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Solder Mask and Low Standoff Component Cleaning – A Connection?

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Abstract
Today, printed circuit boards used within electronic assemblies for high reliability applications are typically subjected to cleaning or defluxing processes. As assembly complexity has increased, that is, more densely populated with greater use of stacked and leadless components and with ever reducing standoff heights, effective defluxing is increasingly challenged.

Copper traces and pads are integral to PCB design. In order to protect these from corrosion and oxidation, the PCB is covered by a solder mask. This prevents performance degradation by providing a barrier between soldered joints and other conductive elements on the PCB. As detailed in IPC SM-840D, solder mask materials applied to the printed board substrate shall prevent and/or minimize the formation and adherence of solder balls, solder bridging, solder build-up and physical damage to the printed board substrate. The solder mask material shall help impede electromigration and other forms of detrimental or conductive growth [1].

The solder mask is necessary for long term reliability of PCBs, but can its presence also impact cleaning process effectiveness? When incorporating a solder mask, the designer can specify the solder mask as either Solder Mask Defined (SMD), Non-Solder Mask Defined (NSMD) or No Solder Mask (NoSM). Although there are design considerations for using either solder mask approach depending upon component details, in general with SMD and NSMD, the component standoff height is slightly less when compared with NoSM which could impact the cleaning process effectiveness.

For this study, the authors wanted to assess the impact of different solder mask options on under component cleanliness. The solder mask specification for the substrates used in this study included SMD and NSMD as well as NoSM for comparative purposes. The solder mask used on the test vehicles employed for this study was liquid photo-imageable (LPSM or LPI) solder mask. The test vehicles were populated with numerous chip cap components with four solder paste types: no-clean tin-lead solder paste (old generation), no-clean tin-lead solder paste (new generation), no-clean lead-free solder paste (old generation) and no-clean lead-free solder paste (new generation).

All test vehicles were cleaned in a spray-in-air (SIA) inline process utilizing two different water-based engineered cleaning agents, one alkaline and the other pH Neutral. Additional variables considered were wash exposure time and wash temperature. Thus, for each solder paste used, variables included solder mask type, cleaning agent type, wash exposure time, and wash temperature. The test plan employed full factorial analysis.

Cleanliness assessment was conducted by visual inspection per IPC TM650. All components were mechanically removed from the test vehicle thereby enabling thorough under-component inspection. Localized extraction and Ion Chromatography analyses were also conducted in accordance with current IPC standards.

Keywords
Bottom Terminated Components (BTC), PCB defluxing, solder mask, failure mechanisms, component standoff.

Introduction

As PCB board designs have increased in complexity, so has component density. Bottom Terminated Components (BTCs) are increasingly used as these are relatively low cost and attractive for volume applications. Typical examples are quad flat no lead (QFN), dual flat no lead (DFN), land grid array (LGA) and micro lead frame (MLF) which have very low standoff. These challenge steps in the manufacturing process including assembly, inspection and cleaning [2].

Other components, such as chip capacitors and resistors, offer similar challenges due to the ever-shrinking standoff heights. Within the industry, low standoff height is generally considered to be less than 1 – 2 mil or 25 – 50 microns. However, standoff height less than 1 mil or 12.5 to 25 microns, is not uncommon.

Electronic assemblies designed for high reliable applications (Class 2 and Class 3 as defined by IPC-A-610E) are very likely to be cleaned. Given the pervasive use of BTCs and shrinking standoff heights, effectively cleaning flux residues from around and under today's components is increasingly challenged. Many cleaning processes include SIA cleaning systems, either batch or inline. Modern aqueous based cleaning agents designed for use within SIA cleaning equipment are formulated with low surface tension, typically less than 30 dynes/cm. Given this, the mechanical, thermal and chemical energy of the cleaning process must be optimized so that the cleaning agent can penetrate underneath the components, solubilize the residue, and be effectively rinsed away [3].

Cleaning substrates with these challenging components usually requires aggressive process settings. That is, longer exposure or wash time and higher wash temperatures [4]. PCB density and component geometry and standoff greatly influence the effectiveness of any cleaning system. However, another contributing factor to consider is the potential impact of the solder mask on the cleaning process.

All PCBs are designed with solder masks. Solder masks, also known as solder resist, are essentially a polymer layer applied to the PCB surface in order to protect the copper traces and pads from oxidation and corrosion as this can lead to electrochemical migration, leakage current, and ultimately assembly failure.

The solder mask is critical to the long-term reliability of the assembly. There are three main types of solder masks available: Epoxy Liquid, liquid photo-imageable solder masks (LPSM), and dry film photo-imageable solder masks (DPSM). The Epoxy Liquid solder mask is the cheapest type and is applied through a silk-screening process. LPSM can be silk screened or sprayed onto a board before it is exposed and developed and is generally used with boards with unusual topography. DPSM are applied using vacuum lamination and are best used for flat surfaces.

After applying the solder mask, the exposed areas of copper must be plated with a surface finish. The most common type is Hot Air Solder Leveling (HASL). Other finish options are Electroless Nickel Immersion Gold (ENIG), Immersion Tin (ImSn), Immersion Silver (ImAg) and Organic Solderability Preservatives (OSP) [5].

Once a solder mask type is selected, the application to the pad must be defined. The options include Solder Mask Defined (SMD) and Non-Solder Mask Defined (NSMD). NSDM is also known as copper defined.

With SMD, the solder mask openings are smaller than the copper pads. Additionally, the solder mask covers the PCB area between adjacent pads and overlaps on top of the pad edges. With NSMD, the solder mask openings are larger than the copper pads and it also covers the area between the pads. Reference Figure 1.

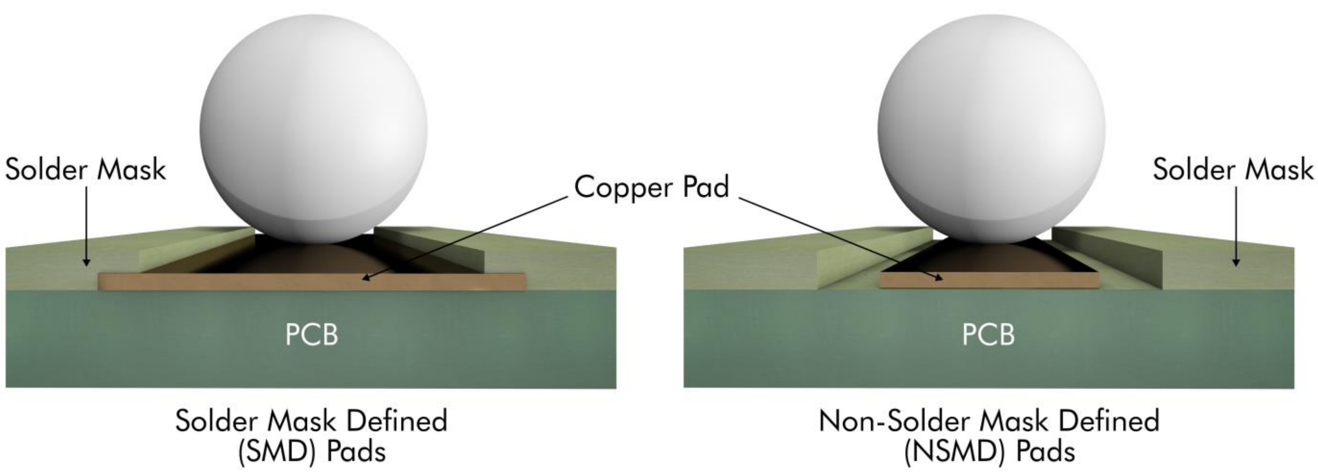


Figure 1: SMD & NSDM Pads

It's also possible that the PCB be designed such that there is no solder mask around or between the pads. Reference Figure 2 representing the three solder mask options.

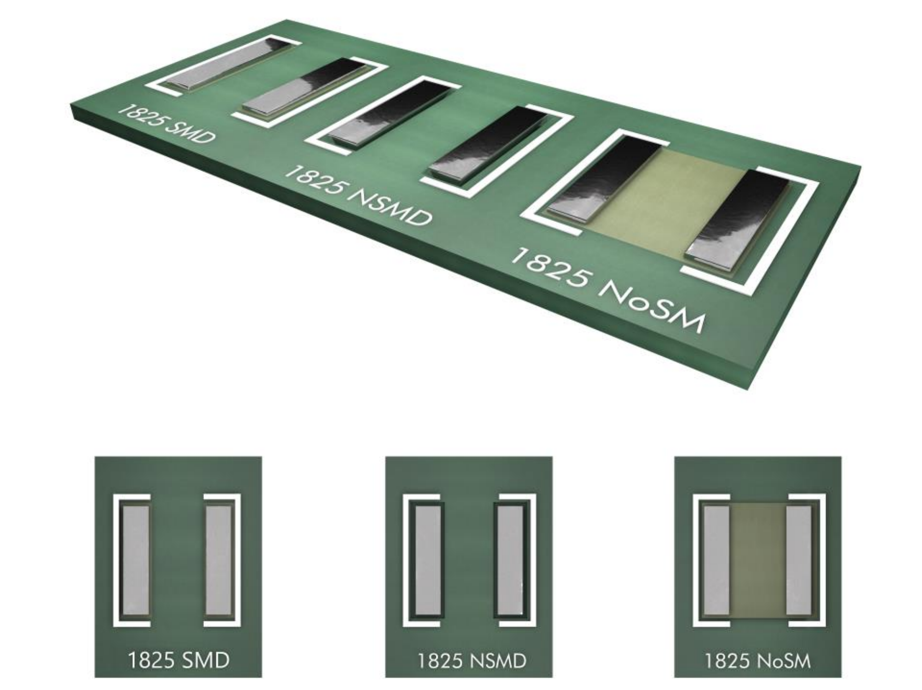


Figure 2: SMD, NSDM & NoSM Pads

Why consider solder mask selection as a factor that can affect cleaning process effectiveness? The solder mask impacts the component standoff height. Of the three options, NoSM can increase the standoff height which may enhance the cleaning process. Standoff height will vary depending upon board design and component selection, so it is difficult to quantify standoff height for each solder mask selection and specific component. However, reference Table 1 for average standoff heights for specific component groups [6].

Table 1: Standoff Height

Component Type	SMD & NSMD (micron)	NoSM (micron)	Additional Clearance with NoSM (microns)
Chip Caps	30 - 70	60 - 90	~ 30
BTCs	20 - 40	40 - 80	20 - 40
BGAs	80 - 120	90 - 130	10

By using NoSM, the component standoff height can be increased by 10 to 40 microns depending on the component type, thereby increasing the potential of the cleaning agent to more effectively penetrate underneath low standoff components.

Each solder mask type has its pros and cons for use. The purpose of this study is not to address the benefit of the various solder mask designs, but rather the impact, if any, each design has on cleaning process effectiveness.

The authors developed a DOE in order to assess the impact of the three solder mask designs on defluxing effectiveness. For this study, standard substrates and inline cleaners were used. The substrates were populated with numerous low standoff chip cap components and soldered with both no-clean tin-lead and lead-free solder pastes. Two aqueous based cleaning agents were selected and multiple wash temperatures and wash exposure times were evaluated.

Cleanliness assessment was conducted by visual inspection per IPC TM650. For each substrate, all components were mechanically sheared, enabling thorough under-component inspection. The under-component surface was rated as either clean or not clean. The effectiveness of the cleaning process was calculated by dividing the number of clean components by the total number of components on each substrate and detailed as a percentage. Cleanliness results were analyzed using Main Effects plots and Factor Analysis of Mixed Data (FAMD).

Percentage Cleanliness (%) = No clean components / total number of components

In addition to visual inspection, the authors planned to conduct Ion Chromatography (IC) analysis on selected test vehicles for each solder mask option and solder paste. To verify the test methodology, IC test was conducted on un-cleaned boards

(NSMD) for each type of solder paste to verify if this method can be used for data analysis. However, because all tests yielded passing results for all of the un-cleaned boards, this method was deemed not useful for further data analysis and therefore abandoned.

It is important to note that this study was conducted as a comparative analysis to understand the impact of solder mask on test vehicle cleanliness assessment at specific wash temperature and conveyor speed. All other cleaning process parameters were maintained constant and no attempt was made to optimize the cleaning process.

Methodology

The purpose of this study is to assess the impact of solder mask selection on cleaning process efficacy with a given solder paste and selected process parameters. The goal was not to optimize the cleaning process, but rather to quantify the impact of the solder mask type for the given set of variables selected.

The study was limited to three variables: solder mask option, wash solution temperature, and conveyor speed. Three process conditions were identified for each variable. Reference Table 2.

Table 2: Process Conditions

Process Variables	Conditions
Solder Mask Option	SMD, NSMD & NoSM
Wash Temp (delta of 10°C)	144°F, 162°F, 180°F
Conveyor Speed	0.5 fpm (10.4 min), 1 fpm (5.2 min), 1.5 fpm (3.5 min)

Four solder pastes were selected. Reference Table 3.

Table 3: Solder Paste Selection

Solder Paste	Type
Solder Paste A	No-Clean Tin-Lead
Solder Paste B	No-Clean Tin-Lead
Solder Paste C	No-Clean Lead-Free
Solder Paste D	No-Clean Lead-Free

Two cleaning agents were selected. Reference Table 4.

Table 4: Cleaning Agent Selection

Cleaning Agent	Type
Cleaning Agent A	Surfactant-free alkaline uninhibited
Cleaning Agent B	Surfactant-free pH Neutral inhibited

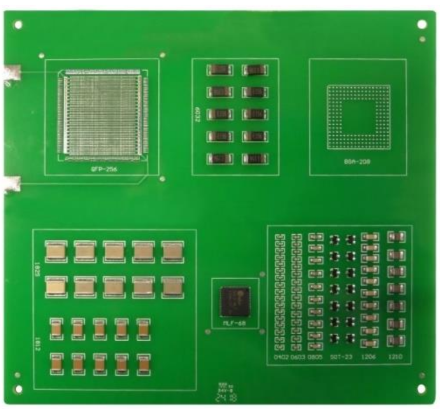


Figure 3: Test Vehicle

A standard test vehicle was selected and populated with 104 commonly used low standoff chip cap components. Reference Figure 3 and Table 5.

Table 5: Component Types

Component Type	No. of Components
6032	10
1825	10
1812	10
MLF-68	1
0402	17
0603	15
0805	10
SOT-23	14
1206	10
1210	7
Total:	**104**

In total, eighteen (18) trials were conducted, nine (9) for each cleaning agent type. Reference Table 6.

Table 6: Test Condition

Trial No:	Cleaning Agent	Wash Temp (°F)	Conveyor Speed (fpm)	Solder Mask Option
1	A	144	0.5	SMD, NSMD, NoSM
2	A	144	1	SMD, NSMD, NoSM
3	A	144	1.5	SMD, NSMD, NoSM
4	A	162	0.5	SMD, NSMD, NoSM
5	A	162	1	SMD, NSMD, NoSM
6	A	162	1.5	SMD, NSMD, NoSM
7	A	180	0.5	SMD, NSMD, NoSM
8	A	180	1	SMD, NSMD, NoSM
9	A	180	1.5	SMD, NSMD, NoSM
10	B	144	0.5	SMD, NSMD, NoSM
11	B	144	1	SMD, NSMD, NoSM
12	B	144	1.5	SMD, NSMD, NoSM
13	B	162	0.5	SMD, NSMD, NoSM
14	B	162	1	SMD, NSMD, NoSM
15	B	162	1.5	SMD, NSMD, NoSM
16	B	180	0.5	SMD, NSMD, NoSM
17	B	180	1	SMD, NSMD, NoSM
18	B	180	1.5	SMD, NSMD, NoSM

For each trial, four (4) test vehicles were prepared, one for each paste type & solder mask option. In total, 216 test vehicles were required. Each was reflowed, cleaned and inspected for cleanliness on both surfaces as well as underneath the component.

Standard Tin-Lead and Lead-Free reflow profiles were used. Reference Figures 4 and 5.

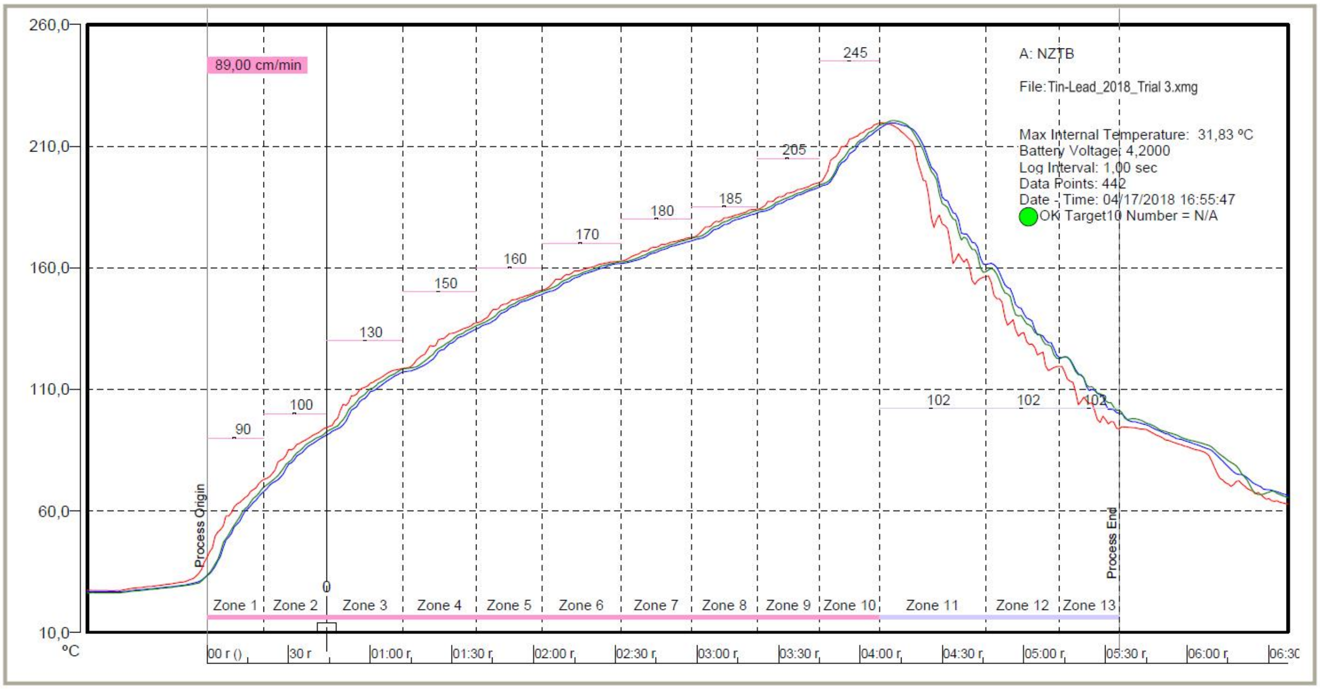


Figure 4: Standard Tin-Lead Reflow Profile

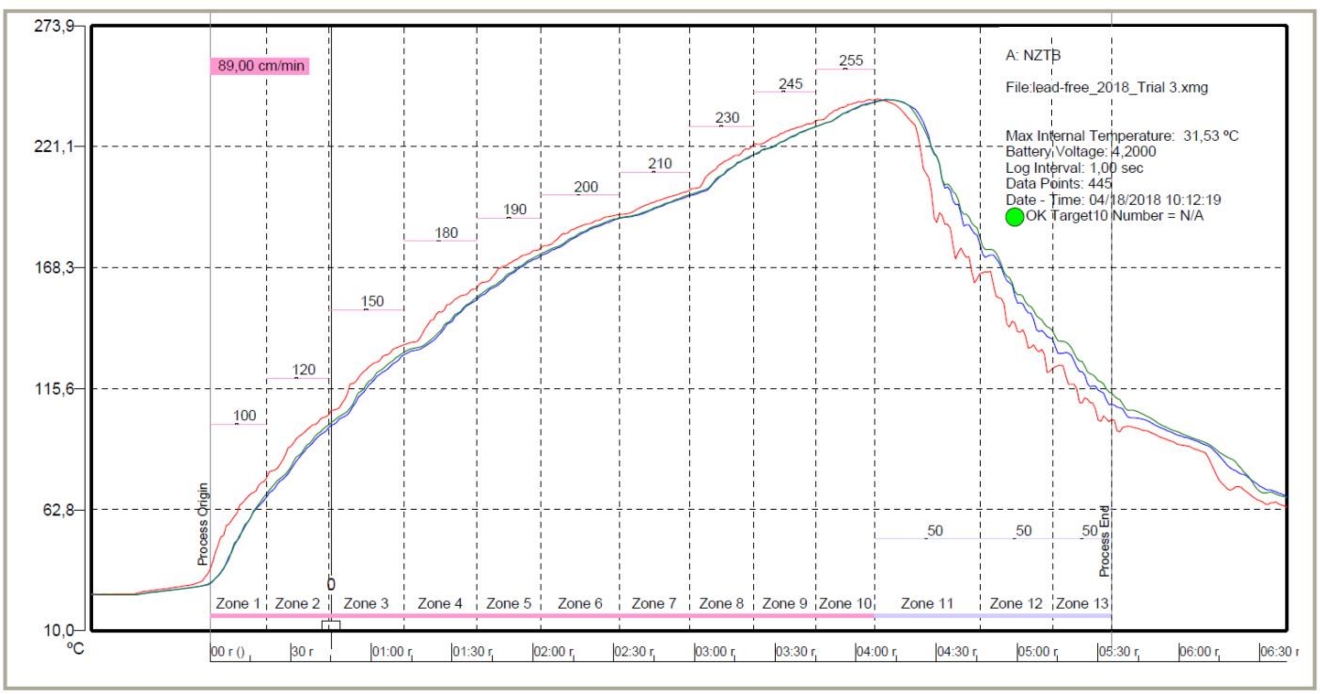


Figure 5: Standard Lead-Free Reflow Profile

The selected equipment was a spray-in-air inline cleaner manufactured with high temperature resistant polymer material. The process operating parameters selected are detailed in Table 7. Other than conveyor speed and wash solution temperature, all parameters were held constant for all trials.

Table 7: Process Operating Parameters

Cleaning Process	Inline
Equipment	Inline Spray-in-air
Concentration	15%
Conveyor Speed	1.5 fpm, 1 fpm, 0.5 fpm
Pre-Wash Pressure (Top/Bottom)	50 PSI / 30 PSI
Wash Pressure (Top/Bottom)	80 PSI / 60 PSI
Wash solution Temperature	144°F, 162°F, 180°F
Chemical Isolation Pressure (Top/Bottom)	25 PSI / 25 PSI
Rinse	
Rinsing Agent	DI-water
Rinse Pressure (Top/Bottom)	80 PSI / 60 PSI
Rinsing Temperature	150°F
Final Rinse Pressure (Top/Bottom)	30 PSI / 30 PSI
Final Rinse Temperature	Room Temperature
Drying	
Drying Method	Hot Circulated Air
Drying Temperature (D1)	180°F
Drying Temperature (D2)	210°F
Drying Temperature (D3)	210°F

Results

All boards were inspected for surface cleanliness after being cleaned. Other than the MLF/BTC components, surfaces around all other components were found to be fully cleaned for all trials. Reference Figures 6 and 7 for representative pictures of component surface cleanliness.

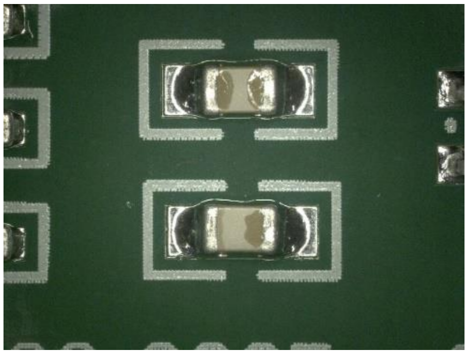


Figure 6: Component 0805 – Before Cleaning

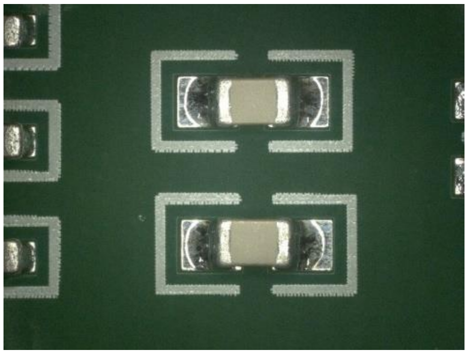


Figure 7: Component 0805 – After Cleaning

Reference Figures 8 and 9 for representative pictures of fully cleaned and partially cleaned surface of the MLF-68 component.

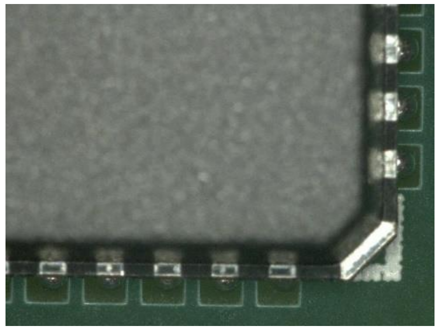


Figure 8: MLF-68 Fully Cleaned Surface

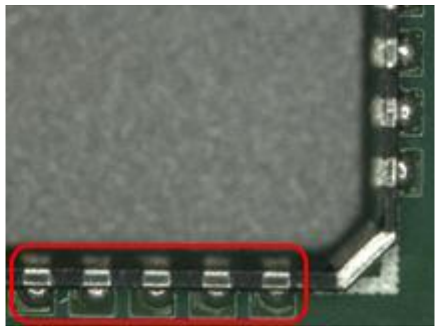
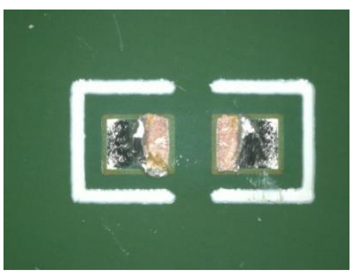
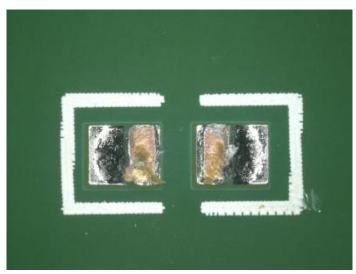
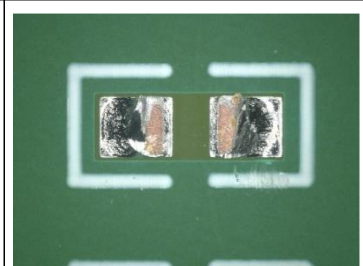
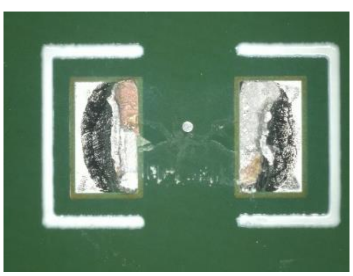
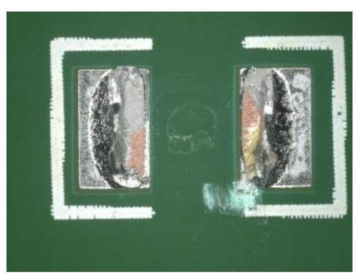
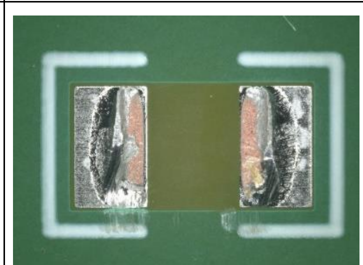
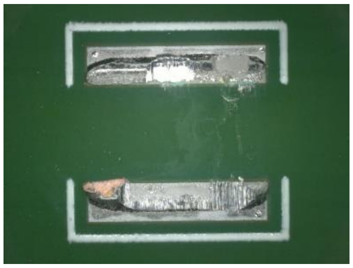
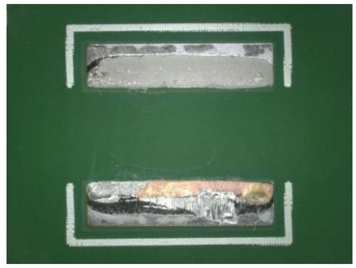
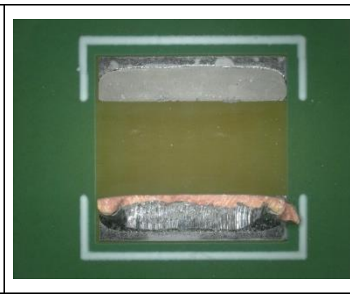


Figure 9: MLF-68 Partially Cleaned Surface

Reference Table 8 for representative pictures of area under-components after cleaning at specific setting (Cleaning Agent A @ 162°F wash temp, 1 fpm conveyor speed – Paste C).

Table 8: Representative After Cleaning Pictures (under-component)

	SMD	NSMD	NoSM
0805			
1210			

1825			

Following surface inspection, all boards were visually inspected for under-component cleanliness in accordance with current IPC standards. In order to do so, all components were mechanically sheared from all boards, and the surface underneath the component was rated as either 'fully cleaned' or 'not cleaned'. For each test vehicle, the ratio of cleaned components to total components was calculated and plotted.

The impact of solder mask, conveyor speed and wash temperature on under-component cleanliness results for all solder pastes are detailed in Figures 10, 11 and 12 respectively.

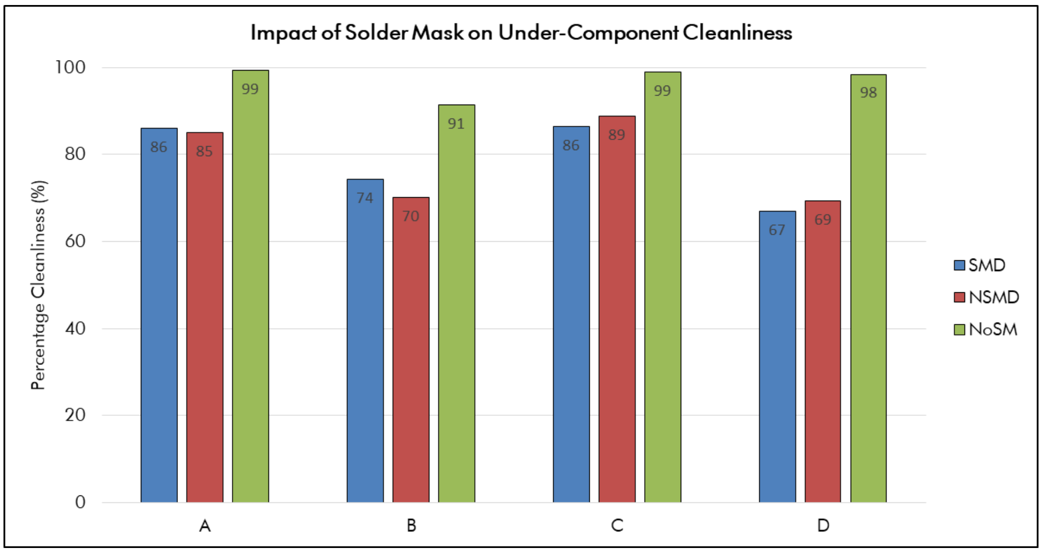


Figure 10: Under-component Cleanliness: Impact of Solder Mask Option

For all test variables, regardless of solder paste and cleaning agent used, test vehicles with NoSM yielded best overall cleanliness results: 97.07% versus 78.4%.

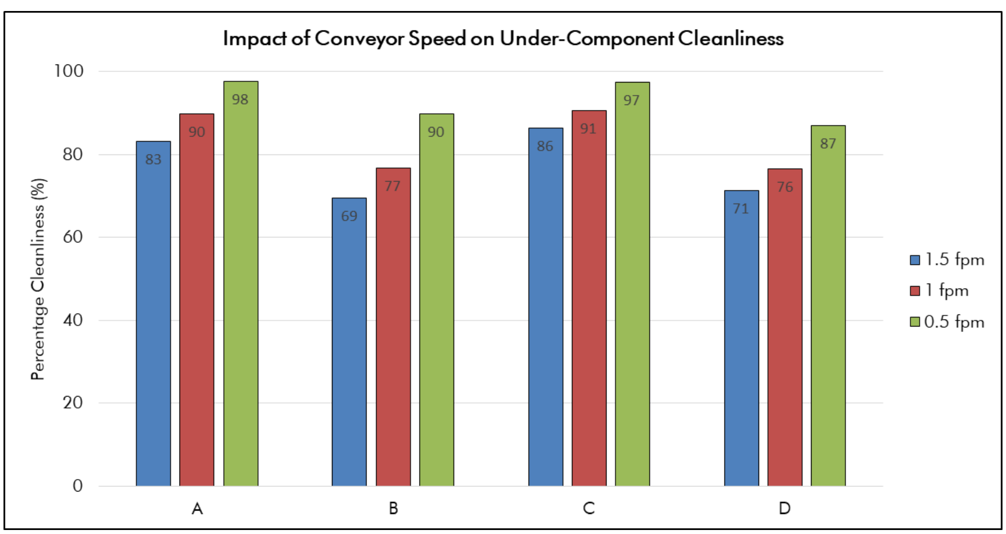


Figure 11: Under-component Cleanliness: Impact of Conveyor Speed

Cleaning results improve significantly at lower conveyor speed (0.5 fpm) compared to faster conveyor speed (1.5 fpm): 92.97% versus 77.52%.

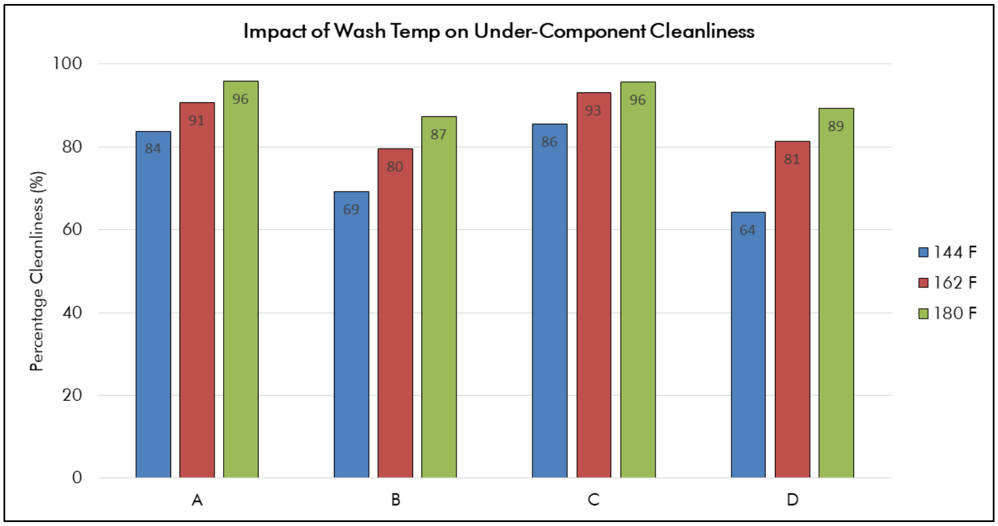


Figure 12: Under-component Cleanliness: Impact of Wash Temperature

Cleaning results improve significantly at higher wash temperature (180°F) compared to lower wash temperature (144°F): 92.04% versus 75.67%.

The following graphs were developed examining the relationship between each solder mask option and conveyor speed and wash temperature. Reference Figures 13 – 15.

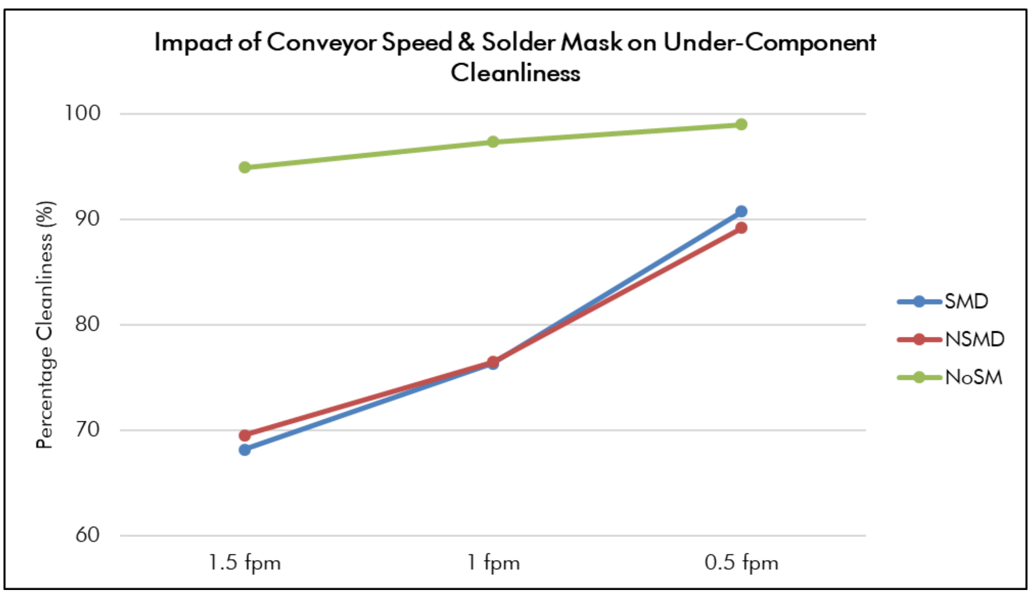


Figure 13: Under-component Cleanliness: Impact of Conveyor Speed & Solder Mask

If NoSM option is used instead of SMD & NSMD, conveyor speed can be increased three times faster i.e. 1.5 fpm from 0.5 fpm, while keeping same wash temperature.

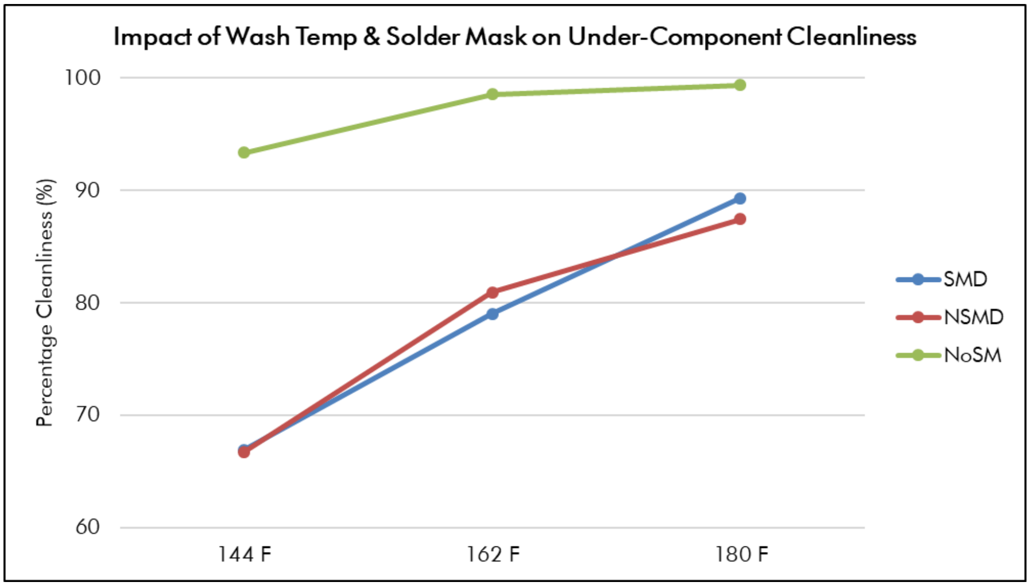


Figure 14: Under-component Cleanliness: Impact of Wash Temperature & Solder Mask

If NoSM option is used instead of SMD & NSMD, wash temperature can be lowered from 180°F to 144°F, while keeping same conveyor speed.

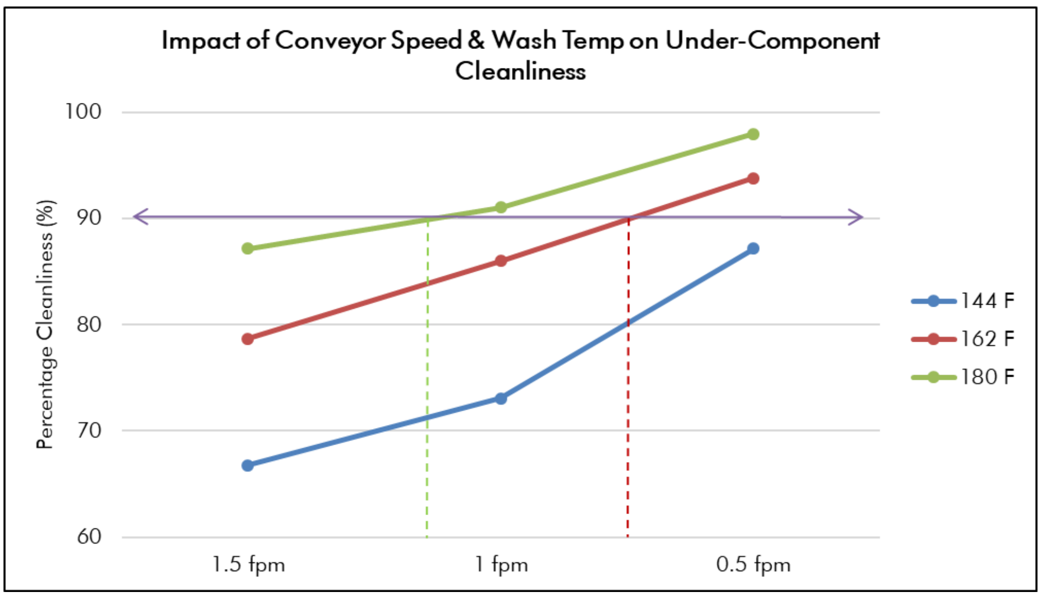


Figure 15: Under-component Cleanliness: Impact of Conveyor Speed & Wash Temperature

Same under-component cleanliness results can be achieved with combination of high wash temperature (180°F) and faster conveyor speed (1.2 fpm) compared to low wash temperature (144°F) and slower conveyor speed (0.4 fpm).

The following "Main Effects" graph was developed to examine the relationship between all variables considered for under-component cleanliness level achieved. This plot examines the differences between level means for one or more factors. A horizontal line indicates no main effect. A non-horizontal line indicates a main effect. The greater the slope, the greater the magnitude of the effect. Reference Figure 16.

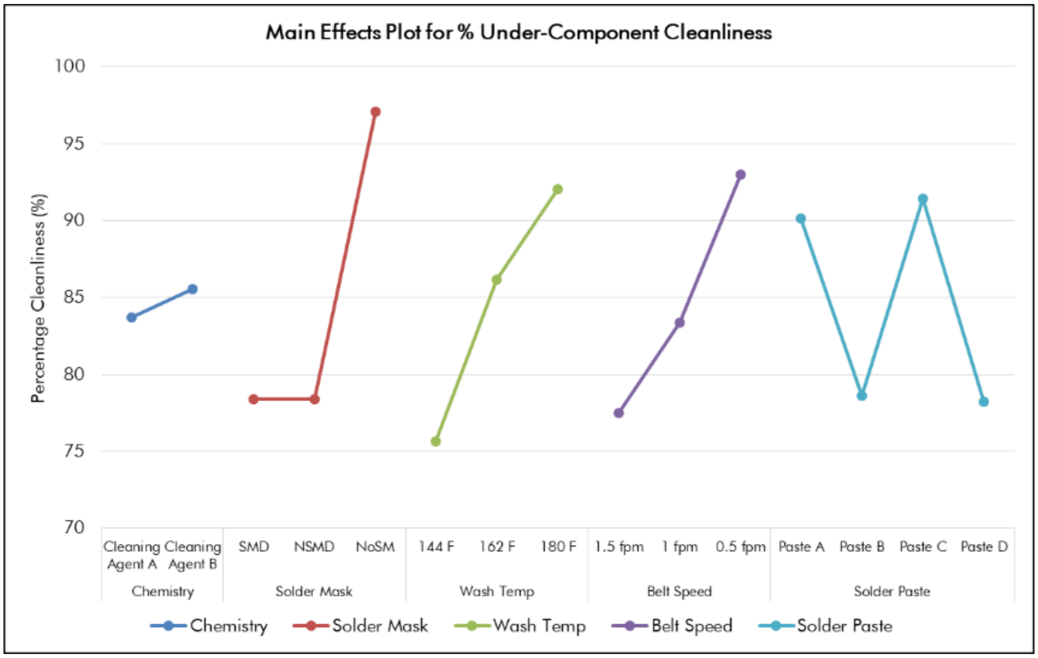


Figure 16: Under-component Cleanliness versus Process Variables

With regard to under-component cleanliness, the "Main Effects" plot indicates:

- Minor effect due to cleaning agent selection: 83% versus 85% for Cleaning Agent A and B respectively.
- No effect using SMD and NSMD (78%), Major effect using NoSM (97%).
- Major effect due wash temperature: 75% at 144°F versus 93% at 180°F.
- Major effect due to conveyor speed (wash time): 77% at 1.5 fpm versus 94% at 0.5 fpm.
- Major effect using Pastes A and C versus Pastes B and D.

The interaction between all variables was also analyzed using Factor Analysis of Mixed Data (FAMD). This tool is useful when analyzing a data set containing both quantitative and qualitative variables. It makes it possible to analyze the similarity between individuals by considering mixed types of variables. Additionally, one can explore the association between all variables, both quantitative and qualitative [7].

For this analysis, solder pastes, cleaning agents and solder mask options were treated as qualitative variables, while conveyor speed and wash temperature were treated as quantitative variables.

The Quantitative Plot shows the relationship between conveyor speed and wash temperature on the cleanliness level achieved of each component type. Reference Figure 17.

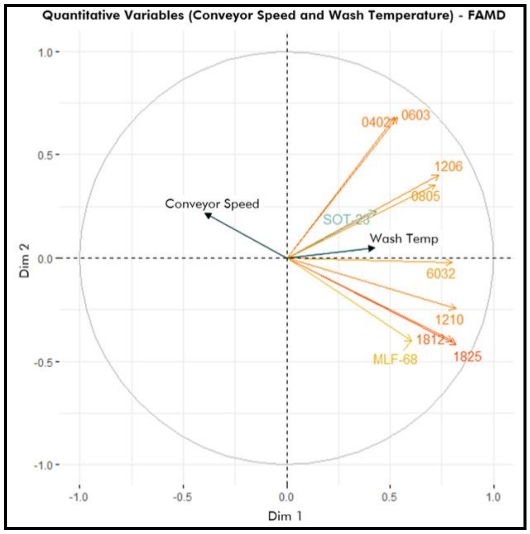


Figure 17: Quantitative Plot

The angle formed between any pair of arrows corresponds to the level of association. Angles between 0 and 90 degrees correspond to positive association, and angles greater than 90° and up to 180° correspond to negative associations. Closeness to 0° indicates high level of positive association, closeness to 90° indicates no association, and closeness to 180° indicates high level of negative association. The axes (Dim1 and Dim2) have no physical meaning and are merely an analytical means of summarizing all the data and variables. The length of each arrow corresponds to the significance of the variable.

Observations from the FAMD Quantitative Analysis:

- The conveyor speed is in the opposite direction of 1210, 1812, 1825, and MLF-68 components indicating that increasing the conveyor speed is associated with lower cleanliness for these component types.
- Conveyor speed forms an approximate 90° angle with 0402, 0603, 1206, 0805, and SOT-23 components indicating that conveyor speed has less impact on cleanliness for these component types.
- Wash temperature can be seen making a 30-45° with most of the component types indicating a soft positive association.
- The arrows for both conveyor speed and wash temperature are shorter than the arrows for the component types. This indicates that there is greater confidence in predicting the cleanliness results of one component type based on those of another than predict cleanliness results directly using conveyor speed or wash temperature.

The Qualitative Plots show the relationship between the Solder Pastes, Cleaning Agents, and Solder Mask Options on the average cleanliness level achieved for each substrate within the 216 trials. Reference Figures 18 – 20.

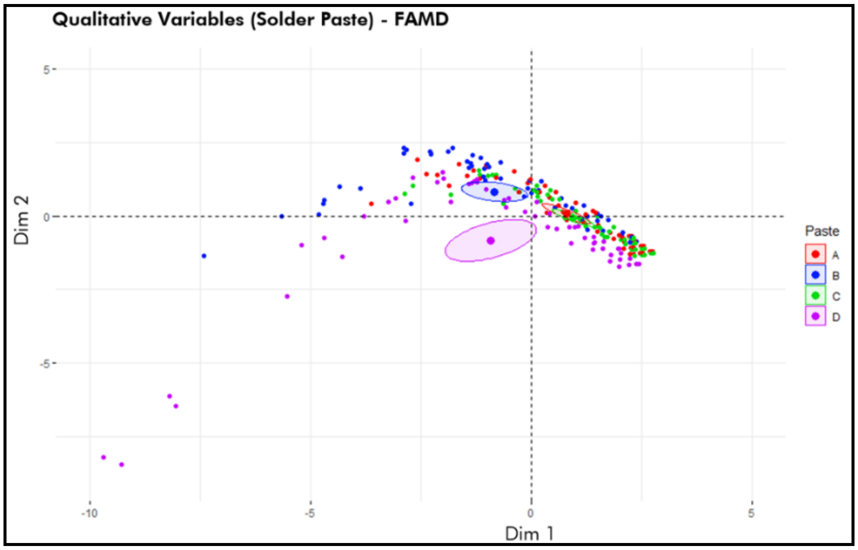


Figure 18: Qualitative Plot (Solder Paste)

Observations from the FAMD Qualitative Analysis (Solder Paste):

- The center of the ellipses corresponds to the average cleanliness results for each solder paste and the area of the ellipses corresponds to variability of those cleanliness results.
- This plot shows the distribution of all boards on the same axes without the quantitative variables. Instead, the boards are color coded based on solder paste used.
- It can be seen that most boards fall within the same region near the origin and in quadrants I, II, and IV. This indicates that the cleaning results for most boards are similar and that there are only a few boards such as those in quadrant III that have results that are extremely dissimilar to the others.
- It can be seen that the center point of the Solder Paste A ellipse is close to the center point of the Solder Paste C ellipse. This signifies that there is little difference in the cleaning results between these two solder pastes. Additionally, the ellipses of Solder Paste A and Solder Paste C are the smallest which means they show the least variability in the cleaning results.
- The center point for the ellipse for Solder Paste D is dragged into quadrant III because of the outlier points. These outlier points show the greatest difference in cleaning results from the average board, which would be located at the origin of the graph. These outlier points also contribute towards the ellipse for Solder Paste D having the largest size and therefore the largest variability.

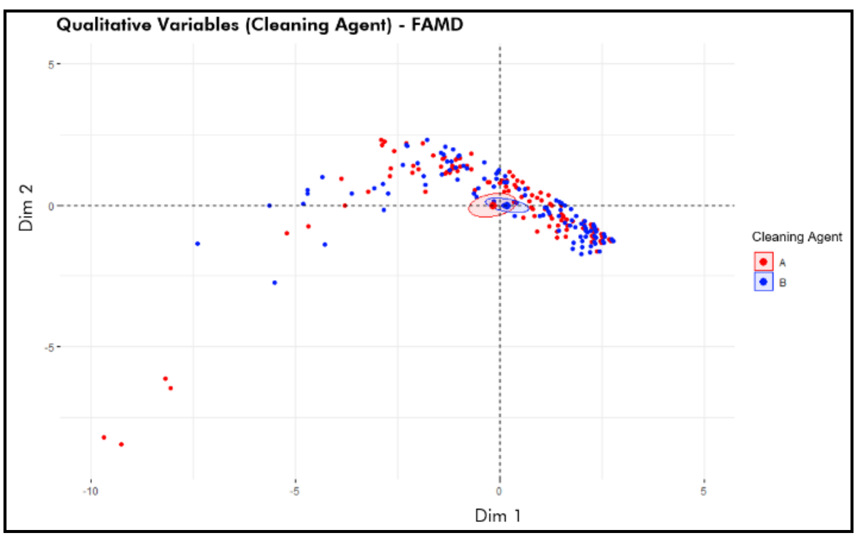


Figure 19: Qualitative Plot (Cleaning Agent)

Observations from the FAMD Qualitative Analysis (Cleaning Agent):

- This plot details the distribution of all boards on the same axes without the quantitative variables. Instead, the boards are color coded based on the cleaning agent used.

- The ellipses for both Cleaning Agent A and Cleaning Agent B are similarly sized indicating that they show similar amounts of variability in the cleaning results.
- Both ellipses are close to the origin which indicates that the average cleanliness for either Cleaning Agent A or Cleaning Agent B is close to the average cleanliness for all of the boards.

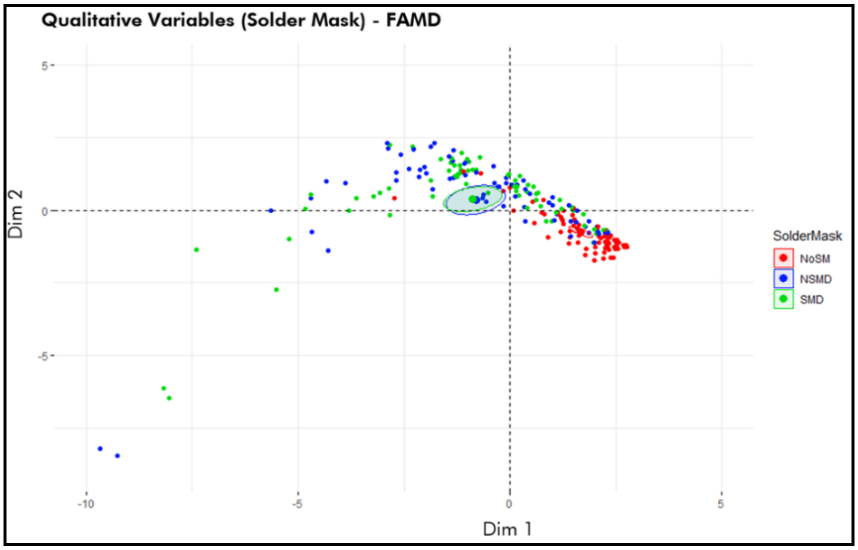


Figure 20: Qualitative Plot (Solder Mask)

Observations from the FAMD Qualitative Analysis (Solder Mask):

- This plot shows the distribution of all boards on the same axes without the quantitative variables. Instead, the boards are color coded based on the type of solder mask.
- The ellipses for NSMD and SMD are similar in both size and location indicating that they show similar levels of cleanliness and variability.
- The ellipse for NoSM is very small indicating that there is very little variability in the cleanliness results. The center point of the ellipses is slightly farther away from the origin indicating that the average cleanliness for NoSM is more different from the overall average than for NSMD and SMD.

Finally, both localized Ion Chromatography (IC) and localized extraction electrical tests were conducted on four (4) select components for each solder paste prior to cleaning (NSMD option board was used). The components selected were 1812, MLF-68, 0805 and 1210.

The localized IC was conducted using the localized extraction method [8]. All IC analysis and localized extraction tests were conducted at the company technical center. The company standards for passing IC results are based on an average used by certified industry labs. The standards used, and the IC data is detailed in the appendix.

As part of the localized extraction analysis, an electrical test was conducted whereby a leakage current event can be identified based on a Class 2 – 3 setting established by the manufacturer of this specific equipment. In brief, using a sacrificial Y-pattern electrode immersed in the collected extraction solution, a 10 Volt bias (+/-0.1V) is applied to the electrode and an internal timer is started to measure the time it takes to achieve a leakage event. The system is measuring the leakage current across the electrode generated by the extraction solution plus the residues extracted from the board surface. A threshold of 250 µA has been set to identify when a current leakage event has occurred. If 250 µA is achieved in less than 120 seconds, this correlates to a corrosive surface and is identified as "dirty". In theory, the more corrosive / conductive the residue, the faster it will take to achieve this event. The less corrosive or conductive the residue, the longer it will take to achieve. Thus, timing events that take longer than 120 seconds have correlated to cleaner, less corrosive residues and are identified as "clean" [8].

For each solder paste and for all components tested, IC and localized extraction electrical test yielded passing results. Reference Tables 9 - 12. As this was the case, the authors chose not to conduct IC on the cleaned boards.

Conclusions

Surface Inspection:

- For all trials, board surface was found to be clean except minor residues around MLF/BTC components on a few boards.

Under-Component Inspection – Impact of Solder Mask:

- Cleaning results improves significantly when using NoSM option compared to SMD & NSMD (i.e. 97.07% versus 78.4%).

Under-Component Inspection – Impact of Conveyor Speed:

- Cleaning results improved significantly at lower conveyor speed (0.5 fpm) compared to faster conveyor speed (1.5 fpm) (i.e. 92.97% versus 77.52%).

Under-Component Inspection – Impact of Wash Temperature:

- Cleaning results improved significantly at higher wash temperature (180°F) compared to lower wash temperature (144°F) (i.e. 92.04% versus 75.67%).

Under-Component Inspection – Impact of Conveyor Speed & Solder Mask:

- If NoSM option is used instead of SMD & NSMD, conveyor speed can be increased three times faster (i.e. 1.5 fpm from 0.5 fpm), while keeping same wash temp.

Under-Component Inspection – Impact of Wash Temp & Solder Mask:

- If NoSM option is used instead of SMD & NSMD, wash temp can be lowered from 180°F to 144°F, while keeping same conveyor speed.

Under-Component Inspection – Impact of Conveyor Speed and Wash Temperature:

- The same under-component cleanliness results can be achieved with a combination of high wash temperature (180°F) and faster conveyor speed (1.2 fpm) compared to low wash temperature (144°F) and slower conveyor speed (0.4 fpm).

Localized Extraction and Ion Chromatography Results:

- Localized extraction and ion chromatography tests were conducted on un-clean boards for each type of solder paste to verify if these methods can be used for data analysis. We had passing results (i.e. “clean”) for all un-clean boards, so this method was not used for data analysis.

Overall Conclusions

- Solder mask is the most critical factor impacting under-component cleanliness. NoSM option is significantly easier to clean as compared to SMD and NSMD options.
- Wash temperature & wash exposure time are critical factors which also impact under-component cleanliness.
- By increasing wash temperature, we can also increase conveyor speed and achieve complete under-component cleanliness.

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Appendix:

Table 9: Ion Chromatography and Localized Extraction Electrical Test Results – Solder Paste A

		Acceptance Criteria	1812	MLF-68	0805	1210
ANIONS	Fluoride (F^-)	3	0.0000	0.0000	0.0000	0.0000
	Acetate ($C_2H_3O^-_2$)	3	ND	ND	ND	ND
	Formate (CHO^-_2)	3	ND	0.4120	0.7940	0.4060
	Chloride (Cl^-)	3	0.0000	0.0000	0.0000	0.0000
	Nitrite (NO_2^-)	3	0.0160	ND	0.0040	0.0100
	Bromide (Br^-)	6	0.0000	0.0000	0.0000	0.0000
	Nitrate (NO_3^-)	3	2.0320	0.0000	0.2080	1.6240
	Phosphate (PO_4^{2-})	3	ND	ND	ND	ND
	Sulfate (SO_4^{2-})	3	0.5940	0.0000	1.1580	0.4920
	WOA (Weak Organic Acid)	25	2.6620	ND	ND	ND
CATIONS	Lithium (Li^+)	3	0.0020	0.0000	0.0000	0.0020
	Sodium (Na^+)	3	0.0000	0.0000	0.0000	0.0080
	Ammonium (NH_4^+)	3	0.0000	0.0000	0.0000	0.0000
	Potassium (K^+)	3	0.8580	0.0000	0.0000	0.7440
	Magnesium (Mg^{2+})	n/a	0.0000	0.0000	0.2120	0.0360
	Calcium (Ca^{2+})	n/a	0.0000	0.0000	2.3420	0.6760
	Localized Ion Chromatography Results		Pass	Pass	Pass	Pass
	Localized Extraction Electrical Test Results	<250µA for 120s or more	Clean	Clean	Clean	Clean

Table 10: Ion Chromatography and Localized Extraction Electrical Test Results – Solder Paste B

		Acceptance Criteria	1812	MLF-68	0805	1210
ANIONS	Fluoride (F^-)	3	0.0000	0.0000	0.0000	0.0000
	Acetate ($C_2H_3O^-_2$)	3	ND	ND	ND	ND
	Formate (CHO^-_2)	3	0.6180	0.7560	0.8700	0.7280
	Chloride (Cl^-)	3	0.0600	0.0000	0.7920	0.8080
	Nitrite (NO_2^-)	3	ND	ND	0.0280	0.0220
	Bromide (Br^-)	6	0.5020	3.5640	0.1100	0.4060
	Nitrate (NO_3^-)	3	0.1340	0.0000	0.4260	0.3520
	Phosphate (PO_4^{2-})	3	ND	ND	ND	ND
	Sulfate (SO_4^{2-})	3	2.1340	0.7280	0.1420	0.0000
	WOA (Weak Organic Acid)	25	ND	23.2920	ND	ND
CATIONS	Lithium (Li^+)	3	0.0020	0.0020	0.0020	0.0020
	Sodium (Na^+)	3	0.0000	0.0000	0.2400	0.0000
	Ammonium (NH_4^+)	3	0.0000	0.0000	0.0000	0.1000
	Potassium (K^+)	3	0.0000	0.0000	0.3660	0.0000
	Magnesium (Mg^{2+})	n/a	0.0900	0.0000	0.1320	0.2220
	Calcium (Ca^{2+})	n/a	0.5600	2.4480	0.0000	0.0480
	Localized Ion Chromatography Results		Pass	Pass	Pass	Pass
	Localized Extraction Electrical Test Results	<250µA for 120s or more	Clean	Clean	Clean	Clean

Table 11: Ion Chromatography and Localized Extraction Electrical Test Results – Solder Paste C

		Acceptance Criteria	1812	MLF-68	0805	1210
OI	Fluoride (F^-)	3	0.0000	0.0000	0.0000	0.0000

	Acetate ($C_2H_3O^-_2$)	3	ND	ND	ND	ND
	Formate (CHO^-_2)	3	0.5160	0.5100	0.6480	0.6980
	Chloride (Cl^-)	3	0.1520	0.0000	0.4580	0.0000
	Nitrite (NO_2^-)	3	ND	0.0300	ND	0.0320
	Bromide (Br^-)	6	0.2360	0.0000	0.1980	0.1620
	Nitrate (NO_3^-)	3	0.4760	0.7000	0.4420	0.3060
	Phosphate (PO_4^{2-})	3	ND	ND	ND	ND
	Sulfate (SO_4^{2-})	3	1.5620	0.2580	2.3280	0.6100
	WOA (Weak Organic Acid)	25	ND	ND	ND	ND
CATIONS	Lithium (Li^+)	3	0.0040	0.0000	0.0040	0.0000
	Sodium (Na^+)	3	0.0000	0.0000	0.0000	0.0000
	Ammonium (NH_4^+)	3	0.0080	0.0180	0.0000	0.0000
	Potassium (K^+)	3	0.0000	0.0220	0.2220	0.0000
	Magnesium (Mg^{2+})	n/a	0.1220	0.2220	0.2820	0.1700
	Calcium (Ca^{2+})	n/a	1.2580	0.0000	0.9140	1.6300
	Localized Ion Chromatography Results		Pass	Pass	Pass	Pass
	Localized Extraction Electrical Test Results	<250μA for 120s or more	Clean	Clean	Clean	Clean

Table 12: Ion Chromatography and Localized Extraction Electrical Test Results – Solder Paste D

		Acceptance Criteria	**1812**	**MLF-68**	**0805**	**1210**
ANIONS	Fluoride (F^-)	3	0.0000	0.0000	0.0000	0.0000
	Acetate ($C_2H_3O^-_2$)	3	ND	ND	ND	ND
	Formate (CHO^-_2)	3	0.6220	0.5100	0.8140	0.8860
	Chloride (Cl^-)	3	0.2100	0.0000	0.0000	0.0260
	Nitrite (NO_2^-)	3	0.0240	0.0340	0.0000	0.0400
	Bromide (Br^-)	6	0.0000	0.0000	0.0560	0.0960
	Nitrate (NO_3^-)	3	0.5180	0.3880	1.0040	0.3160
	Phosphate (PO_4^{2-})	3	ND	ND	ND	ND
	Sulfate (SO_4^{2-})	3	1.1180	0.0000	0.1340	1.2840
	WOA (Weak Organic Acid)	25	ND	ND	ND	ND
CATIONS	Lithium (Li^+)	3	0.0020	0.0000	0.0020	0.0020
	Sodium (Na^+)	3	0.0000	0.0000	0.0000	0.0000
	Ammonium (NH_4^+)	3	0.1240	0.0000	0.2660	0.1660
	Potassium (K^+)	3	0.0000	0.0000	0.3140	0.0000
	Magnesium (Mg^{2+})	n/a	0.1200	0.2360	0.0780	0.2020
	Calcium (Ca^{2+})	n/a	1.6200	0.0000	0.0000	0.6580
	Localized Ion Chromatography Results		Pass	Pass	Pass	Pass
	Localized Extraction Electrical Test Results	<250μA for 120s or more	Clean	Clean	Clean	Clean