# CLEANING HIGH RELIABILITY ASSEMBLIES WITH TIGHT GAPS, A DETAILED ANALYSIS

Thomas M. Forsythe Kyzen Corporation Nashville, TN, USA tom\_forsythe@kyzen.com

## ABSTRACT

As electronic assemblies have grown ever more capable over recent years, their form factors had decreased at an impressive rate of their won. These small gaps and design challenges have emerged in concert with a renewed requirement for entire assembly cleaning driven by an array of requirements led by increasing reliability requirements. Of course, while cleaning has always been mission critical for a number of segments, such as medical and military assemblies, today it is being adopted broadly throughout the industry.

This presents both advanced technology groups and manufacturing engineers with a new process to implement with little tribal knowledge within their organization to base their evaluation on. This paper will study these small gaps and evaluate ionic residues post cleaning by a variety of cleaning agents versus a pair of commonly encountered water soluble fluxing materials. This will allow users to understand the challenges presented by low gap height and the risks associated with various cleaning approaches to remove those residues.

#### **INTRODUCTION**

State of the art electronic devices continue to advance at a rapid rate delivering new capabilities to consumers throughout the world. Mobile phones alone account for over 400 million units per quarter, a solid 35% of which are smart phones. Smart phone production volumes now eclipse PS shipments, even with the generous inclusion of tablet sales in the PC statistics.

As even the casual observer is aware, these smart phones are smart indeed and their capabilities are steady improving. This enhanced performance is a key element driving demand for these devices, not surprisingly as performance improves so does the user's expectations of quality and reliability; if one has their "life on one's phone", we certainly are not happy to see it go up in smoke in any way.

Electro Chemical Migration (ECM) is a critical risk factor in any electronic reliability analysis. Since every electronic device is powered up to function, and virtually every device does so in the presence of humidity, the sure way to prevent ECM is the absence of ionic residues.



Figure 1. Factors contributing to ECM

This paper will detail conduct a thorough review of these residues detected during the DOE developed for this paper.

Key words: electronics cleaning, POP cleaning, flip chip cleaning

Reducing or eliminating residues starts with a welldesigned, validated, well run cleaning process. Such a process has two major building blocks: the equipment delivering the mechanical energy, and the cleaning agent delivering a well matched chemical solution that together remove all undesired contaminants not only from readily accessible surface areas but difficult to reach gaps beneath components and other devices.

The balance between chemical and mechanical elements in the process is critical to robust process design, equally important to a detailed understanding of the assemblies or packages which are to be cleaned.

Those schooled in the art of cleaning know that board density can increase the cleaning challenge, but the critical driver in today's complex designs is the "gap". The gap, also known as the stand-off height, is the distance between the bottom of a device and the board surface; the shorter this distance, generally referred to as the smaller that gap the more difficult the cleaning challenge. Not surprisingly, truly flush mounted components present the greatest challenge.

With a sound understanding of the challenges presented by the assembly design, next we turn to the cleaning process itself. This evaluation begins with certain fundamentals developed during decades of research into cleaning technology which can act as a guide during the process.

- 1. Increased temperature generally enhances processes results. However, the results provided by slightly elevated temperature are often not bettered at very high temperatures. More is not always better, and our data set will guide us to defining the point of diminishing returns.
- 2. Likewise, higher concentrations of the cleaning agents often enhance performance. As with temperature, there is routinely an inflection point of diminishing returns that should be understood in any process design. Operating concentrations have a linear effect on operating costs and always receive close scrutiny.
- 3. The mechanical energy delivery system: pressure, spray patterns, exposure gaps.
- 4. Exposure time to the cleaning agent and mechanical energy. Time is always a precious commodity, and frequently subject to arbitrary limits determined prior to the device evaluation. When considering tight gaps or low standoff height device cleaning, a fifth element comes into play: cleaning agent surface tension and propensity for capillary action. In conjunction with the driving force of mechanical impingement lower surface tension improves capillary action. Together these forces enhance wetting and penetration of the fluid into tight gaps beneath components.

The purpose of this designed experiment is to evaluate the effectiveness of a variety of cleaning agents under an array of process conditions. As such, mechanical energy was limited to allow for full understanding of the chemical driving forces at work as evaluated by ion chromatography.

#### EXPERIMENTAL DESIGN

This DOE focused on cleaning effectiveness of a selected low gap chip scale package.

Two commonly used water soluble fluxes typical for this type of package were selected for comparative purposes, referred to in the paper as WS#1 and WS#2.

Three different cleaning solutions were included plus the commonly used water alone baseline. These materials are referred to throughout the paper as Agents A, B, & C which were evaluated at 2%, 4%, 6%, & 10%. An un-cleaned control samples were evaluated with each soldering material as well as samples cleaned with 100% water which were evaluated at each temperature condition.

Three temperatures of 20C, 40C & 60C were evaluated all with minimal agitated soak via mild shaking agitation. This approach was taken to fully evaluate the chemical driving forces of the cleaning agents. Follow on testing is planned to evaluate various mechanical energy options and their impact on the results.

Response variable included vision inspection at 100x and both anion and cation evaluation via ion chromatography (IC).

# LITERATURE REVIEW AND DATA ANALYSIS METHODOLOGY

Dozens of papers have been presented over the past 10 years, evaluating various aspects of new and novel cleaning processes. These evaluations provide a range of perspectives:

- 1. One mechanical approach compared to various chemical options.
- 2. One or two chemical options across a variety of equipment platforms.
- 3. User driven papers walking through their DOE, often employing sophisticated test cards to simulate the wide variety of designs encountered in their operation.

Each of these approaches has their benefits and contributes to the industries body of knowledge, and indeed this paper follows point one employing one, limited mechanical action approach contrasted with a number of temperature, concentration and agent variations. This DOE attempted to bring another facet to the discussion. That being a large data set, 82 different points each with IC results to compare and contrast an unusually large body of IC data we will attempt to analyze thoroughly.

#### DATA ANALYSIS

We begin the data review with our control sample. What is the state of the substrates prior to any cleaning step at all? Figure 2 provides the anions detail. We have chlorides, nitrates and weak organic acid present. WS#2 has generally lower levels of WOA than WS#1.



Figure 2. Control Anions

One challenge with this DOE is it is a point source analysis. We did not evaluate full assemblies. The reason is surface cleaning is generally not very challenging these days. It can be, but cleaning in these tight gaps is the critical success criteria. For this reason the results are a bit different from other recent studies.

The challenge comes with interpreting the data, current industry standards are logically focused on the acceptability of a full assembly not a single challenging device. The proper approach for scaling down these full assembly acceptable standards is also work that will be addressed in the future.

Cations detail is in Figure 3. We have sodium, lithium, potassium present. WS#2 also generally has lower levels of cations than WS#1.



Figure 3. Control Cations

Water alone was included in the evaluation for one reason. It is the most common cleaning agent used to clean water soluble fluxes throughout the world. The key question is how does it measure up versus the control and the various cleaning agents evaluated.



As shown in Picture Grid 1, WS#1 visually has less residue than WS#2 at each temperature point.



Figure 4. Water Only Anion Results

Evaluating the water only anion results we see that chlorides, bromides, nitrates and weak organic acids are all present while WS#2 has lower levels of WOA.



Figure 5. Water Only Cation Results

Reviewing the water only cation results, we see sodium, ammonium, potassium, magnesium, and calcium present. WS#2 displays lower levels of cations.

Next we will review the results from Agent A.



Picture Grid 2. Agent A Visual Cleaning Results

The visual results for Agent A are comparable for both soldering materials with much less difference between the significant visual contrast displayed by water alone.



Figure 6. Agent A Anions @ 20C







Figure 8. Agent A Anions @ 60C



Figure 9. Agent A Cations @ 20C



Figure 10. Agent A Cations @ 40C



Figure 11. Agent A Cations @ 60C

Inferences that can be drawn from the Agent A data include less visual difference between the two fluxes them than when exposed to water alone and cleaning marginally improved with higher concentration.

Looking specifically at anions, the levels were very low overall. At the lowest temperature point of 20C, we do see the data spread for WOA. As temperature increases all the results trend together with WOA reduced to 0 ppm as temperature increased to 40 & 60C while nitrates and phosphates rose slightly at 40 & 60C.

Cation sodium and ammonium were slightly higher levels. Ammonium levels dropped at 4-8% concentration but slight rose at 10% concentration. Performance seems to improve at higher temperatures. WS#2 continued to have slightly lower levels than WS#1, while WS#1 had a little less overall visual residue.

#### **Interaction and Main Effects Plots**

Agents B & C showed slightly better performance, but rather than review those data points individual we will do so through the use of interaction and main effects plats to allow easy comparison.



Figure 12. Interaction Plot for Fluoride

Here we see little response to Fluoride from water or Agent A & B. Agent C levels are a bit higher, though still very low across all temperatures and concentrations.



Figure 13. Interaction Plot for Bromide

Bromide seems to show identical affects for all cleaning

agents across concentrations and temperatures, with the water and control effects being very similar.



Figure 14. Interaction Plot for Chloride

With Chlorides we do see some spread in the data, though across a very small range. We see Agents A, B & C performing in that order consistently throughout the data though the gaps are very small.



Figure 15. Interaction Plot for Nitrate

Similarly to bromides, nitrates seem to react to all Agents in a comparable fashion.



Figure 16. Interaction Plot for Nitrite

Agent B seems to respond to temperature when looking at the Nitrite data, but generally the materials perform comparably.



Figure 17. Interaction Plot for Phosphate

Agent C seems to have an advantage with phosphate ions, but the values are all quite low for agents.



Figure 18. Interaction Plot for Weak Organic Acid

Water responds meaningfully raising the temperature from 20 C to 40C as one would expect. While WS#2 appears to have lower levels of WOA, the data is skewed by the control and water only results which are meaningfully poorer than all the Agent data. This is a meaningful observation.



Figure 19. Interaction Plot for Lithium

Everything was 100% successful.



Figure 20. Interaction Plot for Sodium

While WS#2 was consistently better than WS#1, it was a slight difference. The major change in the plot was again driven by the control and water points. Sodium also trends better with increased temperature.



Figure 21. Interaction Plot for Ammonium

Agents B & C meaningful improved over Agent A. No other variables seem overly sensitive.



Figure 22. Interaction Plot for Potassium

Concentration seems to help, while temperature does not appear very responsive for the potassium ions.



Figure 23. Interaction Plot for Magnesium

Concentration and temperature seem a bit responsive, but the levels seem quite small. Here is a case where WS#1 seems to do better than WS#2 in general.



Figure 24. Interaction Plot for Calcium

Agent C once a gain a clear winner with little difference between WS#1 & WS#2.



Figure 25. Interaction Plot for Total Anions

Looking at total Anions, Agent C seems to come out on top but it is shades of gray not a real breakout while increased temperature and concentration have modest overall contributions.



Figure 26. Interaction Plot for Total Cations

Once again, Agent C comes out on top for total Cations as well. Not by a wide margin, but a discernible margin.



Figure 27. Interaction Plot for the Grand Total

Not surprisingly, Agent C again breaks out of the data by a small margin.

#### CONCLUSION



Figure 28. Main Effects for Grand Total

With the control data skewed, Agent C breaks out as the winner though temperature and concentration do not trend toward more is better.

The large data package in this DOE makes the analysis rather straight forward. As in most protocols, there are ambiguous results at times and not every dataset reaches the same conclusion. This point is key; any particular product life cycle may have unique sensitivities important to its operating for everyday of its service life. Detailed data such as this, though expensive and time consuming to generate can be enormously instructive for such high value, long lived devices.

## **FUTURE RESEARCH**

Work such as this has several potential paths forward. One is to include more soils into the current data matrix. Another is to keep the same dataset and move downstream into commercial grade cleaning equipment to evaluate the impact of meaningful mechanical energy. More importantly for the industry, as work such as this propagates industry standards will need to be developed and validated for these point source contamination levels.

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