Step Stencil Technologies and Their Effect on the SMT Printing Process

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ABSTRACT
It is a common fact that the print process is one of the most critical elements in SMT production and many of today's assemblies include both miniature components such as 0201's, Micro-BGA's, LGA's and QFN's as well as large components such as large connectors on the same assembly. Printing the proper volume of paste on these assemblies is not always possible by adjusting the apertures on single level stencils. As a result, manufacturers are finding that "Step Stencils" allow them to apply the correct amount of paste to different components on the same assembly with excellent first pass yields.

The intent of this study is to evaluate three step stencil technologies and measure their effectiveness in applying different volumes of paste on the same board during the printing process. The step technologies to be evaluated are chemically etched, laser welded and micro-machined. The step down areas for each technology will be physically measured for accuracy. At a given squeegee speed and pressure, the distance from step edge to nearest aperture will be varied. Also solder paste volume in step down areas for each technology will be measured. Finally, the addition of a Fluoro Polymer Nano-Coating will be applied to the contact side of the stencil and in the aperture walls. Solder paste volumes will be measured and compared to the uncoated step technologies.

This paper summarizes the results of this study with respect to the variables tested. Stencil design recommendations will be made with the intent of eliminating defects in the solder paste printing process when applying different volumes of paste with step stencil technologies. As component miniaturization continues and larger components remain, advancements in step technologies by stencil manufacturers continue to improve.

Keywords: SMT stencil, stencil design, step stencils, laser welded steps, etched steps, machined steps, solder paste printing, aperture clogging.

INTRODUCTION
Components such as Quad Flat No Lead (QFN's), Land Grid Array (LGA's), Micro Ball Grid Array (Micro BGA's), 0201's and even 01005's continue to push manufacturers to use thinner stencil foils to apply the correct volume of paste onto their boards, but larger components such as edge connectors still require larger paste volumes. Step stencils have been used to accomplish this for many years. Historically, the primary method for producing these step stencils has been using a photochemical etching process. Recently, new methods of manufacturing step stencils have emerged including both laser welding and micro-machining.

Photochemical etching is an established process and has been around for decades. It is a subtractive process and is very similar to the process used to etch Printed Wiring Boards (PWBs). The stainless steel stencil foil is coated with a photo-resist, imaged using a photographic process and developed leaving the resist to protect any areas that will not be reduced in thickness or etched. The foil is placed into an etching machine where chemical etchant is sprayed onto the stencil which dissolves the stainless steel foil until the correct thickness is achieved. Once the desired stencil thickness is achieved, the photo resist is removed. The depth of the etched or stepped areas using this process is dependent on the time that the stencil is exposed to the etching chemistry. The chemical etching process is shown below (Figure 1).

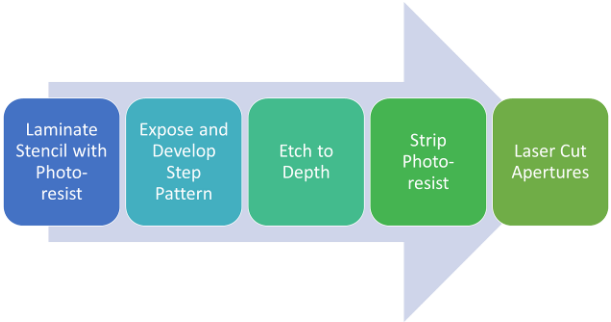


Figure 1: Chemical Etching Process to Create a Step Stencil.

The laser welding process takes stencil foils of different thicknesses and welds them together. There is no chemical etching involved, only laser cutting and laser welding. The step openings are cut out of the first stencil. The corresponding step areas are cut out of a second stencil foil of the desired thickness. The step pieces are placed into the openings of the first stencil. Then the pieces are laser welded into place. The thickness of the step area is determined by the thickness of the steel used. The laser welding process is shown below (Figure 2).

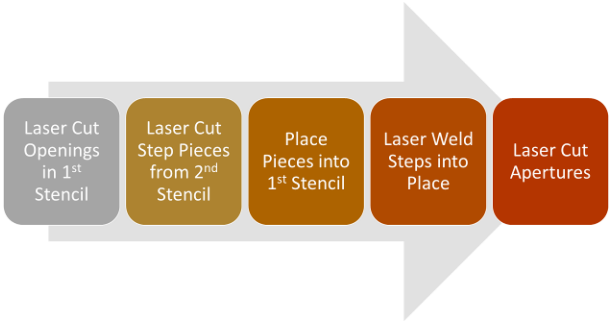


Figure 2: The Laser Welding Process to Create a Step Stencil.

The micro-machining process is a subtractive process similar to the etching process, but no chemicals are used. The micro-machining process uses a very specialized computer numerical controlled (CNC) milling machine to remove very small amounts of material at a time. The micro-machining process is shown below (Figure 3)

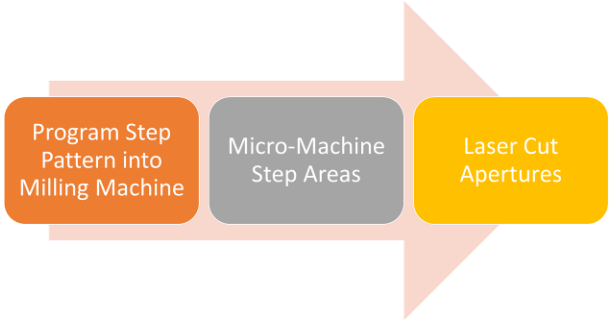


Figure 3: The Micro-Machining Process to Create a Step Stencil.

These three processes for creating step stencils result in different textures within the stepped area. The textures of the step stencils are shown below (Figure 4).

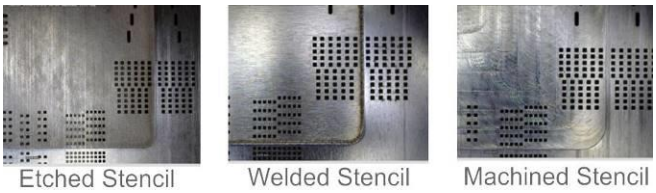


Figure 4: Textures of Step Areas for the Three Step Technologies.

EXPERIMENTAL METHODOLOGY

A step stencil design was created with step down pockets of varying thicknesses. The base stencil thickness was 4.0 mils (101.6 microns) and the step down pockets were 3.5 mils (88.9 microns), 3.0 mils (76.2 microns), 2.5 mils (63.5 microns), and 2.0 mils (50.8 microns) thick. Each step area was 1 inch square (25.4 mm) and the step design is shown below (Figure 5).

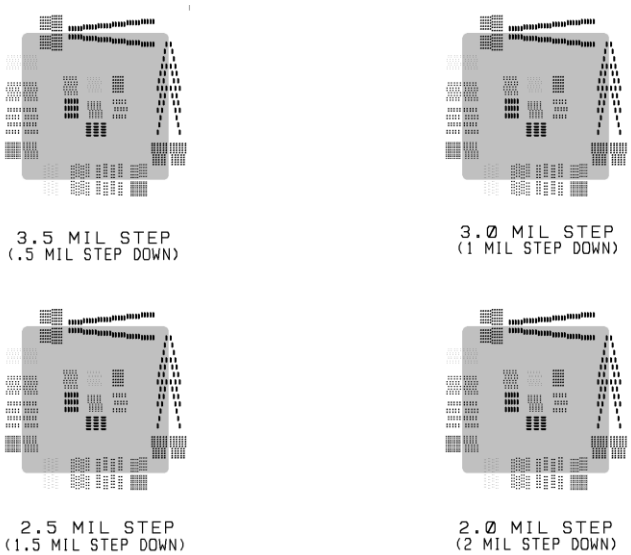


Figure 5: Step Down Pocket Design.

The thicknesses of each step pocket were measured using a FARO arm device. The measurements for each step technology were compared and contrasted.

An aperture pattern was created for the following components: 03015 Metric, 01005, 0.3 mm BGA, 0.4 mm BGA, and 0.5 mm pitch QFNs. Apertures for each component were cut at varying distances from the step edges; 10, 20, 30, 40, and 50 mils. The intention was to determine how close solder paste could be printed to the step edge for each step stencil technology. Apertures were also cut into the center of each step area for comparison. The aperture layout is shown below (Figure 6)

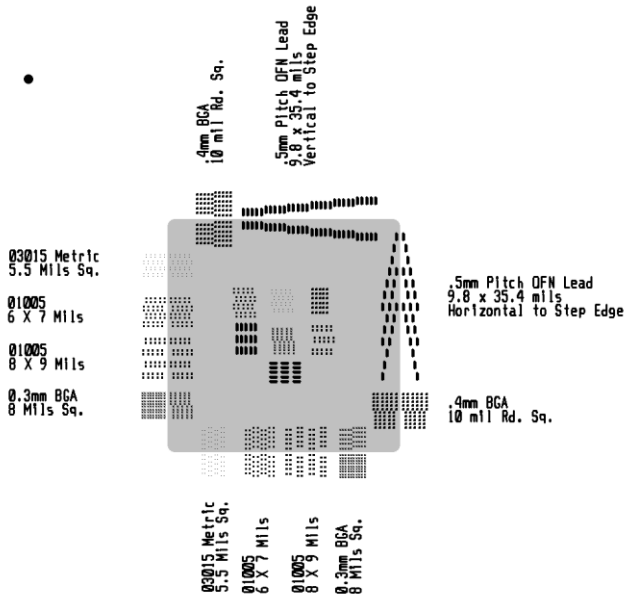


Figure 6: Step Stencil Aperture Design.

Each stencil was made with two sets of steps and apertures. One set of steps and apertures were coated with a Fluoro-Polymer Nano (FPN) coating (Figure 7).

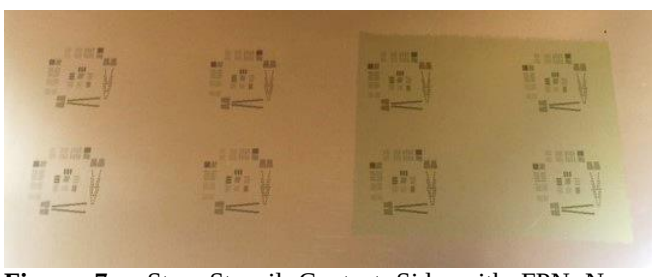


Figure 7: Step Stencil Contact Side with FPN Nano-Coating.

The effects of the FPN coating were compared to the uncoated part of the stencil on printing of solder paste.

A 10 print study was run on each step stencil using a popular no clean, SAC305 Type 4 solder paste. The circuit boards used were bare copper clad material 0.062" (1.57 mm) thick. The printer used was a DEK Horizon 02i. The printer parameters are shown below (Table 1).

Table 1: Solder Paste Printer Parameters.

Parameter	Value
Squeegee Length	300 mm
Squeegee Pressure	0.18 kg/cm (5.4 kg)
Squeegee Speed	30 mm/sec
Squeegee Angle	60 degrees
Separation Speed	1.0 mm/sec
Cleaning Cycle	W/V/D every print
Cleaning Solvent	Isopropanol (IPA)
Solder Paste	NC SAC305 T4

The solder paste volumes were measured using a solder paste inspection system (SPI). The solder paste volume data was analyzed using statistical analysis software and the results are presented in this paper.

RESULTS

Step Stencil Thickness Measurements

Measurements were taken in each step area for each technology. The 3.5 mil step area was not included due to issues with the measurement data. Thickness measurement data is shown below (Table 2).

Table 2: Step Down Thicknesses for Each Step Stencil.

Step Thickness (mils)	Step Depth (mils)	Etched – Depth / STDev (mils)	Welded - Depth / STDev (mils)	Machined - Depth / STDev (mils)
2.0	2.0	2.36 / 0.11	2.08 / 0.19	2.01 / 0.17
2.5	1.5	1.69 / 0.16	1.60 / 0.18	1.25 / 0.15
3.0	1.0	1.15 / 0.19	0.97 / 0.18	1.08 / 0.17

In general, the chemical etching process created deeper step downs than the nominal value, and the welding and machining processes created steps that are closer to the target depth. The standard deviations of step depth are an indication of flatness or roughness in the step areas. The chemical etching process produces a surface that is rougher than the original surface (Figure 4). The welding process involves fixturing a stencil blank into the step area and the blank may not sit perfectly flat as it is welded. The machining process leaves striations on the surface as the cutting tool removes material. Overall, the standard deviations are very similar for each technology.

Solder Paste Printing Data – Etched Stencil

The solder paste volume box plots for the 3.0 mil, 2.5 mil, and 2.0 mil thick etched steps are shown below (Figures 8, 9, and 10 respectively). These are broken out by distance from step edge, aperture size and nano-coating.

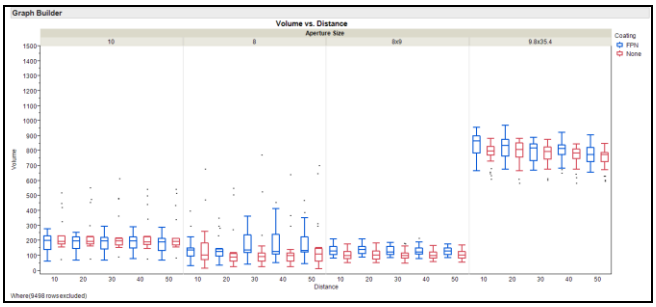


Figure 8: Solder Paste Volumes for the 3.0 mil Etched Step.

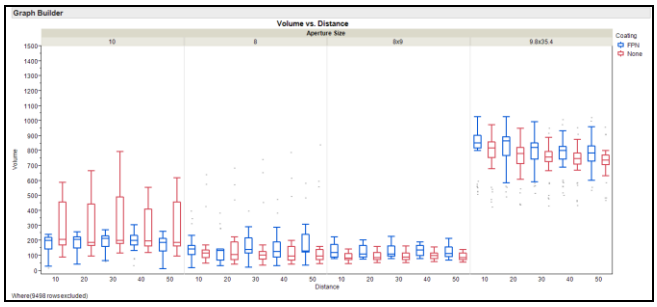


Figure 9: Solder Paste Volumes for the 2.5 mil Etched Step.

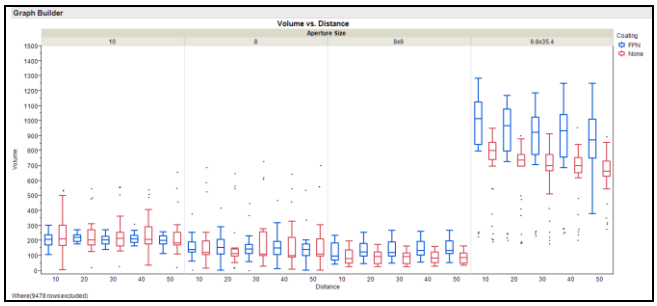
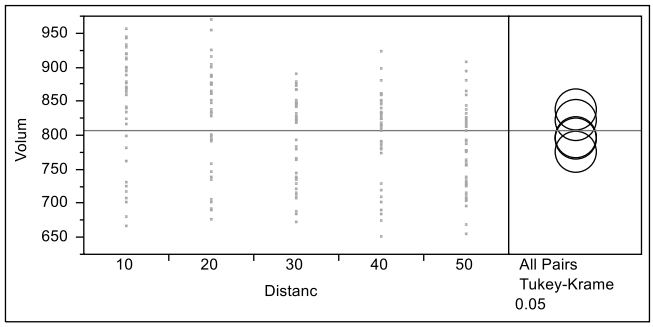


Figure 10: Solder Paste Volumes for the 2.0 mil Etched Step.

In general, the larger apertures which are 9.8 x 35.4 mils in size give higher printed solder paste volumes. The smaller aperture sizes show some differences in solder paste volume. Tukey-Kramer Honest Significant Difference (HSD) testing shows that most of these variations are statistically similar. This means that there is very little difference in printed solder paste volume from 10 to 50 mils from the step edge. There is one exception to this (Figure 11).



Connecting Letters Report

Level			Mean
10	A		839.52500
20	A		823.35000
40	A	B	798.30000
30	A	B	796.65000
50		B	776.22500

Figure 11: Tukey-Kramer HSD Analysis for the FPN Coated, Etched 3.0 mil Step and the 9.8 x 35.4 Aperture.

The printed solder paste volume is higher for the 10 and 20 mil distances than the 50 mil distance. This indicates that the squeegee is not able to conform into the step pocket and squeegee the paste cleanly away from the surface. The same Tukey HSD analysis is true for the uncoated version of this step and aperture size.

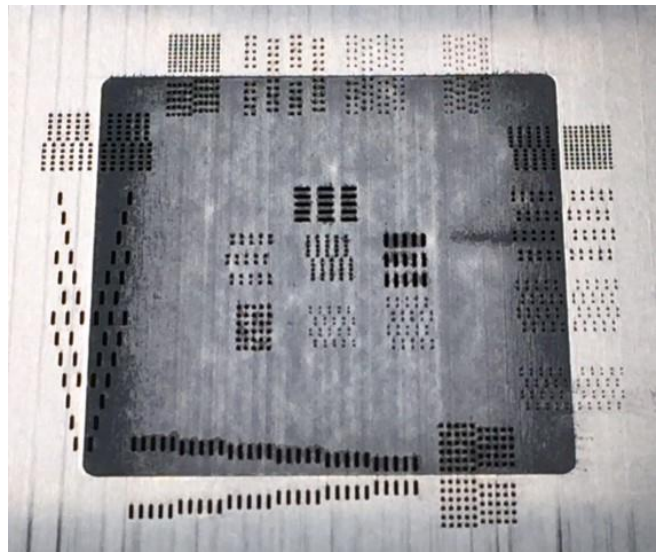


Figure 12: Etched 3.0 mil Step After 1 Print

It is easy to see solder paste residue left near the step wall after printing. This seems to correspond to higher printed paste volumes.

Solder Paste Printing Data – Welded Stencil

The solder paste volume box plots for the 3.0 mil, 2.5 mil, and 2.0 mil thick welded steps are shown below (Figures 13, 14, and 15). These are broken out by distance from step edge, aperture size and nano-coating.

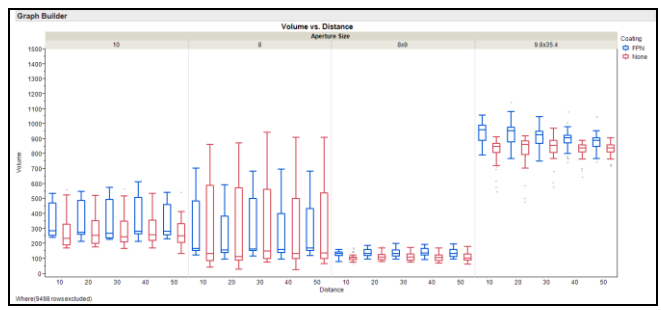


Figure 13: Solder Paste Volumes for the 3.0 mil Welded Step.

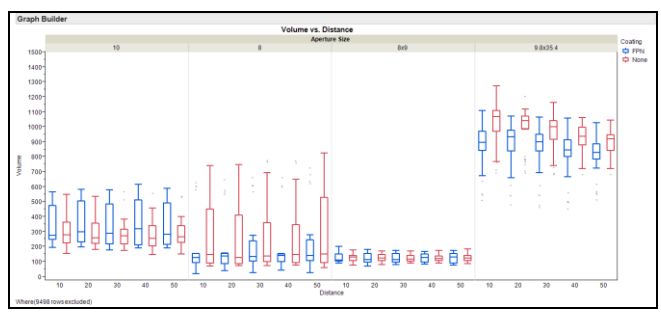


Figure 14: Solder Paste Volumes for the 2.5 mil Welded Step.

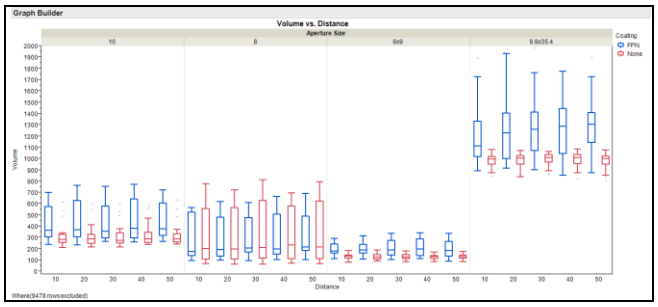
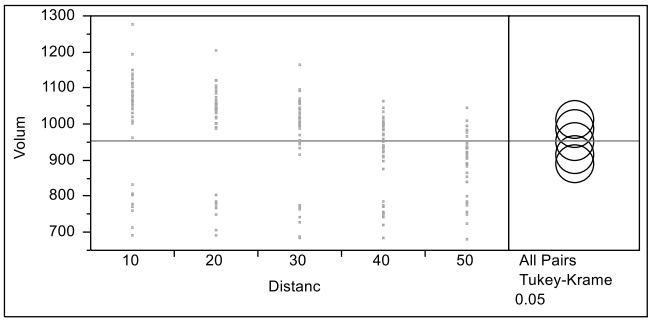


Figure 15: Solder Paste Volumes for the 2.0 mil Welded Step.

The printed solder paste volume did not vary much from 10 mils to 50 mils away from the step edge regardless of welded step thickness. This is very similar to the results seen with the etched steps. Tukey-Kramer HSD testing shows some interesting results (Figure 16).



Connecting Letters Report

Level				Mean
10	A			1015.3250
20	A	B		988.8000
30	A	B	C	954.1750
40		B	C	916.4750
50			C	891.8500

Figure 16: Tukey-Kramer HSD Analysis for the Uncoated, Welded 2.5 mil Step and the 9.8 x 35.4 Aperture.

In this case, the printed solder paste volume at the 10 mil distance is significantly higher than the 40 and 50 mil distances. The printed solder paste volume is significantly higher at the 20 mil distance than then 50 mil distance. Again this indicates that the squeegee could not conform down into the step to remove all of the solder paste from the surface of the stencil during printing. This was also true for the FPN coated version of the 3.0 mil welded step and the same aperture size.

Solder Paste Printing Data – Machined Stencil

The solder paste volume box plots for the 3.0 mil, 2.5 mil, and 2.0 mil thick machined steps are shown below (Figures 17, 18, and 19). These are broken out by distance from step edge, aperture size and nano-coating.

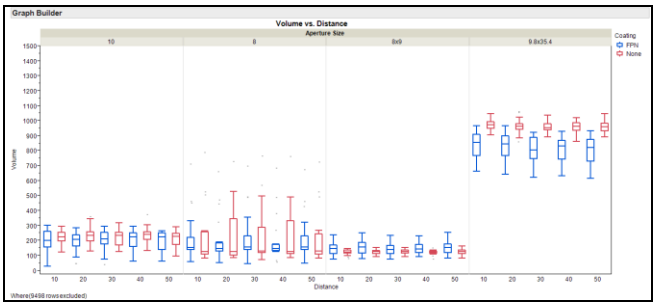


Figure 17: Solder Paste Volumes for the 3.0 mil Machined Step.

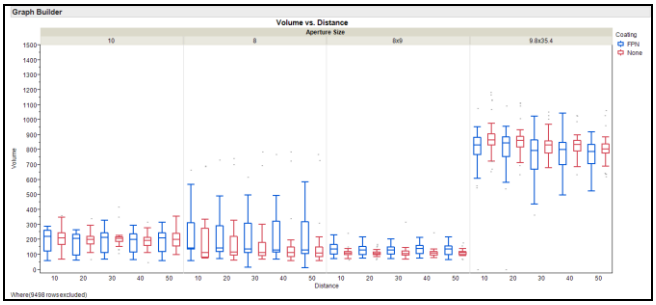


Figure 18: Solder Paste Volumes for the 2.5 mil Machined Step.

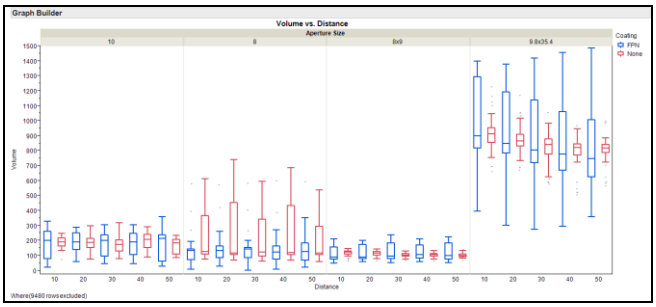
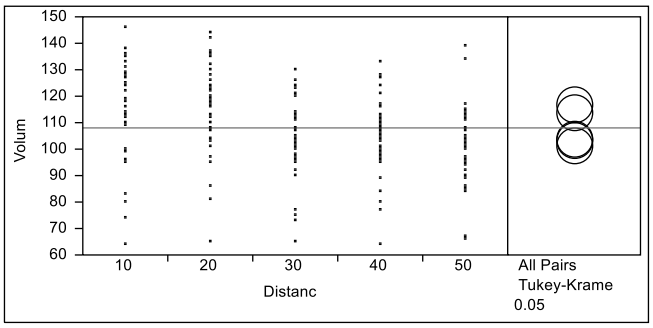


Figure 19: Solder Paste Volumes for the 2.0 mil Machined Step.

The printed solder paste volume did not vary much from 10 mils to 50 mils away from the step edge regardless of machined step thickness. This is very similar to the results seen with the etched and welded steps. Tukey-Kramer HSD testing shows some significant differences in the results (Figure 20).



Connecting Letters Report

Level		Mean
10	A	116.82500
20	A	113.92500

Level		Mean
40	B	104.20000
30	B	103.72500
50	B	101.42500

Figure 20: Tukey-Kramer HSD Analysis for the Uncoated, Machined 2.0 mil Step and the 8 x 9 Aperture.

This Tukey HSD analysis shows that the printed solder paste volume is significantly higher at the 10 and 20 mil distances than the 30, 40, and 50 mil distances. This is also true for the 9.8 x 35.4 mil aperture with 2.0 mil and 2.5 mil machined step thicknesses.

CONCLUSIONS

Chemical etching, laser welding, and micro-machining are each valid methods of producing step stencils. Each process produces different step surfaces.

Regardless of the technology used to produce the step, solder paste volumes for the QFN apertures tend to be higher 10 to 20 mils from the step edge than 30 to 50 mils away. These increased solder paste volumes could lead to shorts with aperture designs for the tested QFN component designs. It would be possible to place apertures this size 30 mils from the step edge and obtain an acceptable solderpaste volume. The smaller 8, 8x9, and 10 mil apertures gave statistically similar solder paste volumes from 10 to 50 mils away from the step edge. Although further investigation is needed, the data shows that small aperture components can be placed as close as 10 mils from the step edge and still obtain acceptable print volumes.

The FPN coating showed a slight increase in volume across all apertures measured. When printing these small apertures, it is recommended to apply a FPN coating.

It is apparent that these step stencil technologies bear further investigation in order to differentiate between them.

FUTURE WORK

Testing is ongoing with these three step stencil technologies. Solder paste volumes at the center of the step area will be compared to volumes near the step edge. The solder paste volumes from a single level stencil of the same thickness as the step down area will be compared and contrasted to the volumes in the step etched stencils. The printed solder paste volume from apertures oriented horizontal to the squeegee will be compared to apertures oriented vertical to the squeegee within step areas. Squeegee pressure and speed will be varied and the effects on solder paste volume will be studied. Finally, we plan to increase the number of boards printed to obtain a larger set of data to expand on these findings.

ACKNOWLEDGEMENTS

We appreciate the support of MET for providing the welded step stencils for this investigation. We also appreciate the support of Fine Line Stencil who provided the etched and machined step stencils and the nano-coating.

REFERENCES

None