaning machine.

The dynamic cleaning rate decreases the process cleaning rate. In a typical spray-in-air cleaning machine, the time needed to clean all residues under the Z-axis is commonly less than 10 minutes of direct spray impingement. In the absence of fluid force, fluid pressure, and directional forces consistently applied to the substrate, residue removal is inconsistent at best. Additionally, flux residues trapped under low standoff components create a flux dam and requires energy consistently applied to develop a wide process window.

Batch dishwasher cleaning equipment applies pump pressure and flow to power dynamic energy through rotating and fixed spray jets. Racking and board placement commonly shields some of the assemblies from spray impingement. The inconsistent dynamic forces applied within the cleaning chamber create cleaning variability under Z-axis components.

PROCESS EQUIVALENCE

Most batch cleaning processes are capable of meeting IPC visual standards on the exposed surfaces. This has been accomplished by optimizing the cleaning fluids and delivery systems. Reaching flux residues trapped under tightly spaced components in a batch cleaner remains a daunting task.

The search is on to bring batch cleaners to an in-line level of performance in removing residues from tight gaps. Lead-free and "no-clean" fluxes can be particularly challenging. The key may lie in the thermodynamic nature of the residue itself.

Removing the residues in a batch cleaner format requires a different approach. The research question asked: What can be done to change the nature of the residues themselves to further optimize batch cleaning rates? Of course, we could not reformulate the solder paste, but we can change the modulus of the flux matrix by heating it beyond its softening point. This paper describes the results of testing performed to evaluate this concept.

HYPOTHESES

H_1: Soft residues require less time to remove flux under the Z-axis

H_2: Wash time is a critical variable when removing flux under the Z-axis

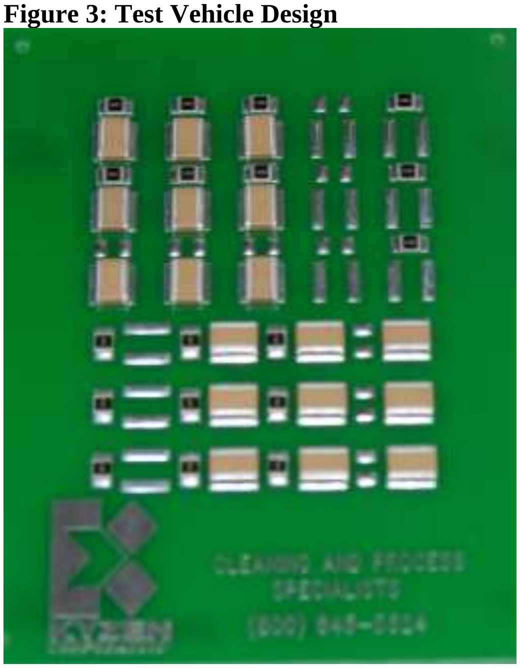
H_3: The rate of residue removal under the Z-axis doubles with 18°F rise in wash temperature

H_4: Pre-heating the circuit cards before cleaning softens the flux residue and increases the cleaning rate

METHODOLOGY

The research design compared one eutectic low residue solder paste and five lead-free low residue solder pastes. Figure 3 illustrates the test vehicle populated with eighteen 1210 chip cap resistors and eighteen 1825 chip cap resistors. Both the 1210 and 1825 chip caps are sealed on two sides with nine caps each placed with the opening in the horizontal position and nine caps each placed with the opening in the vertical position. The strategic placement of the caps shields the egress of the cleaning material to the soil with six caps shielded on one side, six caps shielded on two sides, and six chip caps with no shielding.

Figure 3: Test Vehicle Design



During reflow, the surface tension of the flux residue covers the entire Z-axis under the 1210 chip cap. This forms a flux dam and prevents fluid flow under the cap until the dam is remove from both the static and dynamic cleaning forces. The 1825 is a larger chip cap resister that is packed with flux residue, but not all the caps are totally filled. Some of the 1825s form a flux dam and others leave a small channel for cleaning material to penetrate and flow.

Of the five lead-free solder pastes selected, three form hard residues. Removal of hard residues typically requires longer wash times. Cleaning takes the form of concentric cleaning action; similar to peeling an onion. Two of the lead-free solder pastes form soft residues, which dissolve into the cleaning solution at a faster rate. Cleaning takes the form of channeling, with the dynamic energy pushing the cleaning fluid through the soils, which promotes rapid dissolution. The selection of hard and soft residues is a criterion used when designing for manufacturability.

The factorial experiment evaluated the variables of wash time, wash temperature and wash time. The engineered cleaning material evaluated at a concentration of range of 9-18% with 2% inhibitor added sump-side. The inhibitor design prevents dulling of solder propagated when exposing the circuit assembles to long wash times and high wash temperatures.

As a baseline for removing all flux residues under the Z-axis, three sets of test boards were processed as controls using an aqueous inline cleaning machine. The same engineered cleaning material was fixed at a concentration of 18%. No inhibitor was added. The inline wash used progressive energy dynamics designed to improve Z-axis penetration (Figure 4).

Figure 4: Progressive Energy Dynamics

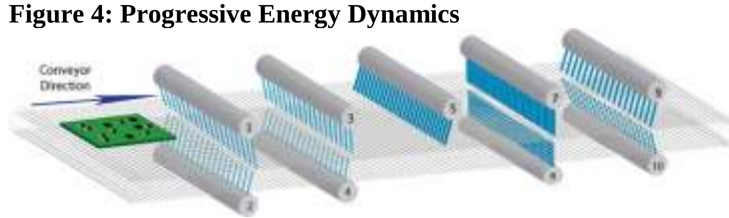


Table 1 lists the factors used to process the three sets of test boards.

Table 1: Spray-in-air inline factors

Inline Test	Wash temp.	FPM	Wash time
Test 1	145-150°F	1.5	2.0 minutes
Test 2	145-150°F	0.7	4.28 minutes
Test 3	130-140°F	0.3	9.0 minutes

Seven sets of test boards were processed in a programmable electronic assembly aqueous batch dishwasher cleaning machine. The stainless steel chamber contains a heating element that elevates the wash cleaning material to desired operating temperatures. Due to the limitations of shielding and inconsistencies of spray impingement across all board surfaces, the variables tested were wash temperature, wash time, and wash concentration. One set of boards was placed in an oven to pre-heat the boards at 200°F to determine if the pre-heat softens the flux residue and promote easier removal during processing.

The wash cleaning solution took time to reach the upper temperature set point. When transferring the wash material from the holding tank, 5 minutes was required to increase the wash temperature from 130-150°F; 10 minutes to increase the wash temperature from 130-175°F, and 15 minutes to increase the wash temperature from 130-200°F. Table 2 lists the factors used to process the seven set of test boards.

Table 2: Batch dishwasher factors

Batch Test	Pre-heat @ 200°F	Wash temperature	Wash Conc.	Total wash time
Test 1		130-150°F	18%	15 minutes
Test 2		130-150°F	18%	40 minutes
Test 3		130-175°F	18%	25 minutes
Test 4		130-200°F	18%	40 minutes
Test 5		130-200°F	9%	40 minutes
Test 6		130-200°F	5%	40 minutes
Test 7	10 min.	130-200°F	18%	40 minutes

DATA FINDINGS

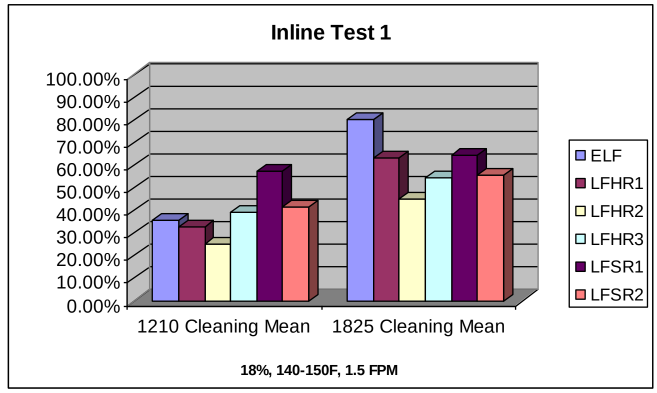
All 1210 and 1825 chip cap resisters were removed from the processed test boards. For this paper, the mean values of the flux residues left under the chip caps are reported. The boards were inspected with 10-30x and graded by a qualified expert.

The six solder pastes use the follow acronyms in the data sheets.

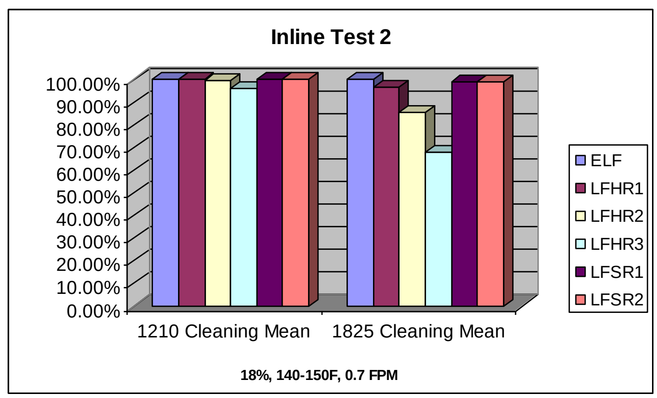
- Eutectic Low Residue ~ ELR
- Lead-Free Hard Residue ~ LFHR
- Lead-Free Soft Residue ~ LFSR

Spray-in-air control test boards

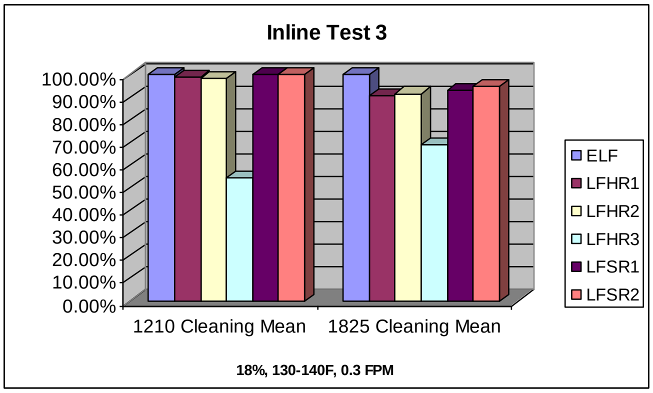
Inline Test 1 processed the boards at 1.5 FPM (2 minutes wash time). The mean value of the LFHR pastes cleaned under 1210 chip caps ranged from 25-40% flux residue removed under the chip caps. The LFSR pastes cleaned under 1210 chip caps ranged from 40-60% flux residue removed under the chip caps. For the 1825 chip caps, cleaning was closer for the LFHR and LFSR and ranged from 50-75% flux residue removed under the chip caps. The data findings indicate that soft residues were more easily removed, which is consistent with the first research hypothesis.



Inline Test 2 processed the boards at 0.7 FPM (4.28 minutes wash time). The mean value of the LFHR pastes cleaned under 1210 chip caps ranged from 95-100% flux residue removed under the chip caps. The LFSR pastes cleaned under the 1210 chips caps was 100% removal. For the 1825 chip caps, cleaning under the LFHR ranged from 70-96% flux residue removed under the chip caps. For the 1825 LFSR, 99% of flux residue was removed under the chip caps. The data from Inline Test 2 correlates with the second research hypothesis that infers wash time and soft residues are critical variables for cleaning under the Z-axis.

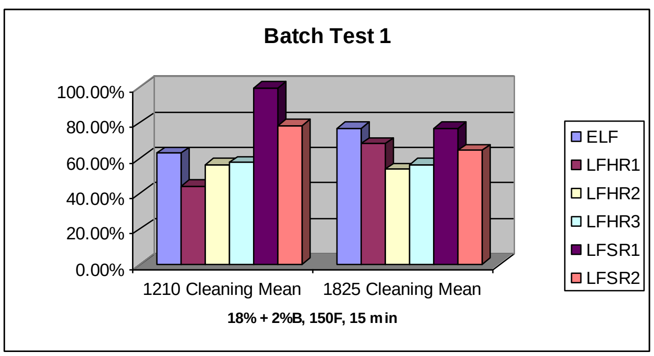


Inline Test 3 processed the boards at 0.3 FPM (9.0 minutes wash time). There was an oversight when processing this set of test boards. The wash was not up to temperature with the boards being processed at a temperature range of 130-140°F. This resulted in two changed variables of wash time and wash temperature. The mean value of the LFHR pastes cleaned under 1210 chips caps ranged from 55-99% flux residue removed under the chip caps. The LFSR pastes cleaned under 1210 chip caps was 100% flux removal under chip caps. For the 1825 chip caps, the LFHR removed 69-92% and the LFSR removed 92-94% flux residue under the chip caps. Based on the data findings from Inline Test 2, we would have anticipated 100% clean boards at the longer wash time. The impact of wash temperature correlates with the third research hypothesis, which suggests that the rate of residue removal doubles with 18°F rise in wash temperature.

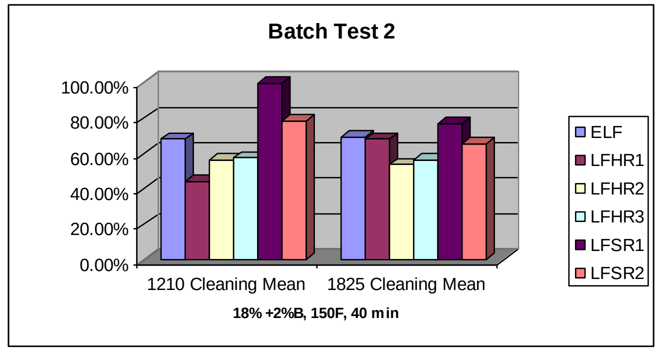


Batch Dishwasher Processed Test Boards

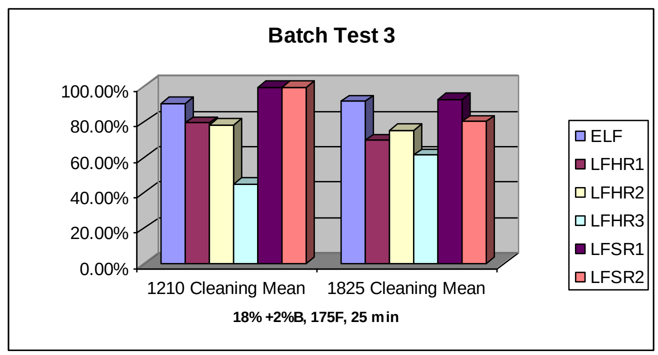
Batch Test 1 processed the boards using a wash time of 15 minutes (5 minutes to come up to 150°F wash temperature and 10 minutes at 150°F wash temperature). The mean value of the LFHR pastes cleaned under 1210 chip caps ranged from 45-58% flux residue removed under the chip caps. The LFSR pastes cleaned under 1210 chip caps ranged from 78-100% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 54-68% and cleaning under the LFSR 64-77% flux residue removed under the chip caps. The data findings indicate that a higher level of soft flux residue was removed under the Z-axis, which is consistent with the first research hypothesis. The data indicates that longer wash time is needed to clean under the Z-axis in the batch dishwasher design due to the lower dynamic cleaning rate.



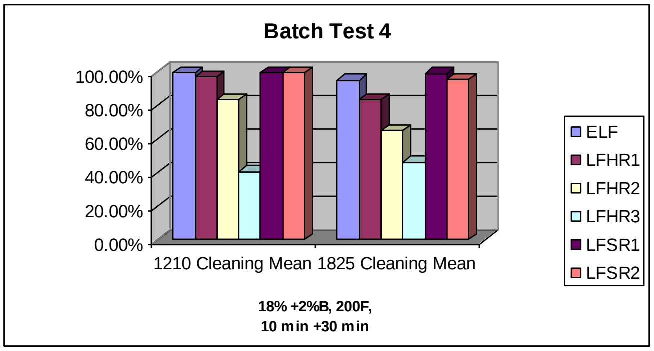
Batch Test 2 processed the boards using a wash time of 40 minutes (5 minutes to come up to 150°F wash temperature and 35 minutes at 150°F wash temperature). For the 1210 chip caps, cleaning under the LFHR ranged from 44-58% and cleaning under the LFSR 66-77% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 54-68% and cleaning under the LFSR 66-77% flux residue removed under the chip caps. The data findings indicate that no improvement over Batch Test 1 from an additional 25 minutes wash time. This finding rejects the second research hypothesis that infers higher wash time improves the static and process cleaning rate.



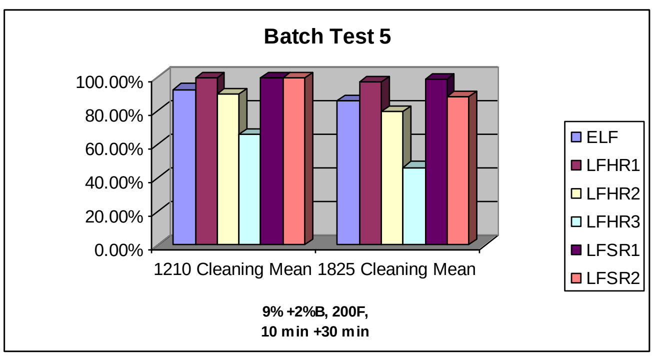
Batch Test 3 processed the boards using a wash time of 25 minutes (5 minutes to come up to 175°F wash temperature and 20 minutes at 175°F wash temperature). For the 1210 chip caps, cleaning under the LFHR ranged from 45-80% and cleaning under the LFSR 100% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 61-75% and cleaning under the LFSR 80-93% flux residue removed under the chip caps. The data findings indicate cleaning improvement from higher wash temperature, which supports the third research hypothesis that the cleaning rate doubles every 18°F increase rise in wash temperature.



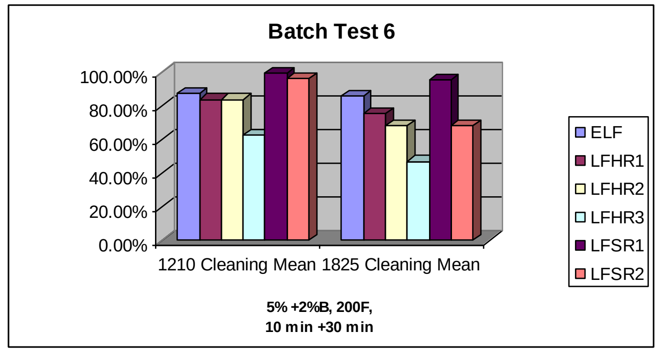
Batch Test 4 processed the boards using a wash time of 40 minutes (10 minutes to come up to 200°F wash temperature and 30 minutes at 200°F wash temperature). For the 1210 chip caps, cleaning under the LFHR ranged from 40-98% and cleaning under the LFSR 100% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 46-84% and cleaning under the LFSR 96-99% flux residue removed under the chip caps. LFHR3 cleaning feel off at the higher wash temperature but the other two LFHR solder pastes improved. The data findings support the first research hypothesis that soft residues are possible to clean under the Z-axis in a batch dishwasher machine and that cleaning typically improves with higher processing temperatures. The data findings also indicates that flux residues do not clean at the same rate and some materials must be matched to cleaning material and temperature effects.



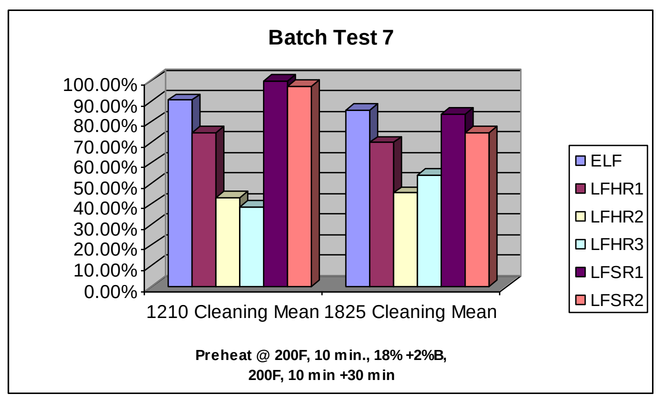
Batch Test 5 processed the boards at a concentration of 9% using a wash time of 40 minutes (10 minutes to come up to 200°F wash temperature and 30 minutes at 200°F wash temperature). The strategic thinking for reducing the wash concentration was to test the surface tension effects, which improve at lower wash concentration. For the 1210 chip caps, cleaning under the LFHR ranged from 66-100% and cleaning under the LFSR 100% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 46-79% and cleaning under the LFSR 88-99% flux residue removed under the chip caps. LFHR3 cleaning was consistent with Batch Test 4 with cleaning falling off at the higher wash temperature. Lowering the wash chemistry concentration indicates the importance of wash temperature but also indicates the value of matching the cleaning material to the soil matrix.



Batch Test 6 processed the boards at a concentration of 5% using a wash time of 40 minutes (10 minutes to come up to 200°F wash temperature and 30 minutes at 200°F wash temperature). The beneficial results obtained from dropping the concentration from 18% to 9% indicated the importance of wash temperature and dissolution properties of the wash chemistry. The question among the research team was what would happen if the wash concentration was dropped to 5%. For the 1210 chip caps, cleaning under the LFHR ranged from 62-84% and cleaning under the LFSR 96-100% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 47-76% and cleaning under the LFSR 69-96% flux residue removed under the chip caps. Decreasing the wash concentration from 9% to 5% slightly tailed off cleaning, which indicates optimal concentration range for the soil matrix.



Batch Test 7 first placed the test boards into a controlled atmosphere oven at 200°F oven using a wash time of 40 minutes (10 minutes to come up to 200°F wash temperature and 30 minutes at 200°F wash temperature) and wash concentration of 18%. For the 1210 chip caps, cleaning under the LFHR ranged from 39-75% and cleaning under the LFSR 97-100% flux residue removed under the chip caps. For the 1825 chip caps, cleaning under the LFHR ranged from 46-70% and cleaning under the LFSR 75-84% flux residue removed under the chip caps. Cleaning dropped off for most of the solder pastes flux residues after exposing the boards to the bake cycle. The thinking behind the bake cycle was to soften the residue before the cleaning cycle. The opposite effect of hardening the flux residue occurred, which rejects the fourth research hypothesis.



INFERENCES FROM THE DATA

Cleaning under the Z-Axis: Removing residues under low standoff components is a function of static and dynamic cleaning forces. Bixenman and Stach (2007)[6] studied dynamic cleaning forces for removing residue under Z-axis components. The research findings found the importance of fluid flow, pressure at the board surface, and directional forces. Optimizing spray jets using progressive energy dynamics reduces time needed to bridge the flux dam under the components, which improves the process cleaning rate.

To validate these findings, three sets of control test boards were processed using progressive energy dynamics. With the exception of one hard residue lead free paste, exceptional cleaning was achieved at an exposure time of less than 5 minutes. Optimizing the cleaning material static cleaning rate and dynamic cleaning energy conclusively improves the cleaning rate.

Temperature Effects: Batch dishwasher style cleaning machines does not consistently provide the same level of dynamic energy across the board surface. To achieve process equivalence with inline cleaning, a process must be developed to lower the dynamic energy required for physical removal and/or increase the static rate of dissolution.

Raising the temperature, improves the static rate, approximately doubling the rate of saponification for every 10°C increase in wash temperature. Increasing the temperature also improves solvency, the ability to dissolve more residue in a given volume of solvent, which directly improves the static rate of cleaning. The data findings indicate that batch wash temperatures 165ºF give a better cleaning result; even in tight spaces.

Softening the flux residues could play an important role. The reflowed flux residue remaining under the parts is a mixture of high molecular weight compounds collectively called resins or rosins. Most resins and rosins soften with temperature. These compounds usually have a softening temperature and a melting point that can vary by more than 50°F. The temperature range between the softening point and the melt temperature is the softening range. It turns out that rosin, the most common flux material, softens at a temperature of 165°F and melts at a temperature of around 212°F[5]. Resins generally used in fluxes have a similar to slightly higher softening range. By heating the part above the softening point of the flux matrix, the residue is softened and is rendered more susceptible to lower energy erosion, thus increasing the dynamic cleaning rate.

From the five lead-free solder pastes in this study, temperature affects significantly improved removal of residues under the Z-axis. One of the lead-free pastes had the opposite effect when increasing wash temperature. The data indicates that LFHR3 cleaning under the Z-axis dropped off when temperature rose.

Soil Selection: When cleaning high-density surface mount assemblies and under Z-axis components the data findings indicate that the selection of the solder paste be considered to ensure that every opportunity is taken to enhance the ability to clean. Lead-free soft residue solder pastes provided a wide processing window, especially when the wash temperature was increased.

Hard residue no-clean solder pastes are more difficult to clean. Some paste formulations' use polymers, which cross-link at reflow. The hard film is designed to encapsulate ionic and non-ionic salts from the reflow process. Since the design of the solder paste is to not clean the residue, the ability to remove the residue under Z-axis components, where impingement effects are reduced, becomes increasingly complex.

The cleaning material used in this study is designed to remove lead-free flux residues. Two of the three hard residue lead-free solder pastes were successfully cleaned. For assemblers who plan to remove solder paste flux residues, the selection of the solder paste from a cleanability perspective should be considered.

Time Effects: The research findings indicate that time is important but not as important as temperature effects. Board processed for an additional 25 minutes for a total of 40 minutes wash time at 150°F were the same as boards cleaned for 15 minutes. The test ran at 175°F for 25 minute wash time clean well. Additional research is needed to quantify time effects in relation to temperature effects.

Pre-heating Boards Before Cleaning: One set of boards was preheated before the cleaning process. The data indicates that cleaning was less effective. This data point indicates that the pre-heat cycle harden the residue making it more difficult to remove under the Z-axis.

Cleaning Material Effects: The research findings indicate the benefit of cleaning under Z-axis components by increasing wash temperature and wash time. A concern with this approach is the circuit assembly material compatibility effects. Aqueous cleaning materials processed at elevated wash temperatures and wash times commonly dull solder joints, remove part markings, attack anodized aluminum coatings, and oxide yellow and soft metals.

The building blocks for engineering electronic assembly cleaning materials consist of:

1. Solvency: Materials that dissolve flux resin and polymer structures, thus placing the soil into solution.
2. Builders: Materials that rapidly soften resin and polymer structures allowing dissolution in the solvent matrix.
3. Wetting: Lowering surface tension by reducing the wash droplet size.
4. Minor ingredients: Materials that destabilize foam and inhibit attack to metal alloys.

When elevating wash temperature and wash time an inherent limitation with most aqueous cleaning materials is attack to the board material subset. Many aqueous materials darken solder joints when exposed to elevated wash temperatures. Part markings are more susceptible to removal at longer wash times and temperatures. Anodized coatings tend to fail at elevated wash times and temperatures.

The cleaning fluid design used for this experiment optimizes the four design building blocks. The boards processed at elevated temperatures and times did not dull solder joints, attack solder mask, or remove part markings. In a few cases the label adhesive failed. Additionally, the cleaning material performed well at removing hard and soft lead-free flux residues.

The high process cleaning rate achieved on the boards processed at 200°F and 18% raised a curiosity among the research team. The team decided to lower the cleaning material concentration from 18% to 9% and to 5%. Reduced cleaning material concentrations lower the dynamic surface tension. Boards processed at 9% cleaning material concentration provided excellent cleaning on all flux residue types except one lead free hard residue. Boards processed at 5% cleaning material concentration also provided excellent results with a slight cleaning drop off from boards processed at 9% cleaning material concentration.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this designed experiment is to report optimized cleaning process parameters for removing lead-free flux residues on populated circuit assemblies using innovative cleaning fluid and batch cleaning equipment designs. Quantitative experiments were run on both inline and batch dishwasher cleaning machines using a best in class cleaning material.

Establishing "process equivalence" between in-line cleaners and batch cleaners assures an equal result in both cleaning processes. This is highly desirable if a company is manufacturing in multiple assembly locations or with different contract manufacturers. This leap in batch process performance requires rethinking the cleaning rate fundamentals.

Results indicate that wash temperature in the wash fluid improves cleaning performance on the more difficult to clean geometries and fluxes comparable to near that of today's best inline processes. Although the time, temperature and cleaning agent concentrations are different, the results were equal if the batch higher temperature process parameters developed in this study were used.

No material effects were noted on the eutectic tin/lead and lead-free solders used. The cleaning agent selected was formulated with corrosion inhibiting agents built-in to the solution to allow longer and hotter cleaning cycles. All solder connections tested remained un-oxidized, bright and shinny. The boards and the components show no signs of discoloration or damage in the higher heat cleaning cycles.

It is clear that high wash temperatures can result in shorter batch cleaning cycles because of the improved cleaning rate. This would result in less power consumption, lower chemical usage, higher throughput, and ultimately, a lower cost to clean.

As mentioned in the introduction of the paper, global environmental mandates are real and require reduction and elimination of lead, volatile organic compounds (VOC's) and other pollutants from our product and our production lines. Understanding the thermodynamics of cleaning can help to minimize environmental impacts and improve the cleaning at the same time.

AUTHORS

This research paper is fifth in a series written by Stach and Bixenman on optimizing electronic cleaning processes presented each year at the SMTAI conference. From these research efforts, key developments have improved cleaning process understanding.

The Process Cleaning Rate theorem infers that the static cleaning rate (chemical and temperature influences) plus the dynamic clean rate (mechanical influences) equals the process cleaning rate. Based on this theorem, follow on research focused on cleaning material, soil, and dynamic energy effects.

Using glass area array test vehicles, the research findings indicates different removal rates for different solder paste flux residues. Soft residues were bridged rapidly from cleaning material and energy effects. Hard residues require more time and removed in layers similar to peeling a union.

Nozzle types were studied to understand dynamic energy needed to bridge flux residue trapped under Z-axis components. Glass test vehicles were bumped using anisotropic adhesive as area array components. Fan and coherent spray nozzles were studied to determine the optimal energy source for removing trapped flux residues. The data findings indicated the importance of fluid flow, pressure at the board surface, and directional forces. From this research, progressive energy dynamics was developed.

This year's research focused on process equivalence. The data findings indicate the importance of wash temperature effects when using batch dishwasher systems. Additionally, the research finds the importance of soil effects and the selection of solder pastes that form soft residues when cleaning under the Z-axis is needed.

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