Engineered Cleaning Fluids Designed for Batch Processing

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Abstract

Highly dense circuit assemblies increase the cleaning challenge. Batch cleaning equipment designs provide a small footprint, low cleaning fluid consumption, and low cost of ownership. Batch cleaning machines use flow, time, temperature, impingement, and advanced cleaning fluids as critical drivers for delivering a clean part. Increased density, low standoff components, and Pb-free flux residues place increased importance on the cleaning fluid design. There is a need for improved cleaning fluids to remove Pb-free flux residues from populated circuit assemblies in batch cleaning machines. The purpose of this designed experiment is test populated circuit cards using innovative new cleaning fluid designs on a range of popular Pb-free flux residues in batch cleaning equipment. Validation will be reported using visual images of the test assemblies processed within the designed experiment.

Introduction

The success of low residue no-clean flux materials increased the popularity of batch cleaning machines as a supplement for circuit designs that required cleaning. Small form factor and the move to lead-free soldering increase the complexity of the cleaning process. Over the past decade, the dishwasher batch cleaning (DBC) machine become the dominate design for batch circuit assembly cleaning processes. DBC cleaning machines use high flow, displacement energy, time, temperature, and cleaning fluids as the critical drivers for delivering clean circuit assemblies.

Numerous solder materials are commercially offered to printed circuit and advanced packaging assembly houses. Process engineers, who have a need to remove flux residue after the soldering process, must identify the appropriate cleaning fluid best suited for the process requirement. Flux compositions are classified in families such as water soluble, rosin, and synthetic engineered compositions. The solder paste, wave flux, core wire, and paste flux materials offered by the various solder material companies fit one of these specific classifications, but the flux materials are most likely different from each of the manufactures. These compositional differences may influence cleaning process parameters, and in some cases, the cleanability of the flux residue.

To improve flux residue removal from populated circuit assemblies, there must be a balance between the dynamic energy and cleaning fluid driving forces. The physical energy delivered to the circuit assembly improves cleaning performance and reduces the time required to remove flux residues. Potential energy is also required from the cleaning fluid to soften, dissolve, and liquefy flux residues in an effort to achieve a totally clean circuit assembly. As the flux residues become increasingly difficult to remove; circuit assemblies decrease in size; component spacing's reduce; and area array interconnects increase; the importance of the integration of the cleaning fluid and mechanical designs becomes critical to process sustainability.

Problem Statement

The changing environment challenges process engineers to design and implement manufacturing processes to meet the emerging needs of their customers. Cleaning electronic assemblies represents a common back end process when manufacturing high reliability printed circuit boards. Emerging technology platforms integrate designs that are highly dense, meet small form factors, and populated with advanced technologies. Leadless chip carriers, µBGAs, chip scale packages, and chip cap components result in reduced standoff and pitch dimensions. The capillary flux forces at reflow fill the underside of the component with flux residue.

The complexity of the cleaning process increases as users implement lead-free soldering. The level of flux residue and its appearance is greater for most lead-free soldering processes. The thermal profile requires increased soak and peak reflow temperatures that increase the cleaning challenge. Process parameters may require increased cleaning fluid concentration, wash temperature, process time, and impingement energy. Low standoff components may require direct impingement and directional sprays. Each of these challenges requires incremental and innovative approaches to cleaning equipment and cleaning fluids.

Methodology

The designed experiment determines appropriate influences of standard and advanced cleaning fluids for removing flux residues using the dishwasher style and ultrasonic batch cleaning machines. The factorial experimental design tests two levels of cleaning equipment, four cleaning chemistries, and three board designs. The process variables of cleaning fluid concentration, wash time, wash temperature, and rinse cycles were fixed for this experiment. Optimization of these process variables may lead to a different end result.

Three board designs were selected to increase the cleaning challenge. Board design #1 tested the cleaning efficacy on surface residues. Board design #2 tested the cleaning efficacy under 1210 and 1825 chip caps. Board design #3 tested the cleaning efficacy of residues under a 1600 IO 75mmx 75 mm glass BGA substrate with a 2 mil standoff. The cleaning difficultly progressively became more challenging for each board design.

Table 1 Factors

Factor Description	**Level 1**	**Level 2**
Machine	Industry Batch Dishwasher Circuit Board Cleaning Equipment	Ultrasonic Immersion using 40 KHz at 16 watts per liter
Cleaning Chemistry Designs	Cleaning Fluid 1: Commercial Design for Batch Dishwasher Machines commonly used for removing rosin and no-clean flux residues from eutectic tin-lead alloys	Cleaning Fluid 2: Advanced cleaning fluid design for Batch Dishwasher Machines to improve removal of rosin and no-clean flux residues from both eutectic tin-lead and lead-free alloys
Cleaning Chemistry in Ultrasonic Machine	Cleaning Fluid 3: Commercial Design for Ultrasonic Immersion Machines commonly used for removing rosin and no-clean flux residues from eutectic tin-lead alloys	Cleaning Fluid 4: Advanced cleaning fluid design for immersion cleaning processes to improve removal of rosin and no-clean flux residues from both eutectic tin-lead and lead-free alloys
Lead-Free Solder Paste #1	Kyzen Standard Board	Kyzen Low Standoff Board
Lead-Free Solder Paste #2	Kyzen Standard Board	Kyzen Low Standoff Board
Lead Free Paste Flux #3	1600 IO BGA printed on Glass Slide	1600 IO BGA printed on Glass Slide
Cleaning Time	20 minutes	20 minutes
Cleaning Concentration	20%	30%
Cleaning Temperature	150F	150F

Table 2 Design of Experiment: Eight Factors, Two Levels, Full Factorial Design

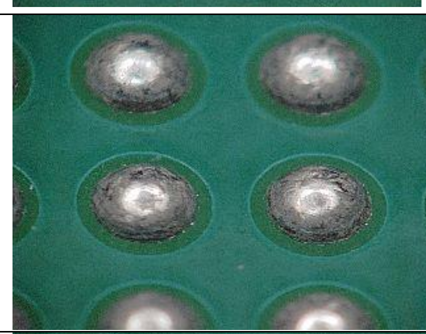
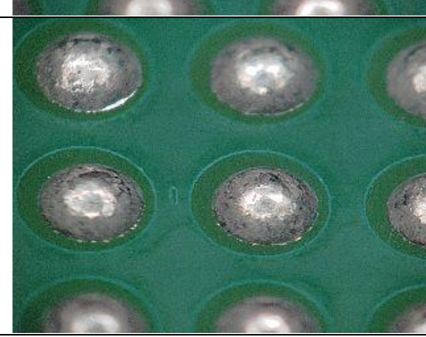
Run	Reflow Profile	No of Reflows	Cleaning Time	Wash Temp.	Solder Material	Conc.	Chemical	Machine
1	Lead-Free	1	20 min	150°F	Lead-Free Solder Paste #1	20%	Cleaning Fluid 1	Batch Dishwasher
2	Lead-Free	1	20 min	150°F	Lead-Free Solder Paste #2	20%	Cleaning Fluid 1	Batch Dishwasher
3	Lead-Free	1	20 min	150°F	Lead-Free Paste Flux #3	20%	Cleaning Fluid 1	Batch Dishwasher
4	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #1	20%	Cleaning Fluid 1	Batch Dishwasher
5	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #2	20%	Cleaning Fluid 1	Batch Dishwasher
6	Lead-Free	1	20 min	150°F	Lead-Free Solder Paste #1	20%	Cleaning Fluid 2	Batch Dishwasher
7	Lead-Free	1	20 min	150°F	Lead-Free Solder Paste #2	20%	Cleaning Fluid 2	Batch Dishwasher
8	Lead-Free	1	20 min	150°F	Lead-Free Paste Flux #3	20%	Cleaning Fluid 2	Batch Dishwasher
9	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #1	20%	Cleaning Fluid 2	Batch Dishwasher
10	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #2	20%	Cleaning Fluid 2	Batch Dishwasher
11	Lead-Free	1	30 min	150°F	Lead-Free Solder Paste #1	30%	Cleaning Fluid 3	Ultrasonic Immersion

12	Lead-free	1	30 min	150°F	Lead-Free Solder Paste #2	30%	Cleaning Fluid 3	Ultrasonic Immersion
13	Lead-free	1	30 min	150°F	Lead-Free Paste Flux #3	30%	Cleaning Fluid 3	Ultrasonic Immersion
14	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #1	20%	Cleaning Fluid 3	Ultrasonic Immersion
15	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #2	20%	Cleaning Fluid 3	Ultrasonic Immersion
16	Lead-Free	1	30 min	150°F	Lead-Free Solder Paste #1	30%	Cleaning Fluid 4	Ultrasonic Immersion
17	Lead-free	1	30 min	150°F	Lead-Free Solder Paste #2	30%	Cleaning Fluid 4	Ultrasonic Immersion
18	Lead-free	1	30 min	150°F	Lead-Free Paste Flux #3	30%	Cleaning Fluid 4	Ultrasonic Immersion
19	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #1	20%	Cleaning Fluid 4	Ultrasonic Immersion
20	Tin-Lead	1	20 min	150°F	Tin-Lead Solder Paste #2	20%	Cleaning Fluid 4	Ultrasonic Immersion

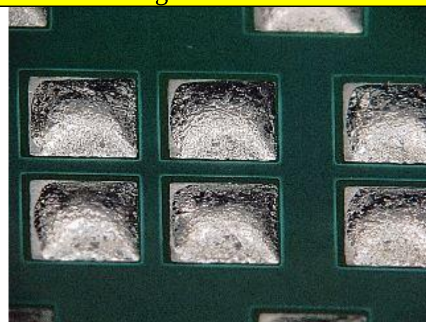
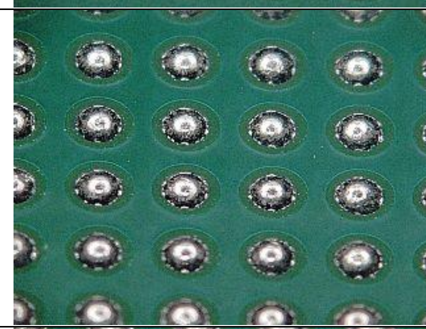
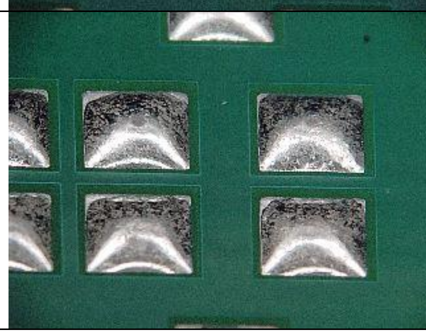
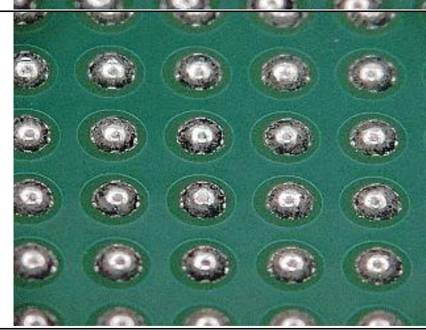
Responses:
The responses measured were visual examination of flux residues after reflow and cleaning processes. Three test substrates were used.

1. Kyzen Standard Test Board was not populated with components. The boards were printed with solder paste, reflowed, and cleaned. After cleaning, the boards were inspected visually for flux residue. Images of selective sites were recorded.

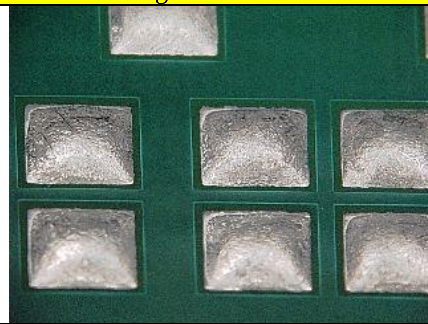
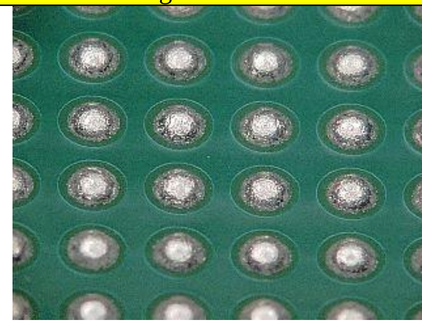
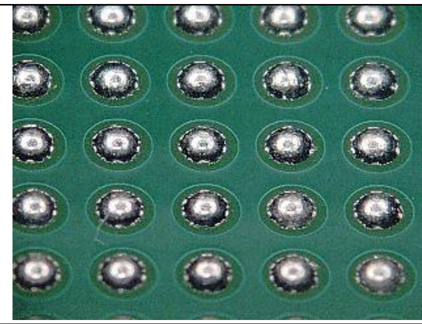
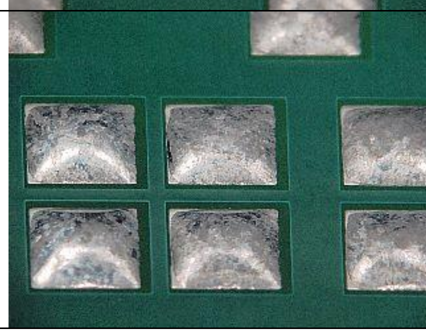
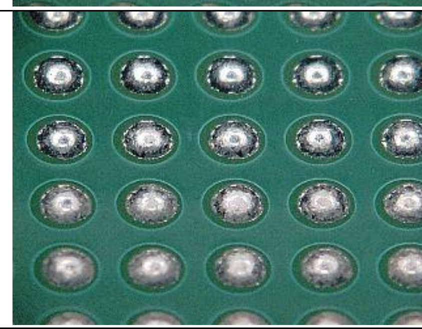
Figure 1

Run	Metrics	Machine	After Cleaning	After Cleaning
1	Cleaning Fluid 1 Lead-Free Solder Paste #1 Kyzen Standard Test Board – No Components	Dishwasher		
4	Cleaning Fluid 1 Tin-Lead Solder Paste #1 Kyzen Standard Test Board – No Components	Dishwasher		
5	Cleaning Fluid 1 Tin-Lead Solder Paste #2 Kyzen Standard Test Board – No Components	Dishwasher		

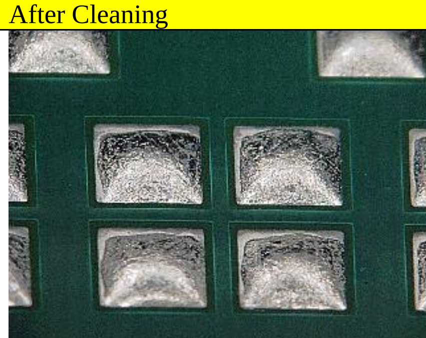
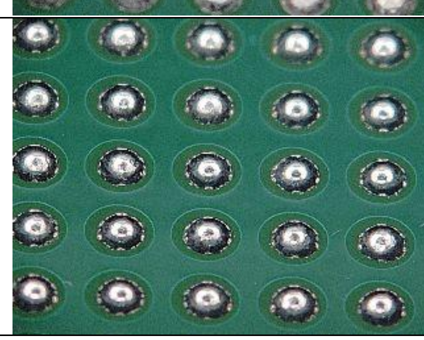
Cleaning Fluid 1 left trace levels of residue on Lead-Free Solder Paste #1 and Tin-Lead Solder Paste #2. The solder joint appearance was etched from as a result of the cycle time employed.

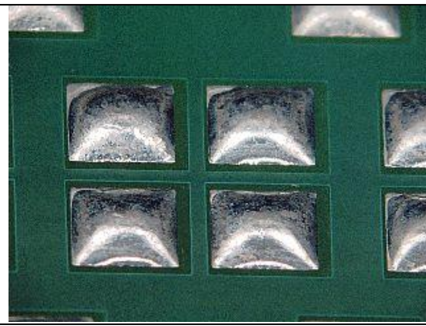
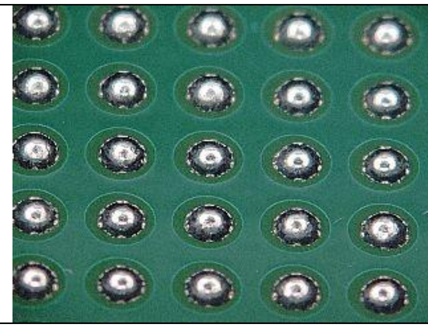
Run	Metrics	Machine	After Cleaning	After Cleaning
6	Cleaning Fluid 2 Lead-Free Solder Paste #1 Kyzen Standard Test Board – No Components	Dishwasher		
9	Cleaning Fluid 2 Tin-Lead Solder Paste #1 Kyzen Standard Test Board – No Components	Dishwasher		
10	Cleaning Fluid 2 Tin-Lead Solder Paste #2 Kyzen Standard Test Board – No Components	Dishwasher		

Cleaning Fluid 2 left no residue. The solder joint appearance was much improved with minor interaction to the solder joint surface.

Run	Metrics	Machine	After Cleaning	After Cleaning
11	Cleaning Fluid 3 Lead-Free Solder Paste #1 Kyzen Standard Test Board – No Components	Ultrasonic Immersion		
14	Cleaning Fluid 3 Tin-Lead Solder Paste #1 Kyzen Standard Test Board – No Components	Ultrasonic Immersion		
15	Cleaning Fluid 3 Tin-Lead Solder Paste #2 Kyzen Standard Test Board – No Components	Ultrasonic Immersion		

Cleaning Fluid 3 left no residue. The solder joint appearance was average with minor interaction to the solder joint surface.

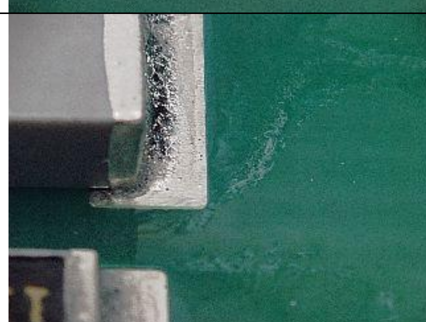
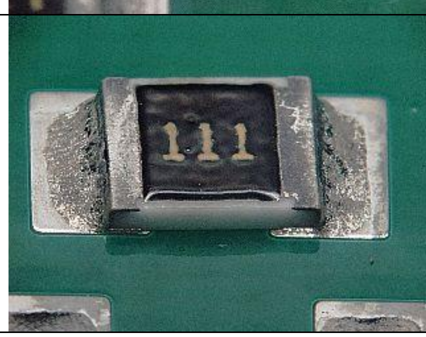
Run	Metrics	Machine	After Cleaning	After Cleaning
16	Cleaning Fluid 4 Lead-Free Solder Paste #1 Kyzen Standard Test Board – No Components	Ultrasonic Immersion		
19	Cleaning Fluid 4 Tin-Lead Solder Paste #1 Kyzen Standard Test Board – No Components	Ultrasonic Immersion		

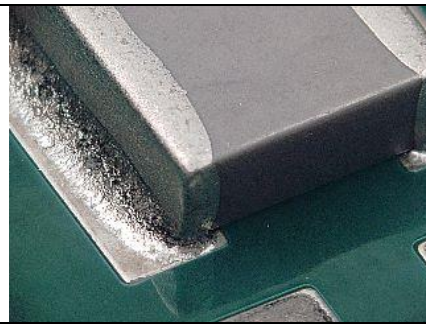
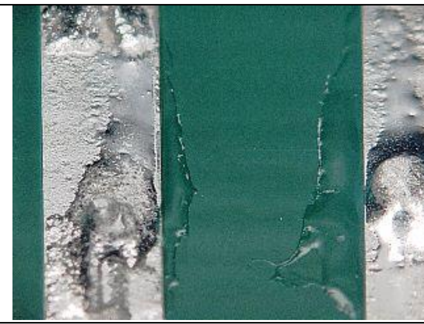
20	Cleaning Fluid 4 Tin-Lead Solder Paste #2 Kyzen Standard Test Board – No Components	Ultrasonic Immersion		

Cleaning Fluid 4 left no residue. The solder joint appearance was good with minor interaction to the solder joint surface.

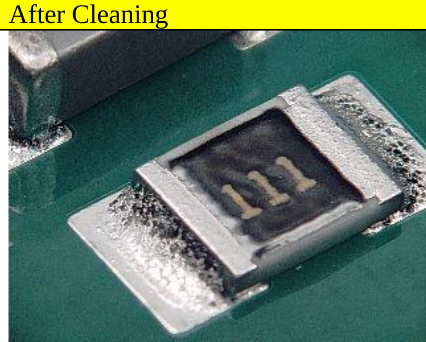
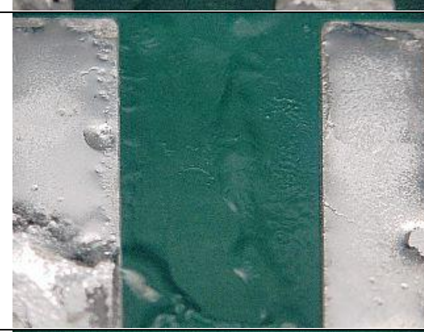
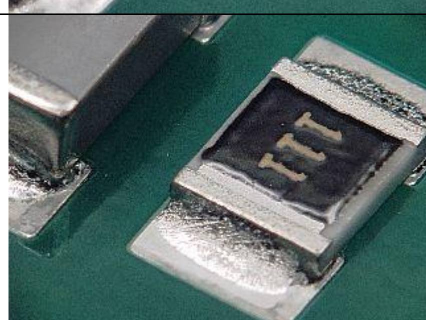
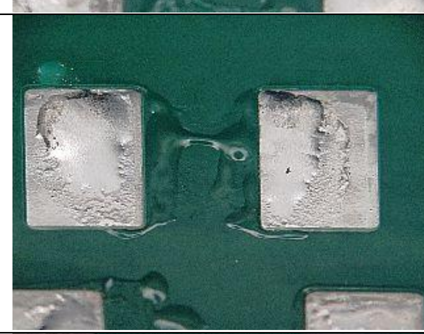
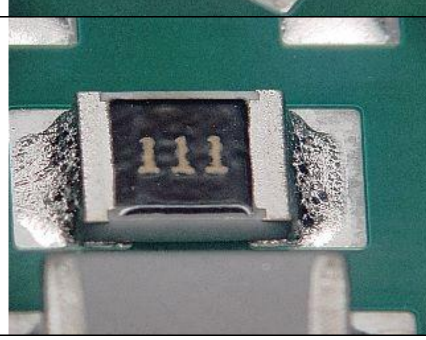
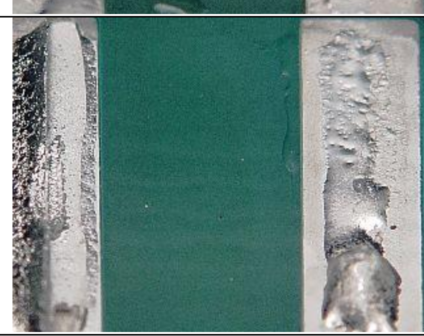
2. Kyzen Low Standoff Board was populated with 1210 and 1825 chip caps, reflowed, and cleaned. After cleaning, the boards were inspected for visual flux residues along the leading edge of the components. The components were removed and inspected for flux residue under the component. A census of the flux residue under the chip caps was graded and charted. Images of selected sites were recorded.

Figure 2

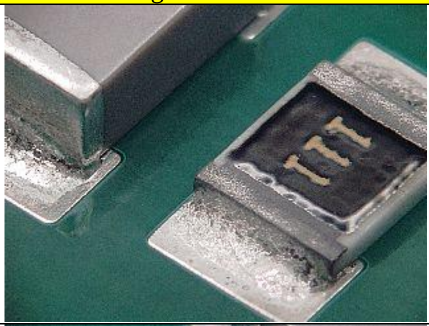
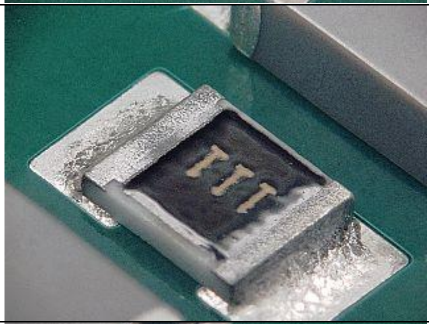
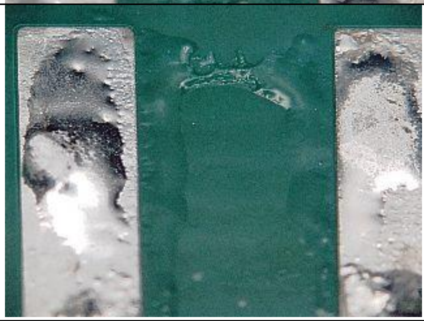
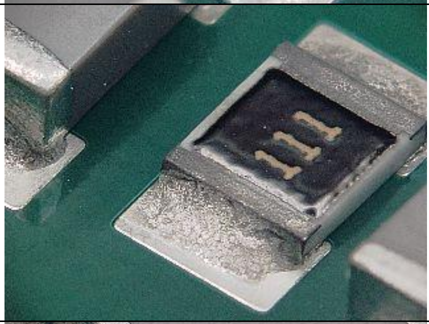
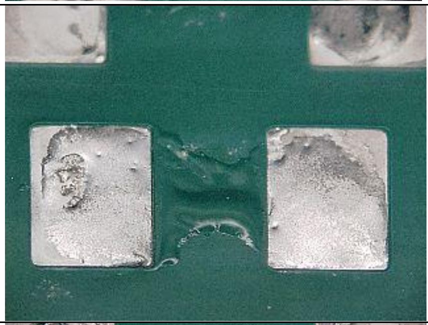
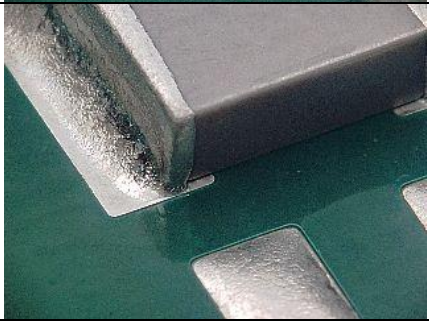
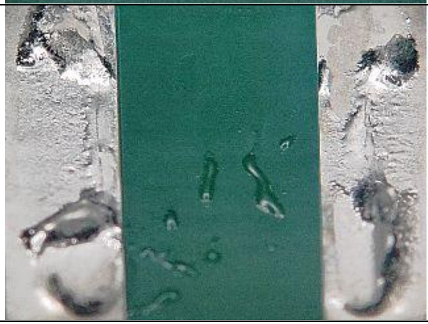
Run	Metrics	Machine	After Cleaning	After Cleaning
1	Cleaning Fluid 1 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		
1	Cleaning Fluid 1 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		
2	Cleaning Fluid 1 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		

2	Cleaning Fluid 1 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		

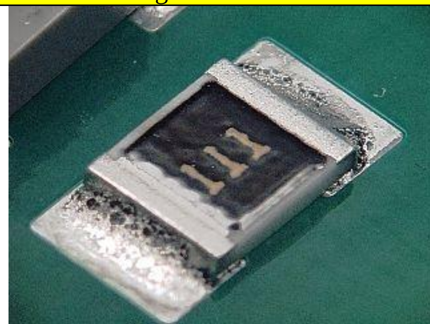
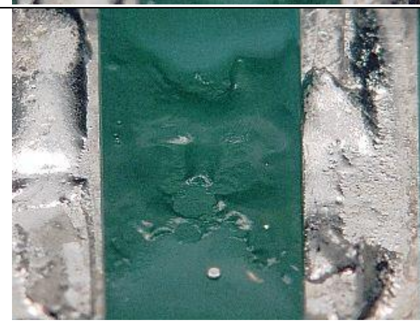
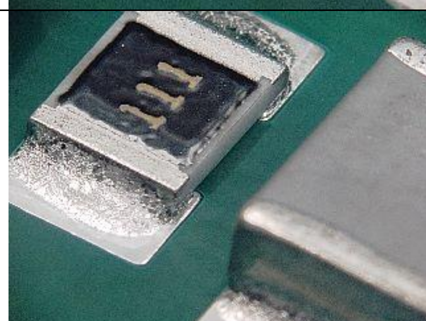
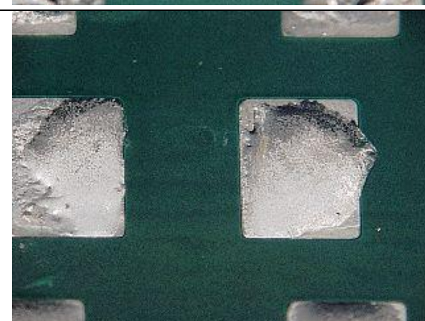
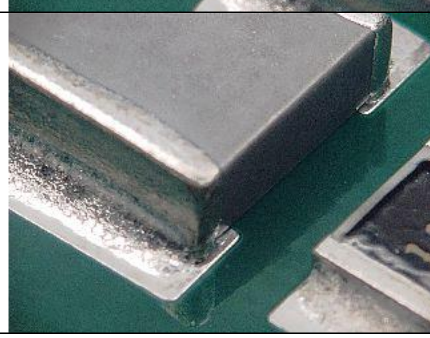
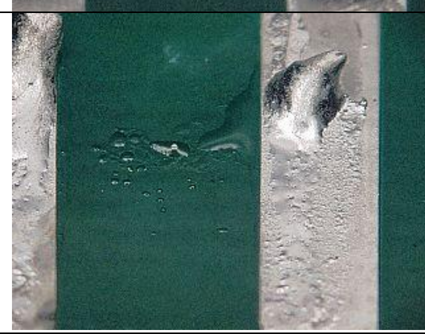
Cleaning Fluid 1 left visible levels of residue on Lead-Free Solder Paste #1 and no visible residue on Lead-Free Solder Paste #2. Heavy levels of flux residue were left under the 1210 and 1825 chip cap on Lead-Free Solder Paste #1 and medium levels of flux residue under 1210 and 1825 chip caps on Lead-Free Solder Paste #2.

Run	Metrics	Machine	After Cleaning	After Cleaning
6	Cleaning Fluid 2 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		
6	Cleaning Fluid 2 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		
7	Cleaning Fluid 2 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		
7	Cleaning Fluid 2 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Dishwasher		

Cleaning Fluid 2 left no visible flux residue around the components or board surface on Lead-Free Solder Paste #1 or Lead-Free Solder Paste #2. Heavy levels of flux residue were left under the 1210 and 1825 chip cap on Lead-Free Solder Paste #1 and medium levels of flux residue under 1210 and 1825 chip caps on Lead-Free Solder Paste #2.

Run	Metrics	Machine	After Cleaning	After Cleaning
11	Cleaning Fluid 3 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		
11	Cleaning Fluid 3 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		
12	Cleaning Fluid 3 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		
12	Cleaning Fluid 3 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		

Cleaning Fluid 3 left no visible flux residue around the components or board surface on Lead-Free Solder Paste #1 or Lead-Free Solder Paste #2. Heavy levels of flux residue were left under the 1210 and 1825 chip cap on Lead-Free Solder Paste #1 and medium to light levels of flux residue under 1210 and 1825 chip caps on Lead-Free Solder Paste #2.

Run	Metrics	Machine	After Cleaning	After Cleaning
16	Cleaning Fluid 4 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		
16	Cleaning Fluid 4 Lead-Free Solder Paste #1 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		
17	Cleaning Fluid 4 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		
17	Cleaning Fluid 4 Lead-Free Solder Paste #2 Kyzen Low Standoff Test Board 1210 Chip Cap	Ultrasonic Immersion		

Cleaning Fluid 4 left no visible flux residue around the components or board surface on Lead-Free Solder Paste #1 or Lead-Free Solder Paste #2. Medium to heavy levels of flux residue were left under the 1210 and 1825 chip cap on Lead-Free Solder Paste #1 and light levels of flux residue under 1210 and 1825 chip caps on Lead-Free Solder Paste #2.

There were 18-1210 and 1825 chips placed onto the low standoff test board. All caps were removed and a census of the flux residue was graded. Chart 1 illustrates the 1210 chip data findings and chart 2 illustrates the 1825 chip data findings.

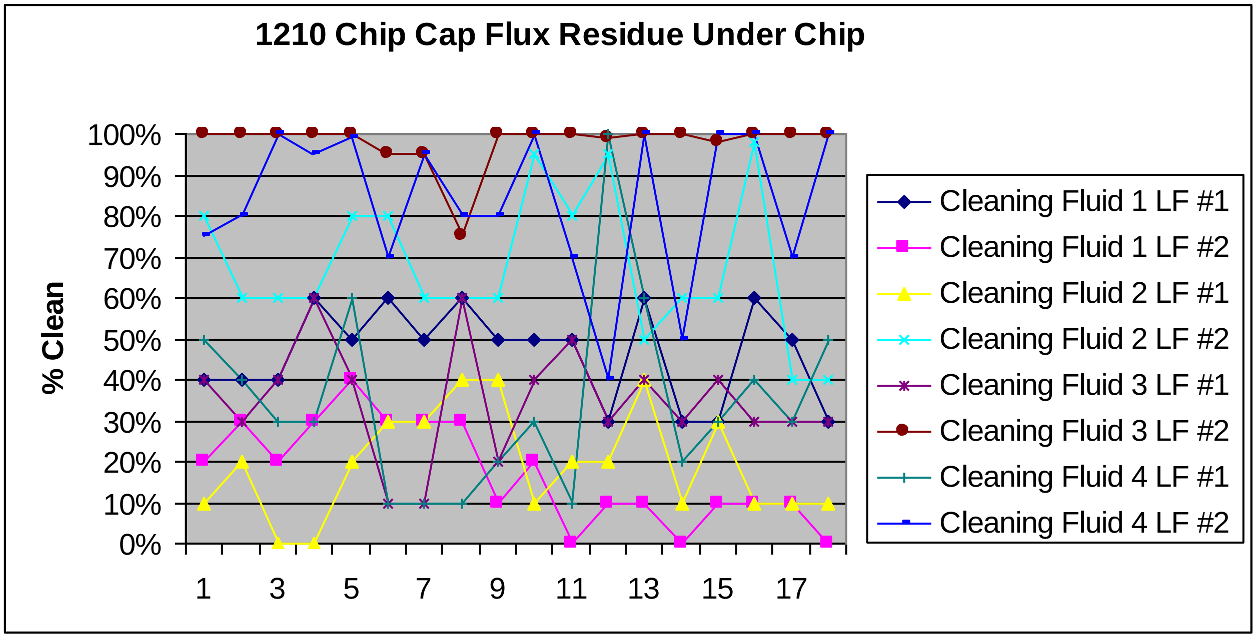


Figure 1: Flux Residues under 1210 Chip Caps

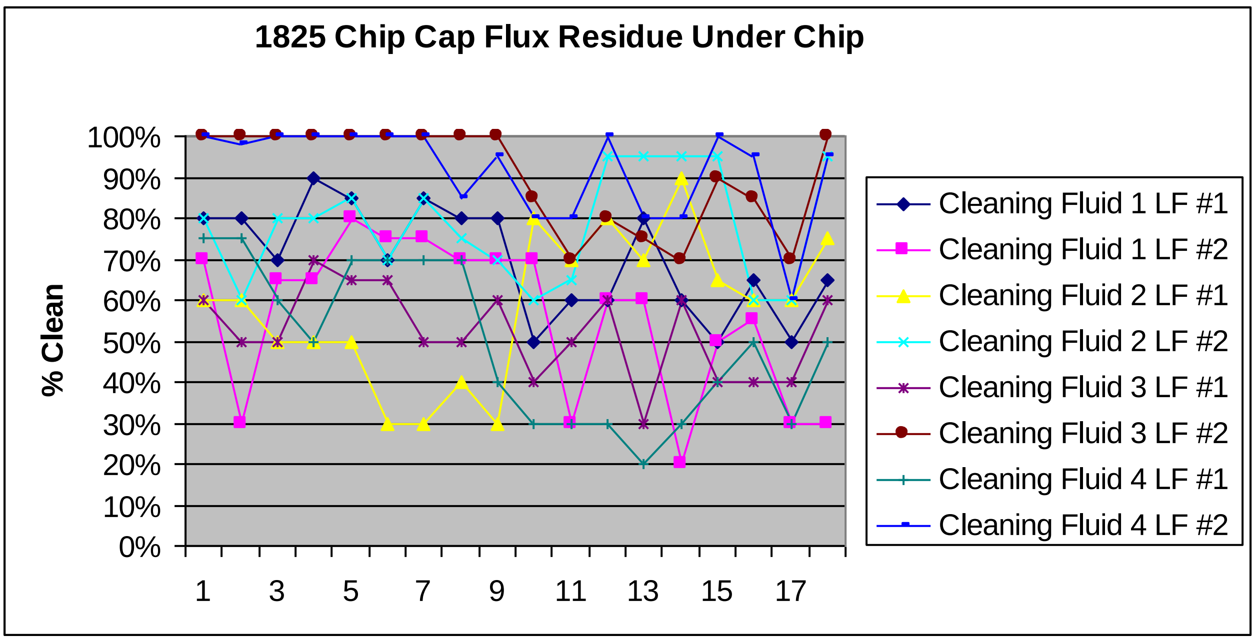
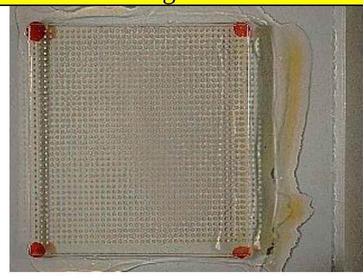
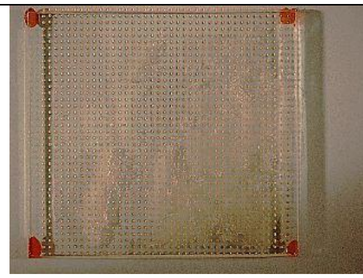
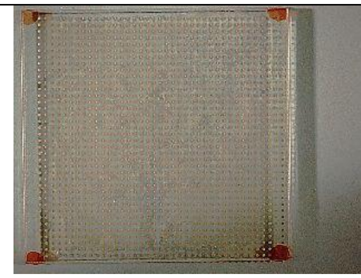
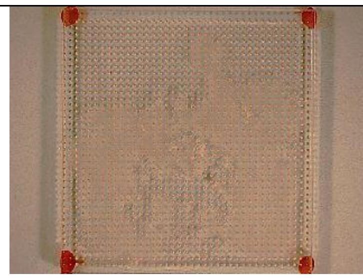
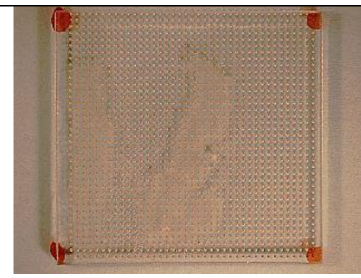
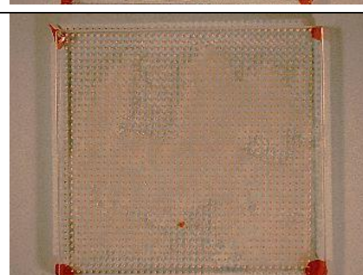
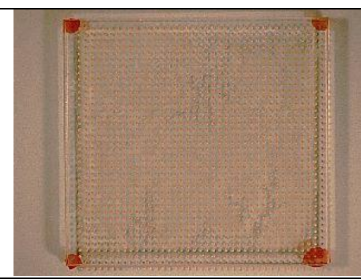


Figure 2: Flux Residues under 1825 Chip Caps

3. Anisotropic silver filled adhesive was printed on a 75x75 mm squared surface of a glass slide for a total of 1600 interconnects. The bumps were milled down to a standoff height of 2 mils. A glass die was attached on top of the 1600 interconnects. Lead-free paste flux was applied at the leading edge of the die and heated to fill the underside of the die. The glass slide was sent through a reflow oven using a Pb-free profile. After cleaning, an image of the glass die was recorded.

Run	Metrics	Machine	After Cleaning	After Cleaning
	Control Lead-Free Paste Flux #3 1600 IO 2 mil standoff			
3	Cleaning Fluid 1 Lead-Free Paste Flux #3 1600 IO 2 mil standoff	Dishwasher		
8	Cleaning Fluid 2 Lead-Free Paste Flux #3 1600 IO 2 mil standoff	Dishwasher		
13	Cleaning Fluid 3 Lead-Free Paste Flux #3 1600 IO 2 mil standoff	Ultrasonic Immersion		
18	Cleaning Fluid 4 Lead-Free Paste Flux #3 1600 IO 2 mil standoff			

None of the batch cleaning processes successfully removed all flux residues under the glass slides. Of the cleaning processes tested, cleaning fluid 2 processed in the dishwasher provided the best results.

Data Analysis

The data provides a series of interesting findings. When analyzing the parts for surface residue, both the DBC (dishwasher batch cleaner) and ultrasonic immersion processes provided encouraging results. When looking under the low standoff parts, the degree of residue removed in DBC and ultrasonic immersion process were not so encouraging. I offer the following observations in an effort make light of the data.

- The three substrates tested were progressively more difficult to clean. Advanced cleaning fluids 2 and 4 removed all surface residues on unpopulated and populated test substrates. On test substrate #2, lead-free flux residue was present in varying levels under the 1210 and 1825 chip caps from each of the cleaning fluids tested, with cleaning fluids 2 and 4 removing a greater level of flux residue under the low standoff components. On test substrate #3, lead-free flux residue was also present in varying levels from each of the cleaning fluids tested, with cleaning fluids 2 and 4 providing the best cleaning results. Removal of flux residue under low standoff components is a challenging requirement and provides a key differentiator when studying cleaning fluid and mechanical designs. The data suggests that the advanced cleaning fluids 2 and 4 improved cleaning results but additional optimization of the time, temperature and impingement designs need additional study to determine a process condition for removing all residues under low standoff components.
- The lead-free and eutectic tin-lead solder pastes selected represent leading materials commonly used in manufacturing of electronic assemblies. From past studies, we know that lead-free flux residues are more difficult to clean. This experiment supported this hypothesis. To improve the cleaning rate of difficult to clean flux residues much research has been applied to studying flux residue compositions. Cleaning fluid 2 and 4 represent advanced cleaning fluid designs that improve the static cleaning rate (rate at which the cleaning chemistry dissolves the flux residue in the absence of mechanical energy). When viewing surface residues, both cleaning fluids performed well. Cleaning fluids 2 and 4 improved cleaning results under low standoff components.
- Significant research has been applied to studying the science of cleaning flux residue under low standoff components. The findings from past research infer that impingement pressure, fluid flow, and directional forces at the leading edge of the component are needed to penetrate and remove all flux residues under the component. The research findings indicate that neither machine provided the needed physical energy at the preset process parameters to remove all residues under low standoff components.
- Low residue no-clean flux residues are designed to leave an encapsulated residue that is benign to electrical integrity. The residue remaining under the low standoff chip caps appeared to be unaffected by the cleaning process. Residues left under these components may be of no concern for some designs.

Infers Drawn from the Research Findings

Past research studies support the difficulty of cleaning flux residues under low standoff components. The data findings from this experiment indicate the need for additional research to open the process window. Common research variables of cleaning fluid time, temperature, concentration, and impingement designs may produce different results. When studying the removal of flux residues from low standoff components in inline cleaning machines, the research findings correlated flux removal with impingement pressure, fluid flow, and directional forces.

The DBC machine represents the dominate cleaning machine design for cleaning electronic assemblies. Limitations of this machine design include shadowing and lack of direct impingement at all surfaces of the part. Leading producers of the batch dishwasher type machines have introduced new designs to address these limitations. Advanced nozzle technology shortens the width of the spray pattern to increase impingement energy upon contact. To address shadowing, the platform osculates to expose board surfaces to impinging forces. Additional research is needed to test these new designs to determine flux removal efficacy under low standoff components improves.

Ultrasonic batch cleaning machines fell out of favor due to the concern of ultrasonic energy cracking solder connections. Additional research on the viability of ultrasonic cleaning machines question this research finding. This batch cleaning machine was included in the research design since ultrasonic impingement creates a path for removing residues from blind holes and low standoff components. The test results improved for cleaning fluid 4, which represents the advanced cleaning fluid. The cleaning efficacy under low standoff components showed promised but additional optimization is needed to determine optimal process variables.

Follow on research collaboration is needed between the solder materials; cleaning fluid and batch cleaning equipment manufacturers to open the process window for removing lead-free flux residue under low standoff components. Testing must focus on three critical variables of upstream processing conditions, static cleaning fluid rate and dynamic cleaning fluid rate. Lead-free flux residues clean at different rates based on upstream processing and composition of the ingredients within the flux itself. Cleaning fluids must be designed to work with a wide range of flux compositions. Dynamic energy must be applied so that all areas of the part are exposed to impinging forces.

Conclusions and Recommendations

Electronic assembly is going through a paradigm shift as assembly operations move to remove lead from the soldering process. Additionally, circuit assemblies are increasing power consumption in highly dense spaces, while moving to increasing smaller form factors. The trend toward highly dense assemblies reduces the spacing between conductors while yielding a larger electronic field. As the industry moves to higher functionality, miniaturization, and lead-free soldering, studies show that cleanliness of the assembly becomes more important.

Over the past fifteen years, no-clean solder paste technology provided a technology that allowed assemblies to leave behind a non destructive residue that protected electrical fields from electro migration. Cleaning was needed on high reliability assemblies, rework, and misprinted assemblies. Batch dishwasher cleaning machines represented the dominate design that supported this industry need. As the cleaning challenge increases, solder material, cleaning fluid and batch cleaning companies must continue to work together and innovate improvements to meet the need of removing all flux residues under low standoff components.

Author

Mike Bixenman is the Chief Technology Officer of Kyzen Corporation. Dr. Bixenman has been associated with teams of customers, material companies, equipment companies, industry standards, and fellow workers that studied and designed electronic assembly cleaning processes. For additional information or questions on cleaning fluid and process improvements for cleaning electronic assemblies, please email Dr. Bixenman. mikeb@kyzen.com