"Cleaning"- The Dirty Word in Packaging Assembly

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Abstract

A majority of the package assembly facilities are using only DI water to remove flux residue from under flip-chip devices, prior to an underfill process. As the new technologies are being implemented, not only has DI water reached its limitations, but some cleaning chemistries are not able to perform adequately to remove ALL of the flux residues. Complete cleaning and removal of the flux residues under low profile components are critical to maintain the reliability of the integrated circuit. Therefore, the cleaning process must be carefully examined and optimized to obtain maximum performance for removing the flux residues. The total cleaning process can be broken down into two subsets:

- Static Cleaning rate & Dynamic Cleaning rate

The Static Cleaning rate is ability of the cleaning chemistry to remove or dissolve the residue in the absence of temperature and pressure. The Dynamic Cleaning rate involves the kinetic forces and energy to remove the residue. This includes the Thermal energy and Impingement energy required to remove the flux residue. The sum of these two cleaning rates (Static and Dynamic cleaning rates) equal the Total Process Cleaning rate (see formula below). This paper will review cleaning problems brought about with the implementation of the latest technologies and explain how the cleaning process can be optimized to guarantee the reliability of the assemblies.

Static Cleaning Rate + Dynamic Cleaning Rate = Total Process Cleaning Rate

Key words: IC Packaging, Cleaning, Flux residue, low profile components, static and dynamic cleaning rate

Introduction

Flux residue cleaning after soldering has been a standard for high reliability assemblies for years especially in the military, aerospace and medical device sectors. But within the last few years, new technologies and component complexities are being implemented at a rate that has not been observed since the SMT implementation almost 30 years ago. These new technologies have increased the complexity of typical flux residue cleaning. Integrated circuit manufacturing processes have also increased in intricacy with much lower stand-offs and circuit gaps. As the latest IC packages implement these new technologies, the need to effectively remove flux residues becoming more critical. And if the flux residues are not adequately removed, the reliability of the circuit can be drastically reduced. In the past, integrated circuit packages that were assembled using a water wash flux could typically and effectively be cleaned of the flux residue using only water. But the times have changed and these packages can no longer be cleaned using only water. Assemblers report that DI-water only is insufficient at removing oxidized residues that result from heat gradients at different points under the die, at the corners of the die, and edges of the die (Figure 1).[1] The flux residues left behind can contribute to IC package failures such as, poor underfill adhesion, thermal instability and electromigration.

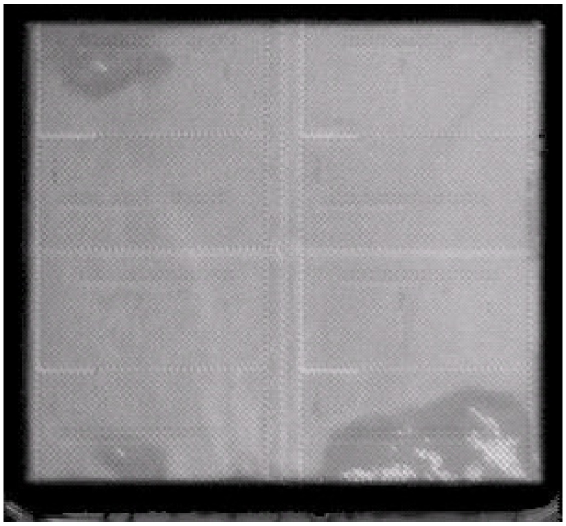


Figure 1 – Flux residue under IC[1]

Process engineers looking to clean integrated package designs typically start by identifying the cleaning equipment and cleaning material. Many use a very small subset of test vehicles to qualify the process. This technique worked well when qualifying a cleaning process for conventional designs but typically fails to address numerous factors when designing leading edge cleaning processes. The design of the cleaning process must dig into critical factors such as the integrated package designs cleaned, characterization of the soil, through-put requirements, materials compatibility, cleaning material, process parameters, cleaning equipment, spray impingement, time in the wash, temperature of the wash, controlling the chemistry, ventilation, water management, environmental constraints, and cost of cleaning.[2]

Therefore, the engineer must consider the Total Process Cleaning Rate. The Total Process Cleaning rate is the sum of the Static cleaning rate and the Dynamic cleaning rate. The Static cleaning rate (as stated above), is the ability of the cleaning chemistry to remove or dissolve the residue in the absence of temperature and pressure. To effectively understand how a cleaning chemistry will remove the flux residue, both the cleaning and flux residue chemistries must be characterized. This characterization process for both the flux residue and cleaning agents have been shown in recently published papers by Kyzen.[2.] The design of the cleaning chemistry will influence 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.[1]

The Dynamic cleaning rate, in basic terms, is how the chemistry is brought to the flux residue. This process involves all of the kinetic and thermal energies required to remove the flux residue and is related to fluid flow, fluid pressure and directional forces. Spray-in-air inline cleaning equipment provides a platform for delivering spray impingement perpendicular or angled to the flip-chip being cleaned. 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 flip chip high I/O die 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 flip chip assembly, residue removal is inconsistent at best. Additionally, water-soluble flux residues trapped under low flip-chip die create a flux dam and requires energy consistently applied to develop a wide process window. [1]

Methodology

To experimentally evaluate the cleaning effectiveness of the water wash flux residue under very low component profiles, a test board was utilized, The circuit board used for the experiment is a Kyzen internally developed test board using two different component types (1210 & 1825) with very low board-to-component body gap (1.0mil and 0.5mil gaps) – see Figure 2. The test board also configures the components in different orientations to maximize the shadowing of the component and increase cleaning difficulty. During reflow, the total underside of the component is filled with flux residue. The components allow access to the flux under the component gaps on two sides making the cleaning challenge increasingly difficult.

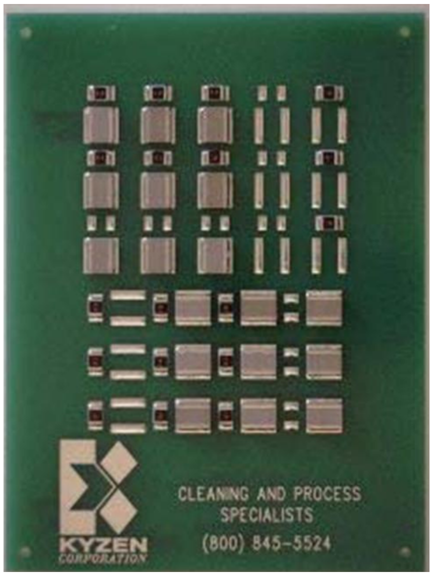


Figure 2 – Kyzen Test Card

During reflow, the total underside of the component is filled with flux residue. The components allow access to the flux under the component gaps on two sides making the cleaning challenge increasingly difficult. Figure 3 is an example of the typical flux residue that is observed under the low stand-off components when the component is removed.

Figure 3 - Flux under removed component

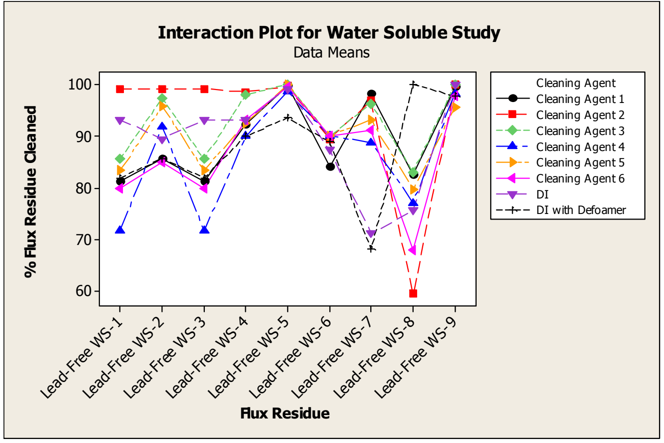
Experimentation – Static Cleaning Process Rate

An initial experiment was completed utilizing the Kyzen low profile component test card for the flux residue removal of nine various Pb-free Water Wash solder pastes using eight different cleaning chemistries. All of the cleaning chemistries were exposed to the same process parameters using an in-line cleaning machine:

- Concentration – 3.5%
- Temperature – 140F
- Belt speed – 3.5ft/min (~1.25 min exposure)

Figure 4 compares the results of the cleaning chemistries for each solder paste.[3] As the data shows, most of the Pb-free / water wash flux residues tested are not easily cleaned using the low concentration and fast belt speeds. Additionally, cleaning agent 2 exhibits the best overall cleaning results in removing flux residues from very low profile components for seven of the nine solder pastes tested. Also, Lead-free WS-8 solder paste was the most difficult flux residue to remove using the cleaning chemistries and may be better suited with using only DI water and defoamer. For Lead-free WS-6, cleaning agent 2 provided the best performance but may require a slightly higher concentration level to open the process window.

Figure 4 – Comparison of Water wash fluxes[3]



So, characterizing the flux residue with the cleaning chemistry is very important, in order to obtain a successful overall cleaning process. The proper choice of a cleaning agent will increase the process window of cleaning process and thus, lower the cost of the ownership. Additionally, the benefit of characterizing the flux residue and matching to the best fit cleaning agent saves time and money over the commonly used trial and error method.

Experimentation – Dynamic Cleaning Process Rate

From the data shown above in Figure 4 it is very important to choose the correct cleaning agent for removing flux residues, but what about choosing the cleaning equipment or process. The choice to use a specific cleaning equipment or process has a significant effect on the dynamic rate of cleaning and how it removes the flux residue. To evaluate various cleaning processes, we will not consider the characterization of the cleaning process, but to compare the different types of dynamic cleaning rates. The goal of the analysis is to determine the cleaning of various solder paste residues using multiple cleaning processes. The following four different cleaning processes were utilized for the experiment:

1. Ultrasonic 80 KHz
2. Spray under Immersion @ 50 psi
3. Batch Spray in Air @ 45psi
4. Planar Spray-in-Air @ 70 psi

Also, different cleaning agents were compared in the multiple cleaning processes, both aqueous and semi-aqueous chemistries.

Ultrasonic Energy: The first cleaning equipment consisted of immersion ultrasonic energy using an 80 KHz generator. Higher frequencies are considered safer for precision cleaning applications. Ultrasound creates microscopic voids or bubbles in the cleaning solution, which are then filled with vapor. As these microscopic bubbles burst, the cleaning fluid cavitates as the liquid mass generates small explosions within the body of the liquid. Ultrasonic agitation has long been considered a technology for removing soils from blind holes. Figure 5 shows the interactions of the flux residue soil with the cleaning agent when using the following process parameters:

1. Ultrasonic 80 KHz generator
2. Wash Concentration
    a. Aqueous ~ 20%
    b. Semi-Aqueous ~ 100%
3. Wash Time 10 minutes
4. Wash Temperature 140°F
5. Rinse DI Water

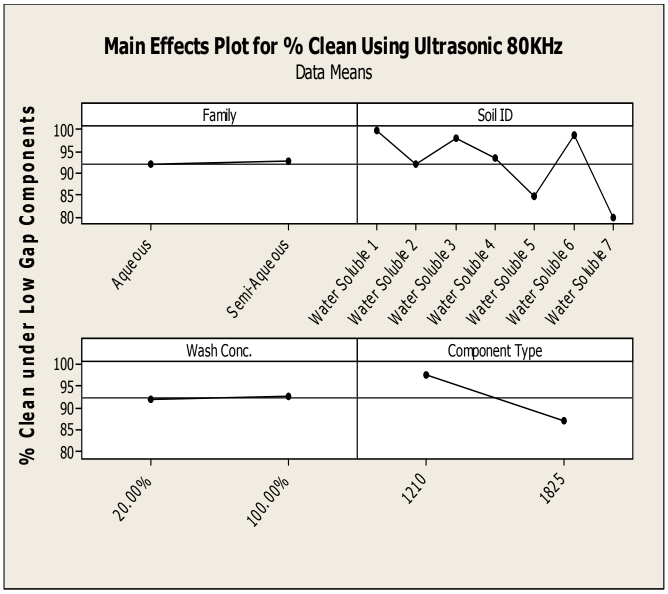


Figure 5

From the main effects plot of the cleaning performance, it is determined that the composition of the water wash flux residue has the highest level of influence on the cleaning effectiveness under low gap components. For a number of the soils represented in this study, the semi-aqueous chemistry provided the better overall cleaning performance compared to aqueous.

Spray-under-Immersion Energy: Spray-under-immersion batch cleaning systems use spray nozzles below the liquid level. The mechanical energy from the pump to the nozzle moves the cleaning solution across the part surface allowing the cleaning agent to penetrate and dissolve the flux residue. The spray pressure is quickly dampened from the liquid mass. Cleaning is more the result of liquid turbulence across the parts surface. Figure 6 shows the interactions of the flux residue soil with the cleaning agent when using the following process parameters:

1. Spray-under-Immersion @ 50 psi
2. Wash Concentration
    - Aqueous ~ 20%
    - Semi-Aqueous ~ 100%
3. Wash time: 10 minutes
4. Wash Temperature 140°F
5. Rinse DI Water

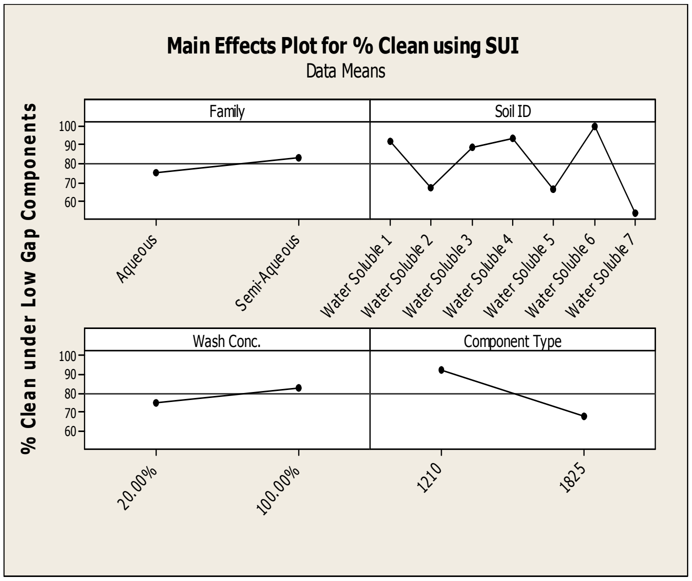


Figure 6

The main effects chart for the Spray-under-immersion cleaning show very similar data findings to the Ultrasonic impingement findings. The greatest variation in cleaning performance is related to the composition of the flux residue. The main effects chart does not show this, but for the easily cleaned water soluble residues, the cleaning was much improved using the SUI process, but the Ultrasonic cleaning process performed, on average, better than the Spray-under-immersion process.

***Spray-in-Air Planar**:* Spray-in-Air planar cleaning systems provide direct unimpeded spray impingement onto the circuit assembly. Spray impingement research advancements have improved cleaning under low gap components. The penetration is achieved through a combination of fluid flow, pressure at the board surface, and directional forces. Spray nozzle designs are used to improve coverage, deflection and penetration. Research data indicates that the planar delivery of the cleaning solution increases the removal of flux residues under low gap components. Wash time is a significant factor. To remove all residues under low gaps, the pressure used to deliver the cleaning solution channels through the flux residue. Once the cleaning solution is broken through the flux residue, fluid flows under the component, which over time removes all residues.

For this study, two spray impingement configurations were used. Based on past research, the spray manifold designs that provided best cleaning under low gaps were selected. Figure 7 shows the interactions of the flux residue soil with the cleaning agent when using the following process parameters:

1. Planar In-line spray-in-air
2. Aqueous material concentration: 15%
3. Wash Temperature 150°F
4. Belt speed: 0.5, 1.0 & 1.5 FPM

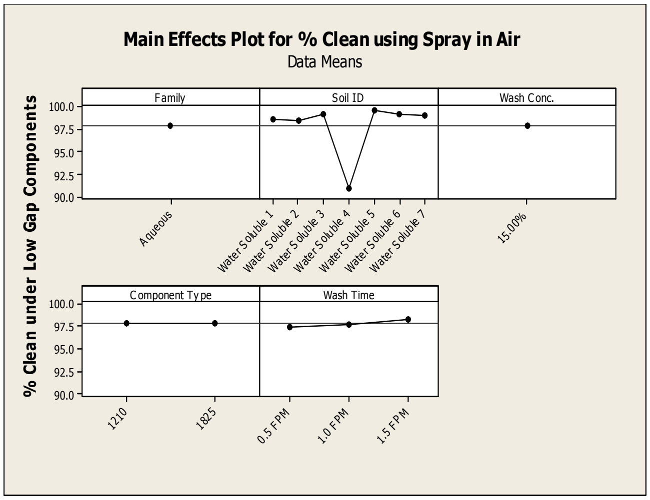


Figure 7

For this study, only one aqueous cleaning agent chemistry was evaluated in the planar inline cleaning study. The data for Spray-in-air was consistent with that from the ultrasonic and spray-under-immersion cleaning studies, but significantly better in the overall performance of cleaning. Most of the water wash flux residues were cleaned easily using the chemistry in the spray-in-air process. Only the water soluble 4 solder paste exhibited problematic cleaning performance using the spray-in-air process with the chosen aqueous chemistry. In order to get the maximum cleaning performance, the cleaning agent must match up with the flux residue to provide effective cleaning under low gap components. The planar cleaning results also revealed the significance of spray impinging forces for removing flux residues under low gap components. Time under spray was significant but not at the same level as the flux residue matched to the cleaning agent.

Conclusion

As the IC Packaging technology is progressing, the package density is increasing & gap height is decreasing, and thus making complete flux removal more difficult. The push towards miniaturization of the IC package is not the only driver in choosing the proper cleaning chemistry. From all of the data shown in this analysis, it is obvious that the Water Soluble flux technology is changing and making the flux residues more difficult to remove. The initiative to implement Pb-free solders has also contributed to these changes in flux technology and increased the problems in cleaning.

The complete removal of flux from under very low stand-off components is not a trivial process, even when using water soluble soldering fluxes. Additionally, implementing the use of cleaning chemistries to remove water soluble flux residues does not guarantee the complete removal of the soil under very low profile packages. To implement a successful cleaning process, the Total Process Cleaning Rate must be characterized. The Total Cleaning Process can be broken down into two subsets of cleaning: the Static Cleaning rate and Dynamic cleaning rate. The Static Cleaning rate is ability of the cleaning chemistry to remove or dissolve the residue in the absence of temperature and pressure. The Dynamic Cleaning rate involves the kinetic forces and energy to remove the residue.

To achieve a successful Cleaning Process, the flux residue must be first characterized prior to choosing a cleaning chemistry. Once the flux residue is characterized, then a cleaning agent can be matched to the flux residue and an optimized process can be developed. Finally, the cleaning equipment must also be considered when optimizing the Total Process cleaning rate. Though the best performance achieved for this analysis was the spray-in-air cleaning process, this doesn’t always prove to be true.

The thought of having one cleaning agent to be able to clean and remove every flux residue is not achievable. The cleaning chemistry must be matched with the flux material and be a primary consideration when choosing a soldering flux material.

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