SMT Stencil, Surface Performance Returning to Basics in the SMT Screen Printing Process to Significantly Improve the Paste Deposition Operation

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Abstract

The SMT assembly process is continuously challenged by the factors which enhance circuit board performance and limit productivity. The pick and place and reflow systems reflect these driven issues by adding more and more controls to their systems, but the fact is one of the age old processes continues to operate within the same rules since the dawn of the SMT assembly world: The SMT screen printing.

The SMT print process is very old and construed as being simple. The process is not complicated but controlling the outcome is complex. Given all the factors involved in boards and technologies, the printer environment is a major factor to control and improve yields from the beginning of the SMT assembly process.

Changing stencil materials (SS, Ni, Electroform or coated, including Nano) is one historically prescribed solution to improve the SMT screen printing process. However, this direction has not given the expected results, the key factor being productivity, for manufacturing. The majority of the SMT community gives direction that stipulates stencils today drive the outcome of the SMT assemblies.

The Nano coated stencil concept improved paste release to pad which is said, resulted in improved stencil cleaning performance, but as with all coatings there is a productivity negative factor; it wears.

This paper showcases a new stencil process that was discovered by reverting to the basics:understanding the reason for each stencil material process, focusing on detailed finishes and a disciplined aperture design process, maintaining original designs, and making the correctly designed apertures to control the paste deposition.The test results drove us to focus the efforts on the aperture walls

In this paperwe will demonstrate with lab tests SMT process results howthe improved paste release results in improved SMT print process performance and its positive impact on SPI yields and EOL performance.

Introduction

The industry created gate factors into the field of the SMT assembly to measure and weed out the process failures which don't meet the process requirements. The SPI (Solder Paste Inspection) and AOI (Automated Optical Inspection) systems, although designed to help improve process controls utilizing their data, have become increasingly more like an automated go-no-go screening system.

The SMT printer's simple concept employs a board and a stencil designed to be a mirror image of the pattern of paste deposition required for the given board. It correlates the board to the stencil positions, and then it raises the board to meet the stencil and prints the paste/cream medium, using a predetermined process recipe by a machine program. It finally separates the board from the stencil and conveysthe board downline to continue the SMT assembly process. When you take into account the various vendors used to facilitate this process, many factors are identified: bare board specifications, solder paste properties, tooling manufacturing, screen printer conditions, and including many other facility ambient conditions. These can all affect the outcome of the repeatability of the print process. These are some of the factors which will in the end affect the SMT assembly yield process.

The increasing demand to miniaturize/economize these assembly processes is becoming a bigger challenge to all SMT assembly lines. The manufacturing sites are seeking improved process controls to increase the EOL (End of Line) yields.

One key element which has seen recent changes and offers good results is the implementation of stencil innovations, helping to improve the Cp and Cpk of the printer process and yielding impact to the EOL. The impact is relevant to the EOL results required to expand our process window capabilities.

The Main Stencil Technologies

There are 4 main stencil technologies currently used in manufacturing:

1. Laser cut; Stainless Steel (SS), Standard or Fine Grain (FG).

This is the most common stencil material and historically provides acceptable results. Typically used for large pitch device challenges, its limitation is the paste release factor. Ithas a defined laser cut aperture that makes a direct mechanical seal against each pad. The conforming propertiesassist the print process.The stainless steel (SS) material will conform to the various topographies of the bare boards and are not subject to breakage, especially as the topography of circuit boards become denser. SS is more flexible than the harder nickel materials.

2. Laser cut Nickel (Ni):

Similar to the SS materials, but due to the hardness properties of the Ni material, the laser cutting frequency differs in the process used during the aperture cut. This difference in the process during the cut for a Ni aperture provides a smoother aperture wall which in turn provides an improved paste release. The hardness of the material alsobrings new issues such as more susceptibility to breakage, prominent in high density boards and aggressive board/part/component geometries/topographies.

3. Electroformed (EF):

The EF Ni Stencil was created to achieve a superior paste release factor.The concept of producing this stencil is using liquefied metals and then attracting the liquid to a defined design. This process finally forms the apertures, theoretically making an ultra-smooth aperture wall. This process though has its shortcomings, the mechanical seal (Figure 1), with a chamfered shaped finish on the board contact and squeegee side of the stencil. This seal or "gasket" is more critical as the component pitch becomes finer.

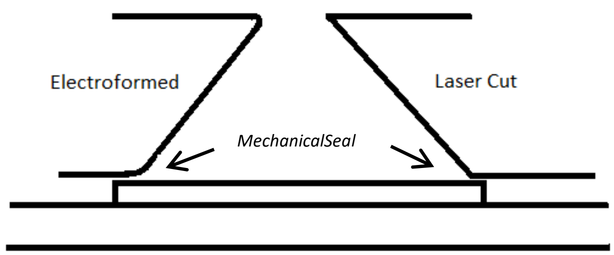

Figure 1. Mechanical Seal Illustration: Electroformed Stencil vs Laser Cut Stencil

The stencil production processused may have consequences for On Time Delivery (OTD).

4. Coated Stencils:

Using the SS laser cut stencil, these stencils capitalize on the mechanical seal values and they adhere a special coating to the aperture walls, which in turn improve the surface and helps the paste release. The paste release improvement is significant with the coatings and it also results in better EOL yields.There are two main constraints:

a. Expensive production of this stencil, due to the coating process, is very costly and OTD is impacted.

b. In a real production environment the stencil is subjective to the CEMs screen print process management.

The recent reporting of board cross contaminations is another concern now surrounding coated stencils as the major defect of this type of stencil is due to a failure of the adhesion of the coating. The coating(s), have different chemical components which during normal use will expire and the adhesion of the coating will be affected. This material is then released at different stages of the SMT process. The most relevant is the stencil washing process, where the coatings are sensitive to the cleaning detergents and require special handling processes to preserve their performance enhancing properties. The other failures of these coatings are simply time and atmospheric conditions which all coatings will fail, also affecting the adhesion of the coating components. These issues have also raised concerns of contamination to board assembly processes.

The review of these different technologies all demonstrated many good points attributed to accomplishing results, unfortunately they don't single handedly encompass a solid solution for the real world production.During the analysis of each of the stencil technologies (SS, Ni, EF and Coated) we focused on 3 factors:Mechanical Seal, Paste Release and Productivity. We utilized the volume deposition results to observe the change in these factors.

Mechanical Seal Factor: The mechanical seal is a major role player to assure the isolation of different component pad designs and geometries producing quality print deposition results.During our process we observed failure modes which were obviously affected by the mechanical seal failure, especially with complex component geometries, such as BGAs as shown in Figure2b.This Electroformed stencil, true to its materials reputation failed to seal the stencil designed aperture to the assigned pads, causing an inconsistency in the paste definition/volume.

Paste ReleaseFactor: The aperture cut was standard amongst the samples. As required the reported quality of paste deposition, for the different stencils was focused on volume. A print readout which would not register as consistent would be indicative that the volume deposition was not constant, for example refer to Figure 2a.The SS stencil because of the known fault due to the cutting of the aperture leavesa rough aperture wall surface, utilizing the same BGA component as the Electroformed stencil demonstrated near same results. Onlyby design the SS issue is due to poor paste release.

Productivity: During the testing we washed the stencils extensively to emulate a real production floor condition. In certain processes the engineer has defined a wash cycle of every 4 hrs. This means the stencil is washed in a SMT stencil washer every 4 hours. The coated stencil data was not reported here as it had no significant value due to the high fail rate. Thenewly fabricated coated stencil is a very good stencil, but productivity on the production floor is what we were trying to prove. Although we did not value the data we encountered, the users of this type of stencils identify this as a weakness for the coated stencils. This process of washing deters the coating(s) and then causes the coating to “crack” and allow solder spheres to lodge themselves in different areas, causing the mechanical seal to fail on critical small pitch components. All the coated stencils registered failures after the washing exercise. The data had no value as the industry will attest.

The Improved Stencil

Improving the SMT assembly process by changing materials (SS, Ni, EF then Coated) hasnot totally benefited the process to the level of content for manufacturing. Yet we historically prescribe this type of solution to this aged process.

During our reviews we focused on detailed finishes, which have yielded results.

1) The plan was to utilizea minor mechanical process to cause change in the finishing of the stencil surface.

2) Focus on the aperture, the laser leaves a rough surface on the stainless steel aperture wall. Conceptually the objective was to smooth the walls.

The basic process consists of:

1) Using the SS material, standard type, proper thickness in accordance with the board/component geometry requirements.

2) Preparing the surface with a mechanical application.

3) Laser cutting the apertures to the designed Gerber requirements, no over cutting of the apertures.

4) Applying the final surface treatment to enhance the aperture paste deposition performance.

We summarize the process by taking a SS stencil, cut apertures to the Gerber design requirementand applyinga process to the surface of the aperture walls, resulting in a permanent process treatment.The surface finish enhanced the paste release properties and utilized the correctly designed apertures to control the paste deposition. This is not a coating process.

One challenge was not permitting any changes to the designed aperture dimensions. Meaning the process of applying this application could not affect stencil thickness or aperture design. Several different materials were used to optimize the aperture walls, starting with a crystal material and ended up with an inert natural material which gave the optimum results desired. In the end this entire process produced a constant paste deposition. In the rest of the document, the new improved stencil is identified as SPO (Surface Processed Option).The SPO is produced in 2 different levels to supply the market with options for their production needs.

The following are available:

1) Option –a: This option is the simplest form where the IP protected process is applied to a level whereby the stencil will meet/exceed a Ni stencil being utilized, but has signs of mechanical seal failures.

2) Option –b: This option is more complex, once again the basic principles of the processes are the same only now the process on this stencil type will allow it to meet and exceed the most challenging of processes currently in the SMT assemblies. Typically this is where you may encounter Nano coated stencils, EF stencils and some step processed stencils used in the SMT assembly process.

Testing the Process Capabilities

The following results are lab related and were based on common component challenges in the CEMs environments. The data collected is based on testing in a SMT lab in Guadalajara, Mexico, using a standard SMT printer and SPI system with auto data analysis to measure paste deposition performance.

1. Standard tooling pin supports, No conforming/special tooling.
2. 60 Deg Squeegees
3. 75mm/sec print stroke speed
4. 1mm/sec, 3mm separation conditions
5. 7Kg of squeegee pressure
6. Lead-free paste, type 4 mesh
7. The printer was equipped with over edge clamping system, not snuggers
8. 25C Temp ambient
9. No washing the stencil between print strokes
10. Printer transferred the printed board to the SPI system.No human intervention during the print to vision inspection phase of this testing.

One common stencil design, along with only a single machine setup was utilized.

1. 5 mil thickness foils
2. 10% aperture reduction, Not 1:1
3. 29x 29 inch frames.
4. Centered image

The Volume measurements were based on the following component nomenclatures:

1. SQFP 12 mil pitch
2. uBGA 16 mil pitch
3. 0402 (chip type)
4. 0201 (chip type)

Based on the analysis of the stencil technologies we defined three different mediums to run the test:

a. SS-Industry Standard Stainless Steel
b. EF- Electroformed Ni
c. SPO-Industry Standard Stainless Steel with Surface Process Option

Note: The Nano coated stencils deteriorated in their process control phase and therefore were not included in this final analysis. All the stencils were washed using a common process, ultrasonic washer with a mild solution process for SMT stencils. The Nano coatings consist of variable components which with time, depending on ambient conditions and stencil maintenance processes, will degrade. This is why a coated stencil starts to fail or as a minimum the print begins to sway from the original quality of print when the stencil was new vs. once used or washed; this is a normal for all coated stencils.

The following graphs reflect the data collected by the SPI measurement system, during the lab tests.

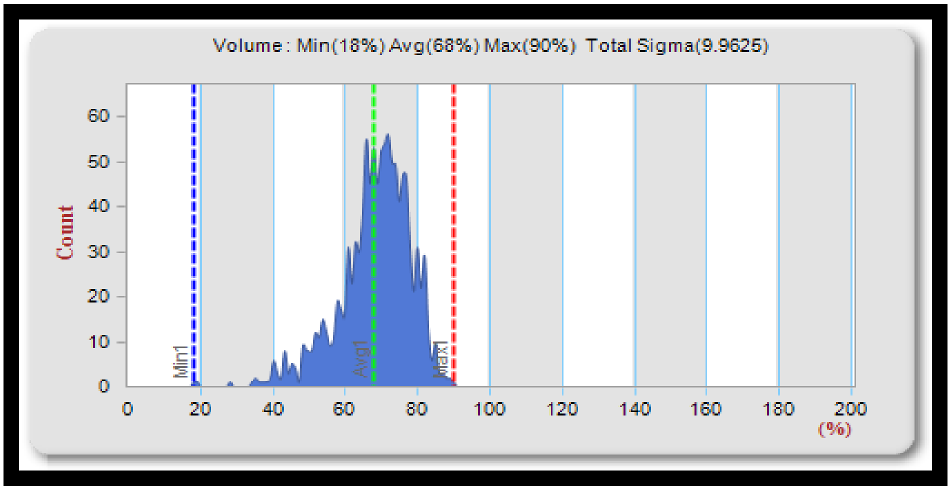

Figure 1a.SQFP 0.3mm-SS 5 mil thickness

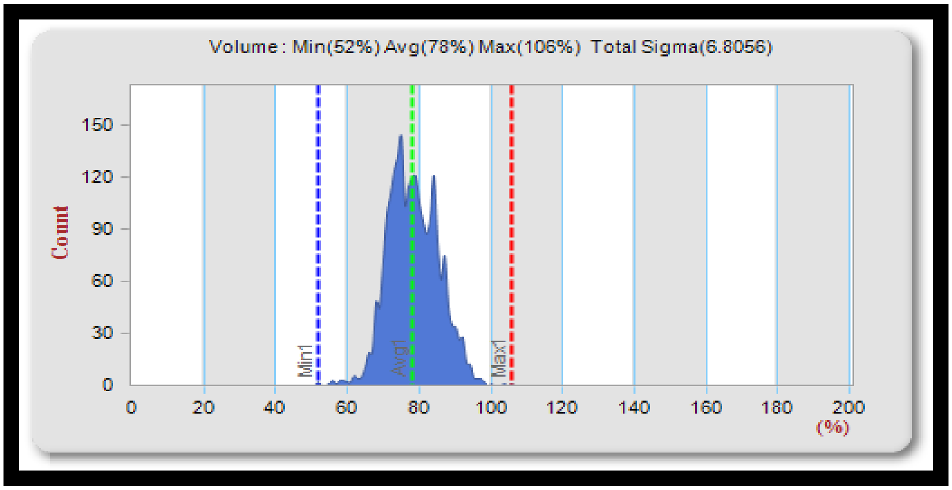

Figure 1b.SQFP 0.3mm - EF 5 mil thickness

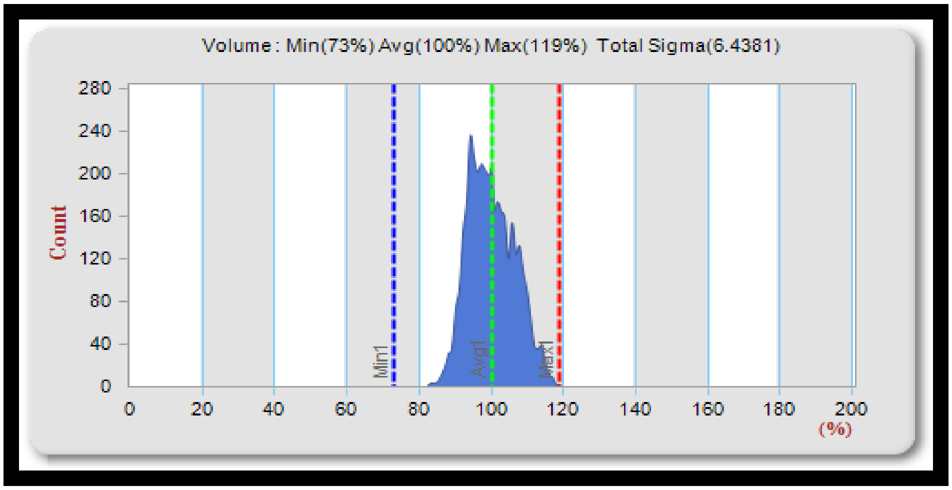

Figure 1c. SQFP 0.3mm-SPO-b 5 mil thickness

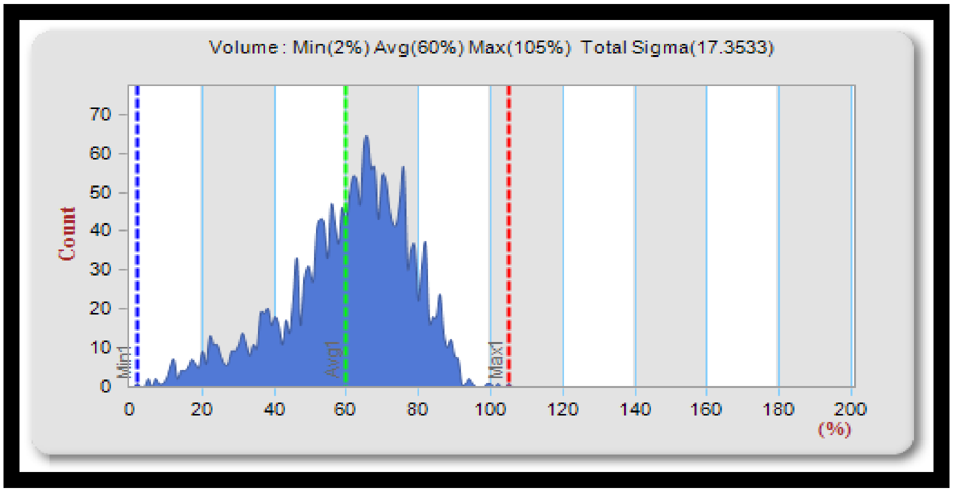

Figure 2a.uBGA 0.4mm-SS 5mils thickness

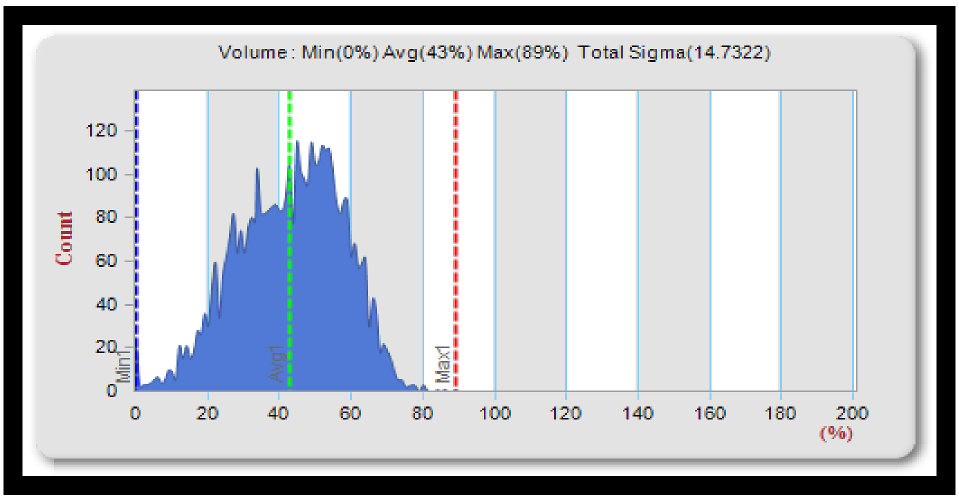

Figure2b. uBGA 0.4mm - EF 5mils thickness

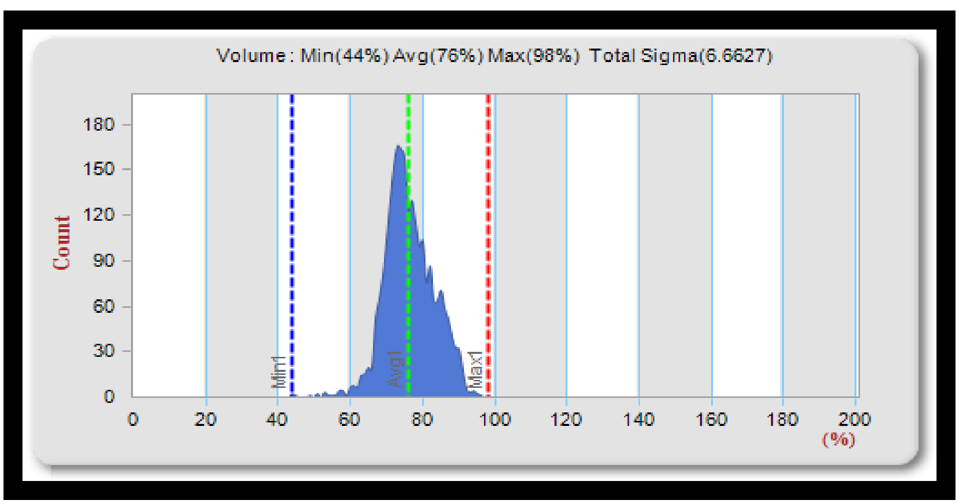

Figure 2c.uBGA 0.4mm - SOP-b 5mils thickness

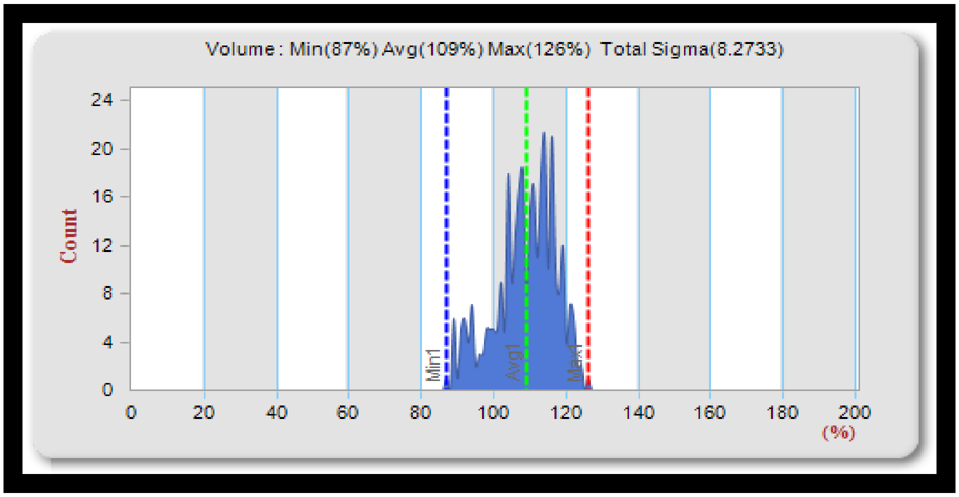

Figure3a. Cap 0402 - SS 5mils thickness

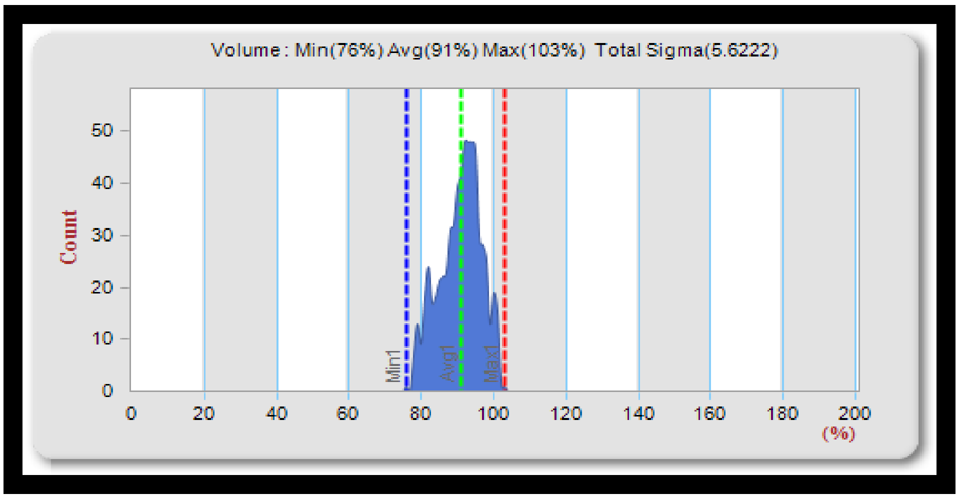

Figure3b. Cap 0402-EF 5mils thickness

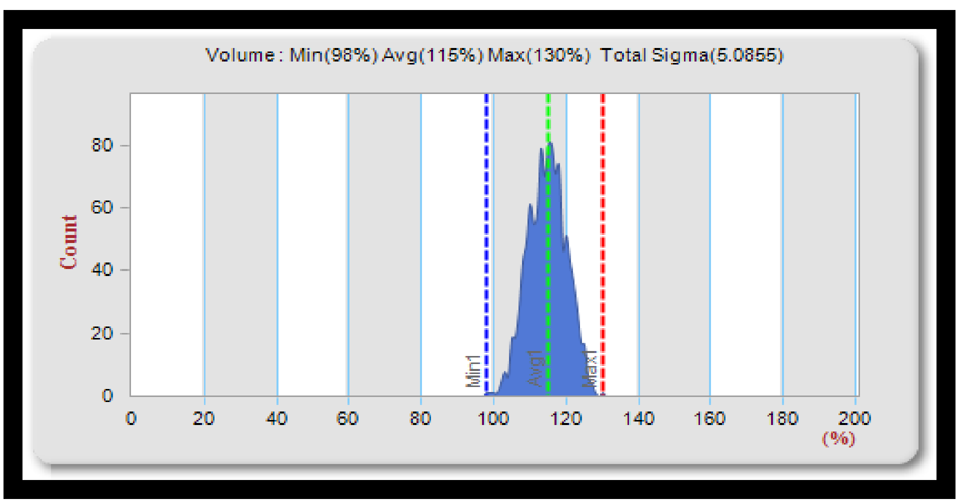

Figure3c. Cap 0402 - SPO-b 5mils thickness

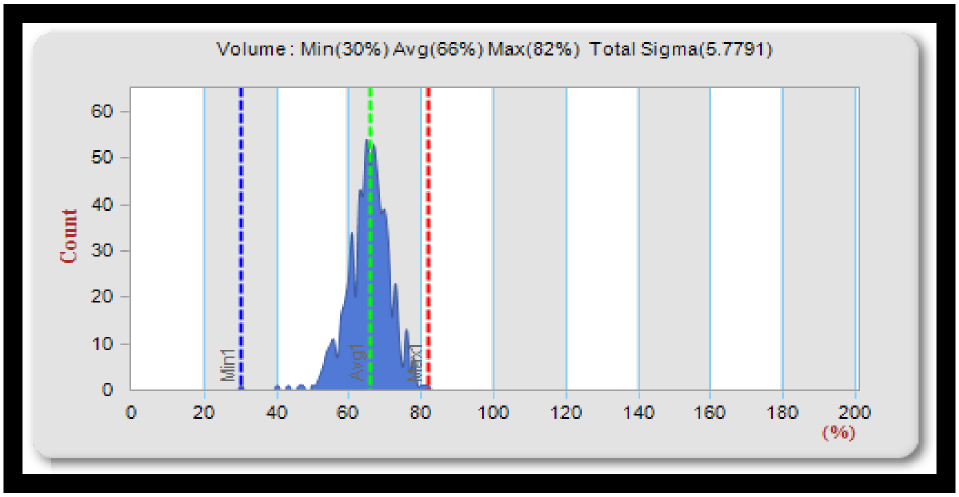

Figure4a. Cap 0201 - EF 5mils thickness

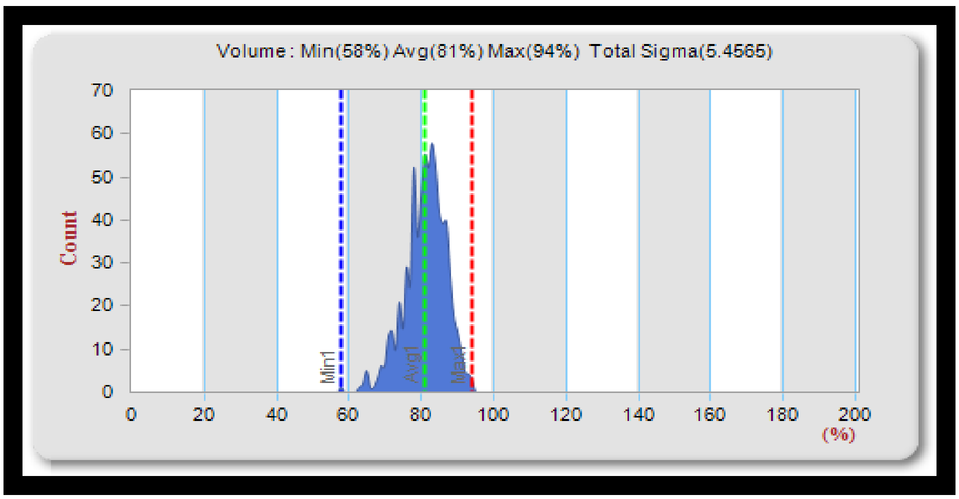

Figure 4b. Cap 0201 - SPO-a 5mils thickness

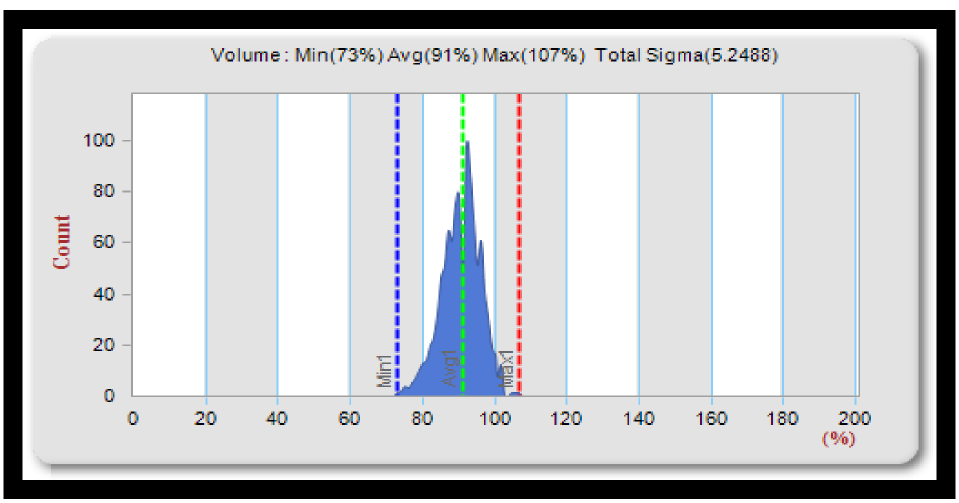

Figure4c. Cap 0201 - SPO-b 5mils thickness

Asignificant delta in performance was observed utilizing the SS, EF, and the new Surface Processed Option (SPO -a and -b).

Discussion

The coated stencil and the SPO –b worked competitively, as newly fabricated products. The problems arose once the coated stencil entered into the manufacturing process world. The breakdown of this coating will affect the paste deposition, hence affect the EOL yields. The SPO is permanent and will not degrade. The data demonstrated that the effects of the process improvements is long term and consistent.

The stencil is a major role player in this solution, considering all the merits of the different technologies. The SPO was designed to emulate the combination of these merits. The results of the SPO-a proved that we can actually improve the industry standard stainless steel material to emulate the Ni stencil option as well, in all aspects of the manufacturing needs.Furthermore, the SPO eliminated the cross contamination element totally.

Summary

The common challenge is sustaining a paste deposition capable of meeting the SMT assembly requirements based on design. The experiments proved that each of the technologies used for stencils have merit, but not one has a complete scope of the print environment. The constant here is the tools, which must be improved to help produce the results required. This process tool, which with proper design will enhance the printers performance and support the EOL yieldsmeetsthe demands of the manufacturing world, while improving the process and maintaining it.

Beware! All processes must be evaluated prior to actual design. The theory of improving a stencil aperture design to improve manufacturing yields is achieved by improving the age old original stencil. Back to basics.

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