Does Water Do the Job on Its Own?

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INTRODUCTION:

Water-soluble fluxes are widely used for modern advanced packaging devices. While electronic components advance toward fine-pitch and miniaturization, some electronic assemblies are also adopting water-soluble fluxes for soldering processes. This is often because modern electronic devices create more problems while using conventional No-Clean fluxes. Water-soluble fluxes are designed to be cleaned by de-ionized water. This sometimes leads IC packaging houses and electronic assemblers to clean water-soluble flux residues with DI water only to reduce the additional costs of cleaning agents.

However, incomplete cleaning and electrical defects have been reported on devices cleaned in the field by DI water only. Studies have revealed that certain amounts of flux residues were commonly observed under flip chip dies or bottom terminated components (BTC). Many factors must be considered and evaluated before implementing a cleaning process using only DI Water. The purpose of this technical paper is to demonstrate the key barriers to cleaning modern electronic devices with DI water including (1) product miniaturization, (2) soldering reflow temperature, and (3) a variety of water-soluble flux formulae (multiple).

KEYWORDS:

Advanced Packaging, Electronic Assembly, Miniaturization, Standoff Gap Height, Surface Tension, Heat Exposure

PRODUCT MINIATURIZATION:

Market demand has driven the miniaturization of electronic devices while increasing their function and performance. Product designers must advance product designs with more compact circuits to achieve market needs, particularly smartphones, smartwatches, and other handheld devices. By looking at new semiconductors and electronic assembly technologies, chip designers create more functionality and efficiency on chips by utilizing 7nm to 5nm wafer foundry technologies to create more I/Os per unit area. Downstream product assemblers adopt advanced technologies such as TSV 3D ICs, Cu pillar flip chip, SiP, and PoP to advance packaging components and HDI with many leadless components to assemble circuit boards. The advanced technologies all include smaller bump size, fine-pitch, and low standoff gap height (distance from the board surface to the bottom gap of the component, as shown in **Figure 1**). As a result of these features, water-soluble flux residue is routinely trapped under bottom terminated components and bridges conductors (**Figure 2**) after the soldering process, creating a high-risk product reliability.

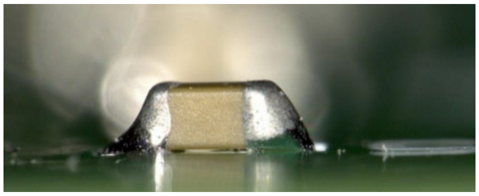


Figure 1: Standoff gap height between board and component.

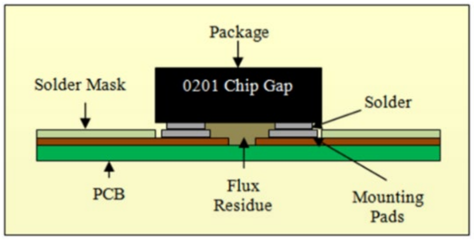


Figure 2: Flux Residue Bridges Conductors

Compared to no-clean flux, water-soluble flux is easier to clean but contains high levels of ionic content left behind after the soldering process. Without the ideal post-cleaning process to completely remove corrosive ions, ionic residues will corrode metallization and create electrochemical migration. This can quickly lead to electrical leakage or electrical shorts, resulting in product reliability failure. To remove water-soluble flux residues under flip chip dies or bottom terminated components (BTC), the cleaning fluid needs to penetrate very low standoff gap heights between components and substrates allowing it to create flow channels to remove flux residues.

While standoff gap height has continued narrowing to 1-2 mils (25um-50um) or smaller on modern components including Cu flip chip packaging, QFNs, and chip resistors, higher mechanical energy and longer wash times are required to deliver cleaning fluid into those narrow gaps to achieve ideal cleanliness. In addition to those two cleaning parameters, it is key that the cleaning fluid has a low surface tension generating better wetting performance allowing cleaning fluid to easily access gaps. The surface tension of DI-water is 72 dynes/cm and forms a large droplet (Figure 3)

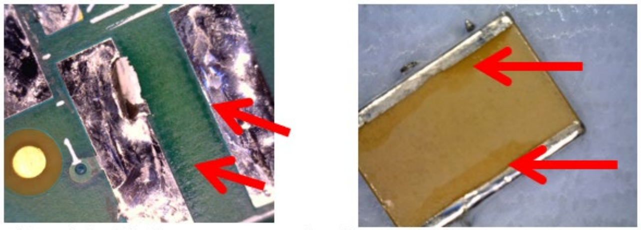
Figure 3*:* DI water (on the right) forms a large droplet.

A previous study has also shown that DI-water alone has difficulty entering gaps of less than 2 mils in common cleaning recipes. One PCB assembler claimed they could not achieve ideal cleanliness by DI-water only, despite maximizing the accepted process window in their operation for mechanical energy and wash time. In this case, a side-by-side cleaning trial was performed to compare the cleanliness between PCBs cleaned with DI water only and those cleaned with an aqueous cleaning agent. The cleaning parameters and results of this trial are as follows:

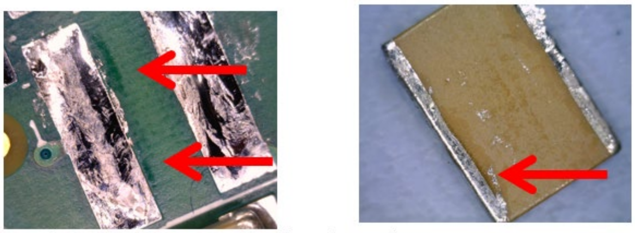
CLEANING COMPARISON BETWEEN DI-WATER AND KYZEN CLEANING AGENT:

DI-Water Cleaning (Table 1)

Cleaning Agent	**Wash Temp**	**Belt Speed**
DI Water	145°F/62.8°C	2ft/min



Board 1, C1 flux on cap underside and PCB

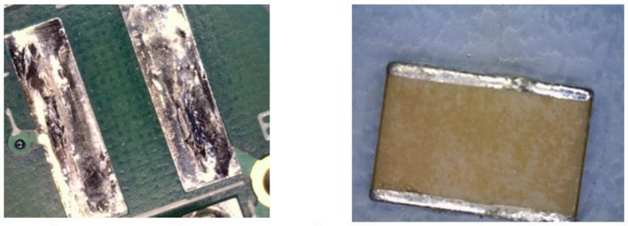


Board 1, C2 flux on cap underside and on PCB

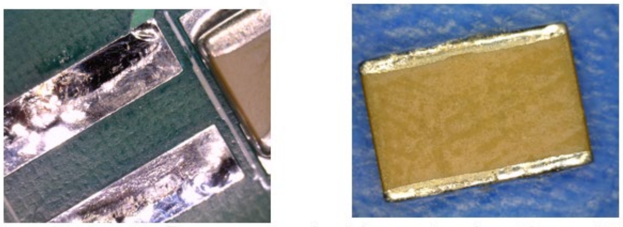
Figure 4: Test board 1, cleaned by DI-Water only.

KYZEN Chemistry Cleaning

Cleaning Agent	Wash Temp	Belt Speed
A-xxxx@3%	140°F/60°C	2ft/min



Board 2, C1 No Flux on cap underside, no visual residue on PCB



Board 2, C2 No flux on cap underside, no visual residue on PCB

Figure 5: Test board 2 cleaned by KYZEN cleaning agent.

The cleaning trial was performed using an existing cleaning recipe (Table 1). The results of the trial (Figure 4) showed flux residue left behind on the bottom side of the chip capacitor and PCB of Test board 1 after it was cleaned by DI water. Test board 2 showed no flux residue (Figure 5) during microscopic inspection after it was cleaned with a KYZEN aqueous cleaning agent. The data findings also proved that with a 3% cleaning agent, the cleanliness of the board can be improved while cleaning at a lower temperature, thereby reducing operational costs. Further evaluation and optimization could be necessary to produce and verify ideal cleaning parameters.

SOLDERING REFLOW TEMPERATURE:

Modern electronic devices commonly use No-clean (NC) or water-soluble (WS or OA) fluxes in the soldering process. As most applications move toward miniaturization, NC flux residues become more problematic and represent a higher risk to product reliability because weak organic acids (WOA) are difficult to activate completely. No-clean flux residue is also harder to remove than water-soluble flux residue, especially under a small standoff gap, and may also create electrochemical migration if exposed to the right conditions. Thus, water-soluble fluxes have become the mainstream materials for the soldering process on miniaturized devices used in the consumer markets.

The use of SAC (Sn-Ag-Cu) alloys has driven many changes in the electronics manufacturing process including soldering materials. An elevated soldering temperature and changing flux compositions often create hard-to-clean flux residues. Excess time above liquidus or overheating during the soldering process can even result in flux polymerization, char, or burnt-out flux residues as shown in **Figures 6** and **7**. Next, the properties of flux residues can be changed and unmatched to the cleaning agents. For example, when water-soluble flux is polymerized due to excess heat, DI water cannot remove non-ionic polymerized materials resulting in incomplete cleaning and residue. Another common case occurs when water-soluble fluxes are burnt out. Sometimes described as cross-linked. Those residues can never be removed, even when cleaning agents are used.

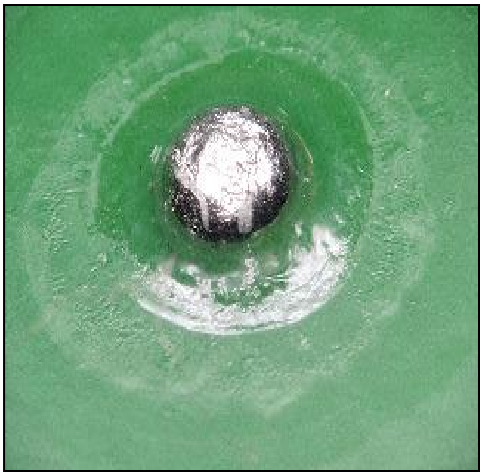


Figure 6: Polymerized Flux

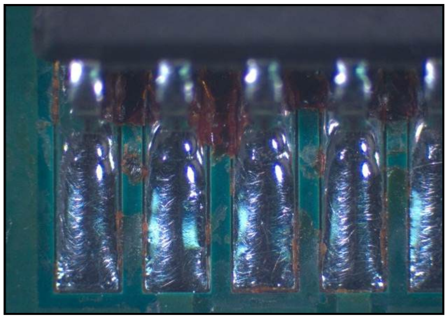


Figure 7: Burnt Flux Residue

Some advanced packaging and electronic assemblies may require multiple reflow processes. Users tend to clean flux residues after all soldering processes are done to save time and cleaning costs. Under these conditions, some flux residues may become much harder than others on the same product. When using this approach, users may encounter poor cleanliness in certain areas when cleaning with DI water because of the changes in the flux residue properties during the second (or multiple) reflow processes in addition to fluxes that do not match well to DI water alone. Proper control of upstream soldering temperature is key to opening a cleaning process window to achieve ideal cleanliness when exclusively using DI water. However, when users see the difficulty of optimizing heat exposure during the upstream process, the best approach to overcome the barriers while improving cleanliness is applying a cleaning agent to the cleaning process.

WATER-SOLUBLE FLUX VARIETY:

Water-soluble flux typically contains (1) Resin, (2) Activator, (3) Solvent, and (4) Rheology modifiers. Water-soluble flux residues consistently leave high levels of ionic materials behind with a high potential for dendrite growth. This means residues must be completely removed after the soldering process. By its formula, water-soluble flux is designed to be cleaned by DI water only. However, flux suppliers have continued modifying water-soluble flux formulas to meet application requirements due to constant decreases in the distance between soldering pads and pitch, particularly for miniaturization.

The features of miniaturization and lead-free products force flux suppliers to formulate more polar functional materials, higher oxygen barriers, and a higher level of WOA (weak organic acid) to increase the water-soluble capacity of wetting and oxidation removal.

Due to the reduction in the distances of soldering pads, after printing or the dispensing process, solder paste should sit on pads with proper thixotropy index to avoid soldering bridging issues. Thus, higher molecular weight vehicles and non-ionic materials are added to prevent solder paste slump issues. Each of these factors contributes to the water-soluble flux residue properties being created unequally due to the different materials selected by each supplier, thereby impacting the post-reflow cleaning process. **Figures 8** and **9** show the different cleaning capabilities of DI water between two, water-soluble fluxes. Both water-soluble flux residues were cleaned under spray nozzles for 30 seconds with DI water. **Figures 10** and **11** show the improved cleaning rate by applying a KYZEN cleaning agent (CA) at 5% for 30 seconds between the two flux residues. A comparison of the results indicates that water-soluble fluxes in the market are not equal and may bring different challenges during cleaning processes. DI water is a good cleaner for ionic residue. However, it may not be sufficient to meet today's manufacturing requirements because water-soluble flux may also contain some non-ionic materials due to the aforementioned requirements.


Figure 8: WS A by DIW

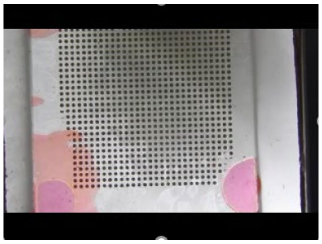


Figure 9: WS B by DIW

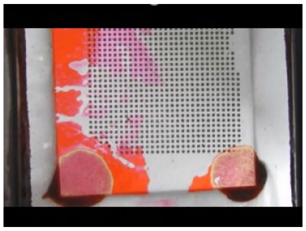


Figure 10: WS A by KYZEN CA@5%

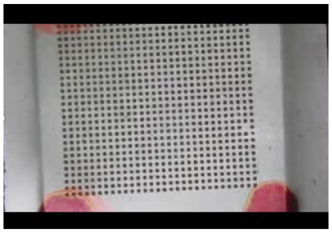


Figure 11: WS B by KYZEN CA@5%

CONCLUSION:

All solder paste flux compositions are not created equally. A specific cleaning solution may fit in one manufacturing process but be incompatible with others. The combination of water-soluble flux versus DI water cleaning may not always prove effective in the field due to the overall limitations of product manufacturing. Low levels of ionic residue may soon lead to product reliability failure due to the features of miniaturization. Many considerations must be made and factors assessed in designing an ideal cleaning process including:

- Component Selection
- Solder Mask Definition
- PCB Circuit Trace Width
- Bump Size, Bump Pitch
- Standoff Gap Height
- Solder Paste/Flux Selection
- Package Placement
- Solder Paste Reflow (Heat Exposure)
- Cleaning Agent
- Cleaning Machine Impingement Energy
- Wash Time
- Wash Temperature

Matching a cleaning agent to the soil it cleans is a key factor of an ideal cleaning process design. This includes affinities and kinetic surface energies for the soil. The soil must also be miscible in the cleaning agent. When users see the challenges in optimizing upstream processes for DI water cleaning, the best approach is to adopt cleaning agents that improve cleanliness and cleaning efficiency.

REFERENCES:

1. Bixenman, M., Jason C. (2013) Cleaning flux residue under bottom terminated components in batch spray-in-air tools. SMTA SEA conference.