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OA Flux Cleaning Studies on Highly Dense Advanced Packages Parameters

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Abstract

Cleaning flux residues post soldering has been a high reliability criterion practiced by assemblers of military, aerospace, automotive, medical devices and other value offerings. Highly dense advanced packages reduce spacing between I/Os and standoff heights. The complexity of removing flux residue increases, while elevating the risk of white residue under low standoff (gap) components. To address this concern, many electronic assemblers use water soluble solder paste and clean post soldering. The purpose of this factorial designed experiment is to evaluate multiple water soluble flux materials and cleaning chemistries, including DI water only, to determine the best chemical properties for removing lead-free water soluble flux residues. The optimal process parameters will be defined with data findings analyzed and presented using statistical analysis and models.

Introduction

The feature size of integrated electronic assemblies and circuit packages are constantly shrinking, while simultaneously increasing the number of transistors incorporated into each device. The need for higher processing speeds force designers to fit more components into smaller doubled-sided assemblies. Many of these devices are required to operate in areas where temperature and humidity are uncontrolled.[1] Reliability concerns result from highly active OA flux residues being trapped under low standoff components and not removed during post soldering cleaning.

The conversion from tin-lead to lead-free soldering requires flux chemistry changes.[2] Difficult to attach components require fluxes high in activation and thermal stability. Many high reliability tin-lead assemblies used water soluble flux technologies due to the ease of cleaning. The water soluble process provided a wide processing window and improved overall first pass yields. Water soluble flux technologies are still an attractive option for lead-free designs due to high activation, ease of cleaning and improved wetting. The issues arise from risks associated with un-activated water soluble flux entrapped under low clearance components, higher processing temperatures, flux burn off, and failure to remove all residues with water only.

Research Objective

Water soluble fluxes are highly conductive and active. The job of water soluble flux is to promote thermal transfer to the area of the solder joint, enhance wetting of the solder on the base metal, and prevent voiding and oxidation of the metal surfaces at soldering temperatures.[3] Water soluble fluxes contain weak organic acids and attract water due to their hydrophilic nature. Low standoff components pose a reliability risk since weak organic acids are not easily detected using the R.O.S.E. ionic cleanliness method.[4] In today's manufacturing environment, there is no good process control check for detecting site specific residues under components. Non-destructive cleanliness screening tests are not feasible as a product assurance and quality control test methods on production hardware.

Water soluble flux has been successfully used on high reliability designs. Users report yield improvement when using highly active water soluble flux packages on difficult to solder lead-free components.[2] When using an active flux, suppliers must provide data driven process conditions and document the details of fabrication and inspection, including acceptance and rejection criteria, and shall provide appropriate test data.[4] The request for approval shall include:

1. A complete chemical characterization of each flux
2. A detailed control system for procurement, receiving inspection, storage, usage, and application
3. Detailed flux removal cleaning processes, monitoring requirements, cleanliness test methods, and their results

Miniaturization is driving multiple changes in water soluble flux technology, which ultimately influence the solubility characteristics and their cleanability using water only for removing flux residues.[5] Small feature sizes require finer powder, with the flux employing higher thixotropic and homogeneous properties to achieve satisfactory consistency in printing and soldering.[6] Also because of miniaturization, the assembly process is more vulnerable to bridging; therefore the solder paste needs to be more slump resistant. The purpose of this research is to test the cleaning parameters needed to remove lead-free water soluble flux residues from under low clearance lead-free components.

Problem Statement

Ion migration in an electric field is propagated by the charge balance at the interface where the total current density entering and leaving the electrolyte causes metal ions to split and form dendrites. The spatial coupling depends on the distance of the conductors with closer areas coupled more strongly.[3] The input / output current decreases for smaller electrodes while the current density increases. This phenomenon can create high current densities in high I/O devices. Highly dense assemblies and the spatial coupling are connected and depend strongly on the geometry of the electrolyte (water soluble flux and moisture) and electrode (voltage).

Literature cites the potential root cause of electrochemical migration failures as the flux chemistry, the flux application method, inadequate thermal activation of the flux, and inadequate cleaning processes.[2] Electronic circuit failures result from excessive and uncontrolled use of wave and tack fluxes, high chloride levels, flux wicking into vias, flux burn off, and un-activated flux pooling under low clearance components.[2] These conditions promote dendritic growth, which leads to conductor shorting and device failure. The problem is that there is no good process control and quality assurance method for detecting flux residue trapped under low standoff components. To address this issue, the cleaning process design must provide a wide processing window for removing all flux residues under low clearance parts.

Methodology

The full factorial designed experiment allows for the simultaneous study of the lead-free flux residue cleaning effects on wash time, cleaning agent, and spray impingement for removing visual flux residue under 1201 & 1825 chip cap resistors. When performing this experiment, the levels of all factors were varied simultaneously in an effort to study the interactions between the factors. The combinations of factor levels represent the conditions at which responses were measured. Each experimental condition and the response measurement were observed.

The experimental design measured responses at all combinations of the factor levels. The design compares cleaning efficacy on 9-lead-free flux residues under low standoff 1210 & 1825 chip cap resistors. Main effect plots were generated to visualize the effect of the factors on the response and to compare the relative strength of the effects. The test board and reflow conditions are illustrated in Figure 1. Table 1 provides an overview of the DOE design.

The components were reflowed using a soak lead-free profile (Figure 1). The positioning of the components place the chip caps are designed so that the leading and trailing gap is sandwiched in between two, chips, one chip, and no chips. After cleaning, the components were removed from the test board and the mean level of flux level under the components was graded. The data were analyzed quantitatively.

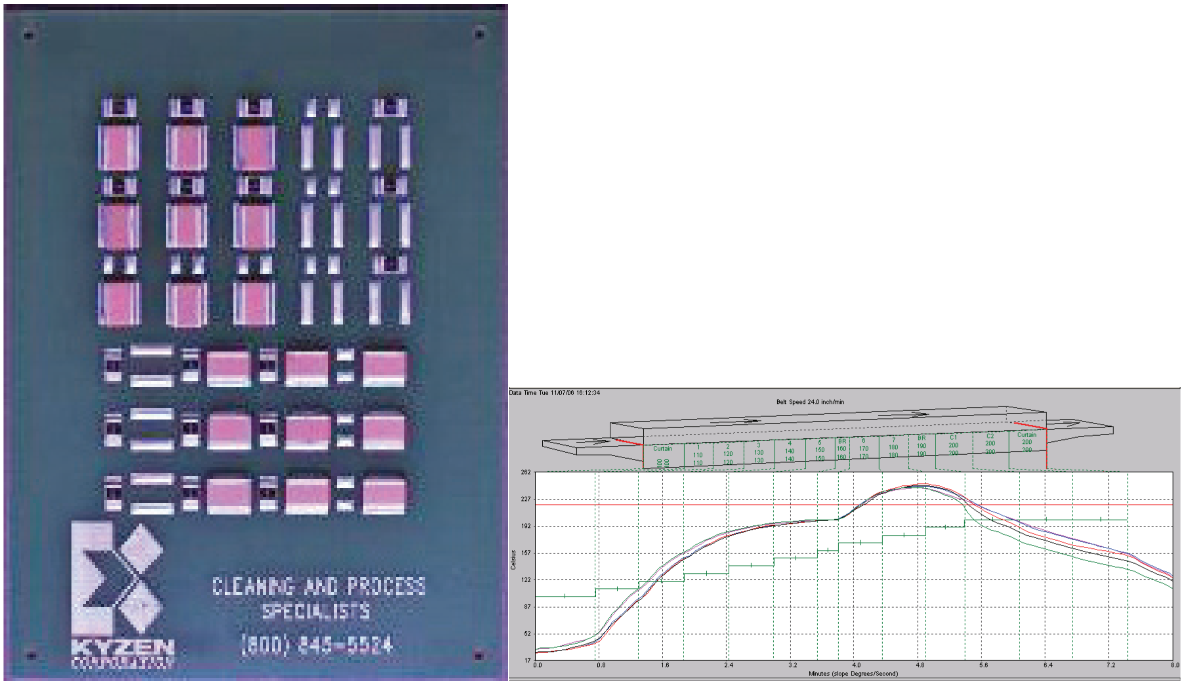

Figure 1: Test Board Design and Reflow Profile

Table 1: Full Factorial Design

Leg	Cleaning Agent	Wash Temp.	Wash Time in Feet Per Minute	Spray-in-Air Manifold	% Residue under chip 1210 and 1825 lead-free chip caps
1-4a	DI Water	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4 b	DI with Defoamer	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4c	Cleaning Agent 1	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4d	Cleaning Agent 2	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4e	Cleaning Agent 3	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4f	Cleaning Agent 4	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4g	Cleaning Agent 5	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4h	Cleaning Agent 6	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9
1-4i	Cleaning Agent 7	150°F	1, 2, & 3	1-4	SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, & SP9

Data Findings

The main effects plot provides a visual comparison of the factors for cleaning lead-free water soluble flux residues left under the 1201 and 1825 chip cap resistors. The factors studied were the mean percent flux residue removed under 1210 and 1825 chip cap resistors, throughput time in the cleaner at 1, 2, & 3 feet per minute, and spray manifold design. The effects show the overall mean for all the data, which represents 108 components for each component type. The factors displayed represent the main effect plots that are significant according to the analysis of variance (ANOVA). A main effect is present when the change in the mean response across the levels or a factor is significant. By comparing the slopes of the lines, you can compare the relative magnitude of the process variable effects.

DI Water Only

The first data set draws a visual comparison of the effectiveness of DI water only for cleaning the nine lead-free water soluble flux residues under the low clearance components (Figure 2).

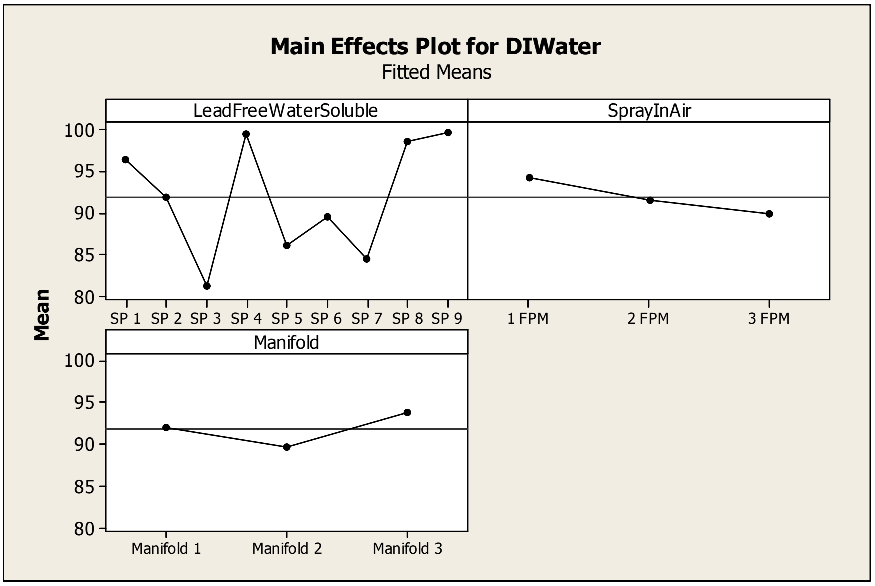

Figure 2: Main Effects Plot for DI Water Only

Water soluble flux residues are hydroscopic and active. Literature is rich with relevant research that conclusively finds circuit failures when leaving behind active water soluble flux residues under components. Water soluble flux technology needed to support lead-free circuit assemblies differ from eutectic tin-lead solder systems. Factors such as high soldering temperature and flux burn-off create pockets of harden residue that may no longer be removed with DI water only. Water with an additive may be needed to remove lead-free water soluble fluxes.

From the nine water soluble lead-free solder pastes in this study, DI water showed good performance on only two of the nine solder pastes. Flux burn-off is a common issue next to the solder joint. The data findings indicate that water with an additive may be needed.

Two other significant factors were found. Numerous research studies over the past five years indicate that high fluid flow and pressure at the surface of the assembly improve cleaning results. Four spray manifolds were tested.

1. Manifold 1 delivered the wash fluid using fan jets
2. Manifold 2 delivered the wash fluid using fan jets combined with the hurricane type water knife.
3. Manifold 3 delivered the wash fluid using proprietary and fan jets.
4. Manifold 4 delivered the wash fluid using proprietary jets.

For DI water only, manifold 4 was not tested due to foaming in the wash tank. The coherent jets showed a slight cleaning improvement.

The third factor tested was throughput rate. Past research studies indicate that longer wash times are needed to removed flux residues under low clearance components. The data finds slower belt speeds improve the mean percent flux removed under low clearance components.

DI Water with Defoamer

Lead-free water soluble flux residues create a foaming condition. To address this issue, a defoamer was added to DI water. The main effects plot in Figure 3 compares the relative strength of the significant factors.

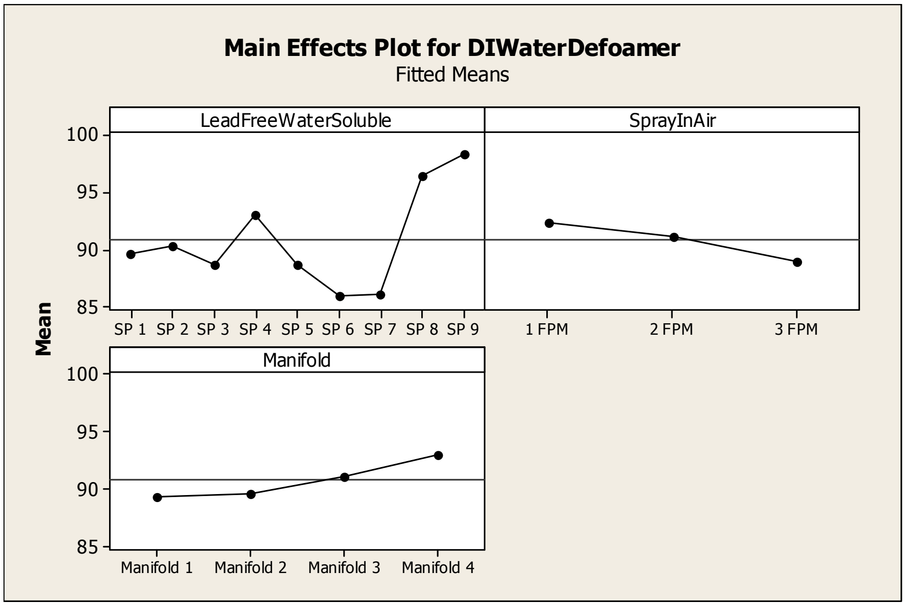

Figure 3: Main Effects Plot for DI-Water with Defoamer

High impingement spray-in-air cleaning machines turn the wash tank over an average of 2 times per minute and shear the wash fluid. The pressure from this shearing effect creates microscopic bubbles within the body of the wash tank. The foam eventually reaches the pump intake. When this occurs, there will be both the loss of pressure and foam build. Eventually this condition drops the low level sensor and shuts the machine down.

Lead-Free water soluble flux residues often create a foam condition in the wash tank. Very small levels of these residues create this condition. To address this issue, DI water with the addition of an antifoam agent was tested. The data finds water with a defoamer to be slightly less effective than DI water only. Only one of the water soluble solder pastes showed promised for removing all residues under low clearance components when using water with a defoamer.

Consistent with DI water data findings, longer time in the wash section improved cleaning results under low clearance components. Additionally, the coherent nozzle design with higher fluid flow improved cleaning.

Cleaning Agent 1

Seven engineered cleaning agents were placed into the matrix. The cleaning agents were used at 5% cleaning agent and 95% DI water. The building blocks used to engineer aqueous cleaning agents are solvency to dissolve non-polar resin structures, activators to buffer and saponify soils, wetting agents to lower surface tension, and non-reactive additives to control foam and increase the immunity region on metal alloys.

Cleaning agent 1 is an aqueous concentrated cleaning agent designed to improve wetting and lower surface tension. Cleaning agent 1 is a low foam formulation and highly effective at controlling foam build in the wash tank.

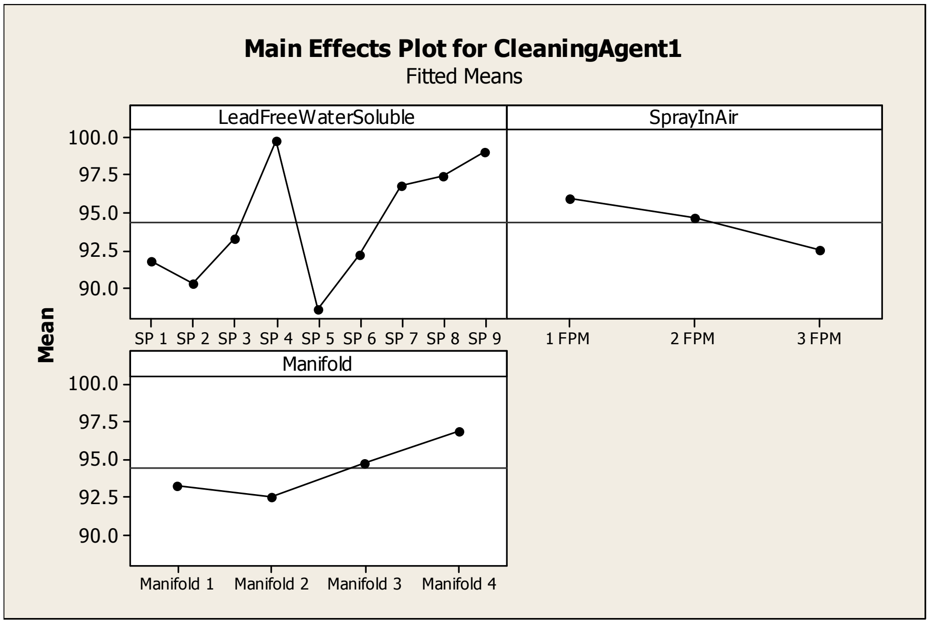

Figure 4: Main Effects Plot for Cleaning Agent 1

The main effects plot finds a slight improvement over DI water. Consistent with DI water testing, solder pastes 4, 8, and 9 were easier to clean. The data also finds that longer exposure time in the wash improves cleaning results. Additionally, higher fluid flow and coherent nozzle designs improved cleaning under low clearance components.

Cleaning Agent 2

Cleaning agent 2 is an aqueous concentrated cleaning agent built with solvency, low reactivity, and surfactancy to improve wetting, lower surface tension, and remove ionic soils (Figure 5).

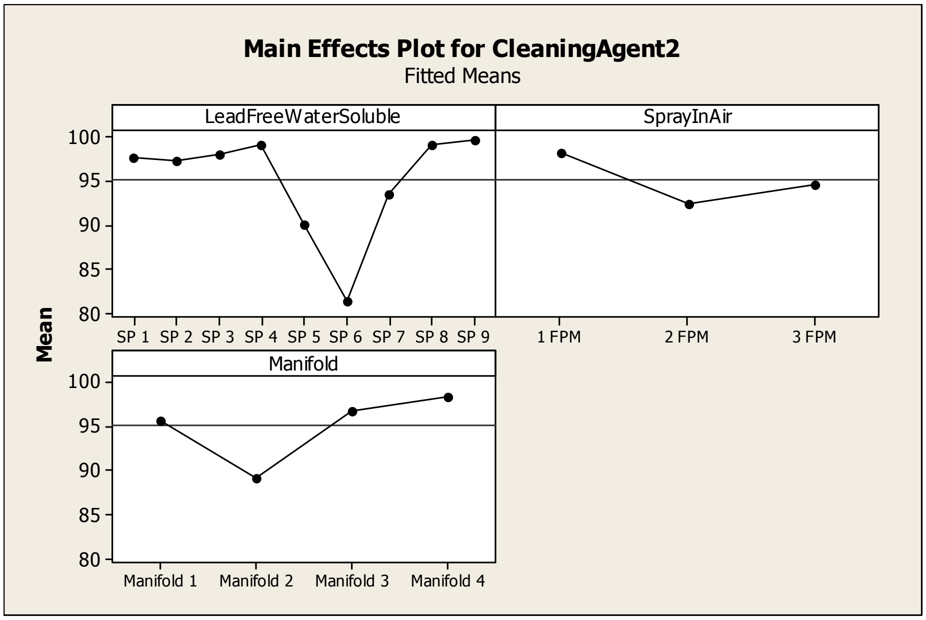

Figure 5: Main Effects Plot for Cleaning Agent 2

The data finds much improved cleaning over DI Water only. Solder paste 6 did not match well with cleaning agent 2. The data point indicates the importance of matching the cleaning agent to the soil. Longer exposure time improves cleaning but the fall off was not as significant at those for DI water. Increased fluid flow and impinging force at the board surface improved cleaning effects.

Cleaning Agent 3

Cleaning agent 3 is an aqueous concentrated cleaning agent designed to saponify flux residues. Cleaning agent 3 contains non reactive ingredients to lower surface tension, wet, defoam, and remove ionic soils (Figure 6). The data findings show improved results over DI water but not as good as Cleaning Agent 2. The cleaning rate was similar at one and two feet per minute but fell off at three feet per minute. High fluid flow and pressure at the board improved cleaning performance.

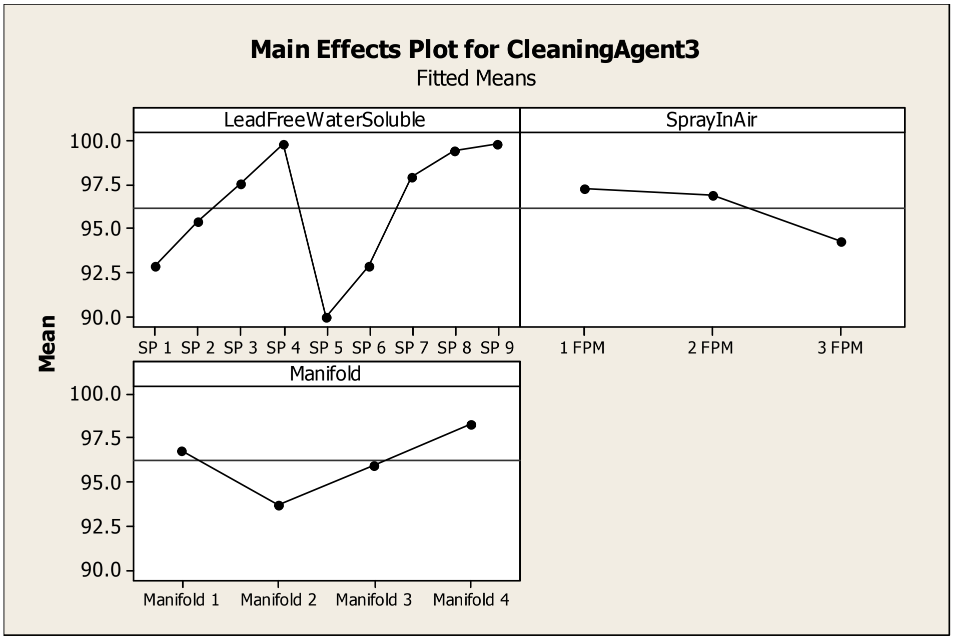

Figure 6: Mean Effect Plot for Cleaning Agent 3

Cleaning Agent 4

Cleaning agent 4 is an aqueous concentrated cleaning agent also designed to saponify flux residues. Cleaning agent 4 contains non reactive ingredients to lower surface tension, wet, defoam, and remove ionic soils (Figure 7). The data continues to point to the power of cleaning agent matching up to the flux residue. In this case, solder pastes 3, 8, and 9 cleaned very well even at three feet per minute.

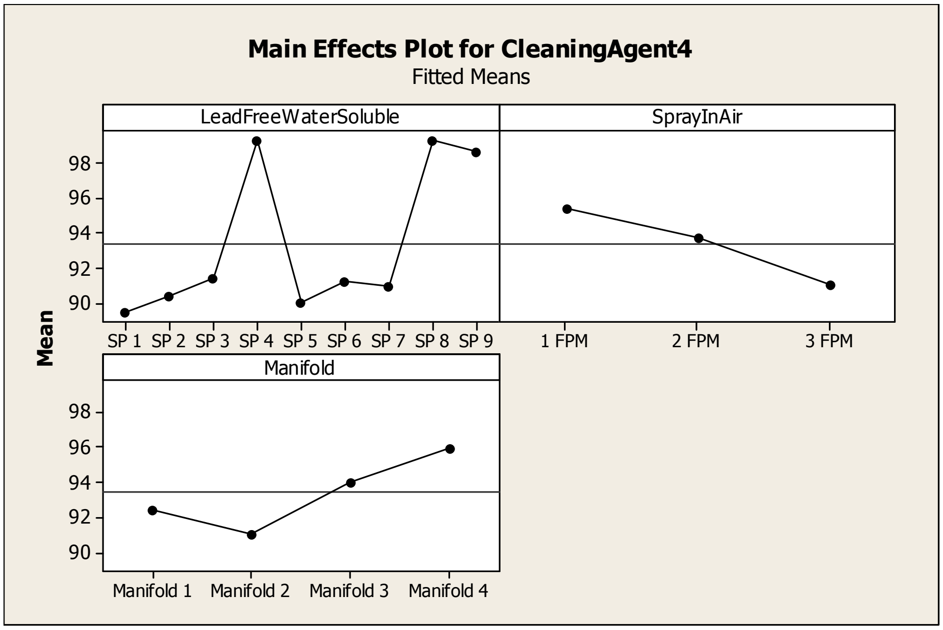

Figure 7: Main Effects Plot for Cleaning Agent 4

Cleaning Agent 5

Cleaning agent 5 is an aqueous concentrated cleaning agent designed to solvate and saponify flux residues. Cleaning agent 5 contains non reactive ingredients to lower surface tension, wet, defoam, and remove ionic soils (Figure 8). Solder pastes 4, 8, and 9 show a strong tendency to clean well with cleaning agents engineered with reactive agents.

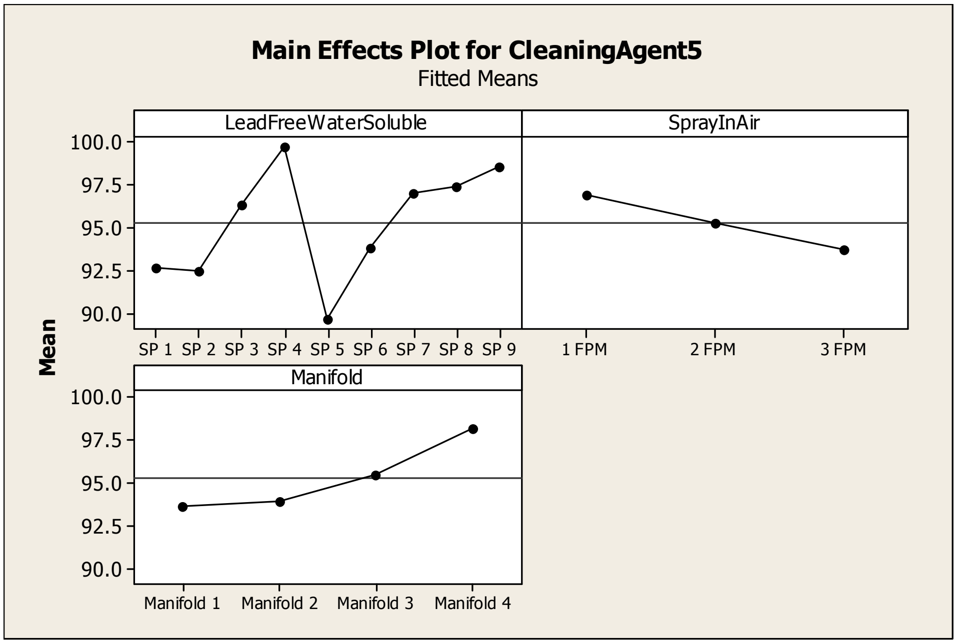

Figure 8: Main Effects Plot for Cleaning Agent 5

Cleaning Agent 6

Cleaning agent 6 is an aqueous concentrated cleaning agent designed to solvate, dissolve and saponify flux residues. Cleaning agent 6 contains non reactive ingredients to lower surface tension, wet, defoam, and remove ionic soils (Figure9). Cleaning agent 6 also shows a strong match for solder pastes 4, 8 and 9.

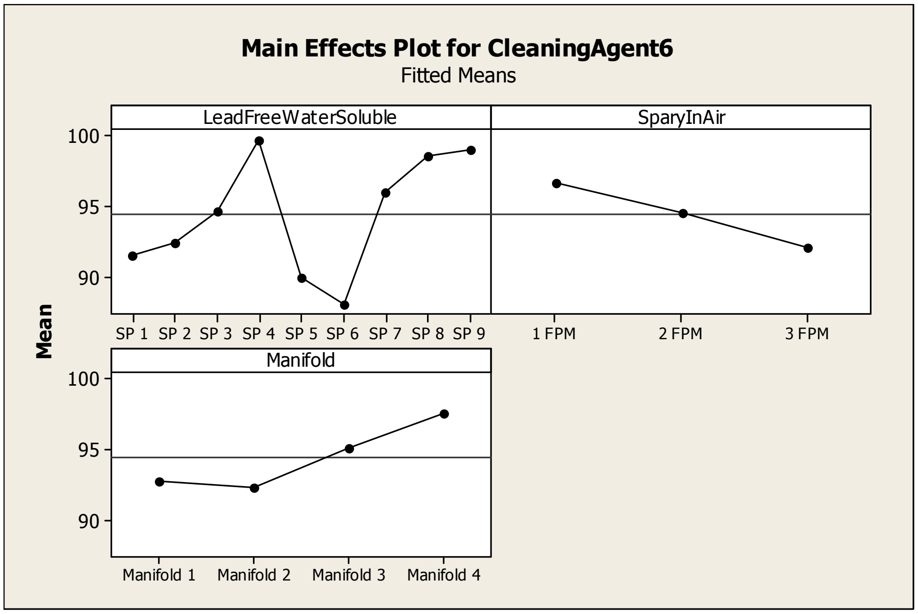

Figure 9: Main Effects Plot for Cleaning Agent 6

Cleaning Agent 7

Cleaning agent 7 is engineered as a neutral aqueous cleaning agent that drives with solvency and surfactancy. Cleaning agent 7 contains non reactive ingredients to lower surface tension, wet, defoam, and remove ionic soils (Figure 9). Similar to the other cleaning agents tested, cleaning agent 7 shows a strong match for solder pastes 4, 8, and 9.

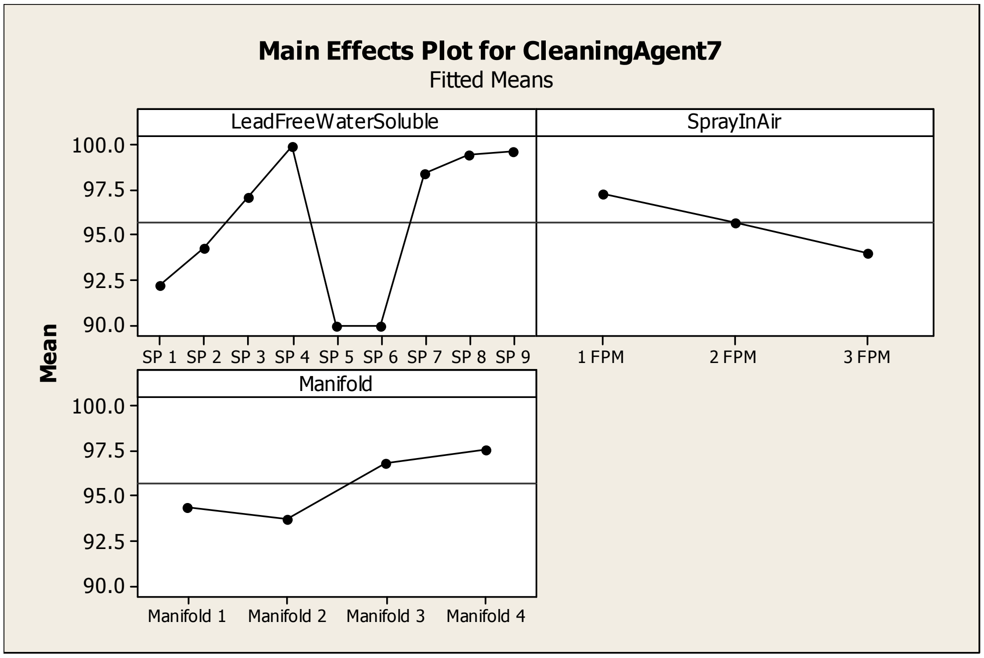

Figure 10: Main Effects Plot for Cleaning Agent 7

Inferences from the Data

The points on the main effect plots are the means of the response variable (% clean under 1210 and 1825 chip cap resistors) at the various levels of each factor. The reference line is drawn as the grand mean of the response data. The main effect plots compare magnitudes of main effects. The worksheet was set up with one column for the response variable and one column for each factor. Each row in the response and factor columns represents one observation.

The data infers four key findings:

1. Lead-free water soluble flux residues may require water with an additive to remove all flux residues under low clearance components. Several research studies report the need for additives to be added to DI water when cleaning lead-free water soluble flux residues. The data findings from this study support this premise.

2. A wider processing window occurs when the cleaning agent is closely matched to the flux residue. Lead-free solder pastes 1, 2, 3, 5, 6, and 7 were harder to clean and did match up as well to many of the cleaning agents tested as did solder pastes 4, 8, and 9. Cleaning agent 2 was a strong match for solder pastes 1, 2, 3, 4, 8 and 9 but was similar to the other cleaning agents on solder pastes 5, 6, and 7. Matching the solubility parameters of the cleaning agent with the flux residue is critical to opening the process window.

3. Four spray manifolds were studied. The differences were not dramatic but significant. Spray manifold 4 improved cleaning results. The manifold design delivered high fluid flow and pressure at the board surface. The data findings infer that this manifold design improves the cleaning result under low clearance components.

4. The data findings infer that time in the wash section improves cleaning under low clearance parts. Cleaning agent 2 was one exception that stood out from the data findings. When the cleaning agent is closely matched to the cleaning agent, time is not as significant of a factor.

Conclusion

Cleaning flux residues post soldering has been a high reliability criterion practiced by assemblers of military, aerospace, automotive medical devices and other value offerings. Highly dense circuit designs reduce component spacing and standoff heights. The complexity of removing flux residue increase as standoff heights reduce. Additionally, lead-free soldering appears to harden flux residues due to higher processing temperatures and flux burn off. The purpose of this research was to test the cleaning parameters needed to remove lead-free water soluble flux residues from under low clearance lead-free components.

When cleaning water soluble flux residues under low clearance components, the data findings indicate that DI water only fails to remove all flux residues. Cleaning agents closely matched to the flux residue improve cleaning results when used at low levels in DI water. With the wide range of soldering materials offered to industry, the data strongly suggests that cleaning agent differentiation comes from knowing how the cleaning agent matches up to the flux soil. This finding is critical when there is a need to remove flux residue under low clearance components. Cleaning agents closely matched to the flux soil allow for higher throughput rates.

The spray impingement manifold design was also a significant factor when cleaning all flux residues under low clearance components. Literature suggests that high flow, impingement pressure and directional forces improve cleaning under low clearance components. The data findings are consistent with these findings.

Author

Dr. Mike Bixenman is the Chief Technology Officer of Kyzen Corporation. Mike has twenty years experience in research, development, and optimization of electronic assembly cleaning agents and processes. He has authored and/or joint authored greater than 50 research papers on the topic of electronics assembly and advanced packaging cleaning. He holds four earned degrees including a Doctorate of Business Administration from University of Phoenix School of Advanced Studies.

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