Lead Free Solder Paste Printing: Stencil and Squeegee Blade Impact

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Introduction

Rarely does a day pass by without a discussion centered on lead free manufacturing and it's future impact on global electronics assembly. The WEEE and RoHS directives drafted in January 2003 with a focus on electronic product recycling and a ban of six hazardous substances in electronics products has created quite an industry buzz. European member states are responsible for passing their own legislation making the directives law and binding in their respective countries. The WEEE directive has slipped implementation in many countries as establishing recycling logistics appears to be more difficult than first thought. On the other hand, RoHS compliance is moving along at a fast pace with many companies finding suitable solutions and replacements for Sn/Pb solders. Engineers are now faced with optimizing the process variables around these new material properties. Many recent studies have analyzed the effect / impact of Lead Free solder paste implementation on a multitude of SMT processes including solder joint strength, wetability of SMD leads as well as pads on the PCB with a variety of board finishes and solder paste compositions. Hardly a day goes by where you don't see an announcement about a new Lead Free implementation Workshop.

This study will focus on the stencil and squeegee blade and their impact on the Lead Free solder paste-printing process. Three different stencils, three different Lead Free solder pastes, and five different squeegee blades are included in the study. The Benchmarker II stencil test pattern was used as a tool in the evaluation. Of particular interest is the surface roughness / smoothness of the stencil squeegee side surface. It is demonstrated that this surface has a dramatic influence on the minimum squeegee pressure for metal squeegee blades to achieve clean wiping of the Lead Free solder paste from the stencil surface. In addition to the surface finish of the stencil it was found that the type of Lead Free solder paste and the type of metal squeegee blade used also played a roll in determining the minimum squeegee pressure to achieve clean wiping of the solder paste.

Experimental Set-Up

All print tests were performed on a DeK 265GSX printer in the Heraeus Applications Laboratory. The squeegee pressure was set for minimum pressure to achieve a clean wipe of the stencil surface for each new print test set-up including stencil type, paste type and squeegee type. The Benchmarker II stencil test pattern was used for all print tests. Fifteen total boards with Copper gold flash pads were printed for each test run. Print speed of 50 mm/sec and separation speed of 10 mm/sec were maintained for all print tests.

Stencils, Squeegee Blades, and Lead Free Solder Pastes employed Three different stencil types were used:

1. AMTX E-FAB® Electroformed stencil, 5 mil thick, with a mirror type finish on both squeegee and stencil contact side. (Hereafter referred to as e-fab.)

2. Laser-Cut Alloy 42 Electropolished stencil, 5 mil thick, with an etched surface that simulated the surface of a step stencil

3. Laser-Cut stainless steel stencil, 5 mil thick, with a typical stainless steel surface finish.

The surface finishes of the three types of stencils is shown below:

Stencil Type	Surface finish in Ra (Micro-inches)	
	X Axis	Y Axis
AMTX E-FAB®	1.0	1.0
Stainless Steel	6.5	3.8
Alloy 42 Step	9.8	9.0

Three different Lead Free solder pastes were used:

a) Composition = 95.5Sn / 4.0 Ag / 0.5 Cu, Viscosity = 1080 Kcps, Solids = 88.13%
b) Composition = 95.5Sn / 4.0 Ag / 0.5 Cu, Viscosity = 990 Kcps, Solids = 88.29%
c) Composition = 95.5Sn / 3.8 Ag / 0.7 Cu, Viscosity = 990 Kcps, Solids = 89.30%

Five Squeegee blades were tested:

Blade	Description	Thickness	Surface Finish Ra (Micro-inches)
(V)	Nickel / Teflon coat	12 mils	3
(W)	Nickel coat	12 mils	5
(X)	OEM supplied with Printer	12 mils	6
(Y)	Nickel Titanium Nitride coat	12 mils	5
(Z)	E-squeegee Electroformed	11 mils	1

Test Results

Inspection after printing was done in two different manners. The first method used the automatic inspection of the DeK printer, which looked for (1) paste coverage of the pads on the board, (2) aperture blockage of the stencil apertures, (3) smearing of the paste on the bottom side of the stencil around the apertures. The second method was visual inspection of the boards under 25 X magnification looking for shorts, opens and insufficients.

DeK printer inspection

Fifteen boards were printed for each set-up. The squeegee pressure was set at the minimum for clean wipe for each set-up. Table 1 describes the pad layout and the stencil aperture size for each of the SMD sites that were inspected. The number of sites inspected is shown in the second column labeled Pads. All 15 printed boards were inspected by the DeK inspection system.

Table 1 - Benchmarker II Pad and Aperture Layout

	Site Name	Pads	Pad W	Pad L	AP W	AP L	Shape	RED	X	Y
	SOIC-1	3	27	85	24	77	Rectangle	19	.258	2.591
	SOIC-2	3	27	85	24	77	Rectangle	19	.510	1.994
	1206	1	80	60	76	57	Rectangle	10	.287	.989
	1206	1	80	60	76	57	Rectangle	10	.444	.989
	0805	2	60	50	57	48	Rectangle	9	1.233	.880
	0603	2	50	40	47	38	Rectangle	11	1.988	.700
	0402	4	30	30	28	28	Rectangle	13	3.737	.599
	.8mm BGA-1	25	16 mil Diameter		15 mil Diameter		Round	12	3.850	1.209
	.8mm BGA-2	25	16 mil Diameter		15 mil Diameter		Round	12	4.005	1.618
	0201Round	6	16	11	11 mil Diameter		Round	47	4.231	.457
	0201Rect	6	16	11	11 mil Diameter		Rectangle	30	4.331	.457
	0201Oval	6	16	11	11 mil Diameter		Oval	34	4.431	.457
	25mil QFPWide1	6	17	80	12	70	Rectangle	38	5.334	.769
	25mil QFPWide2	6	17	80	12	70	Rectangle	38	6.002	.955
	25mil QFPNarow1	6	10	80	9	70	Rectangle	21	5.813	1.624
	25mil QFPNarow2	6	10	80	9	70	Rectangle	21	5.147	1.434
	.5mm QFPWide1	7	16	65	12	61	Rectangle	30	6.153	1.446
	.5mm QFPWide2	7	16	65	12	61	Rectangle	30	6.291	.404
	.5mm QFPNarow1	7	12	65	8	61	Rectangle	37	7.195	1.584
	.5mm QFPNarow2	7	12	65	8	61	Rectangle	37	7.335	.547
	1mm BGA-1	16	30 mil Diameter		28 mil Diameter		Round	13	6.546	.798
	1mm BGA-2	16	30 mil Diameter		28 mil Diameter		Round	13	6.942	1.194

Figure 1a shows paste coverage for the 1205, 0805, 0603, and 0402 chip components for the e-fab stencil using paste (A) and using the E-squeegee squeegee (hereafter referred to as the e-squeegee). Figure 1b shows the Laser-Cut stencils using paste (A) and using the OEM squeegee blade. Paste coverage and CV (Coefficient of Variance) for the e-fab stencil / Paste (A) / E-squeegee combination is better than the Laser-Cut stencil.

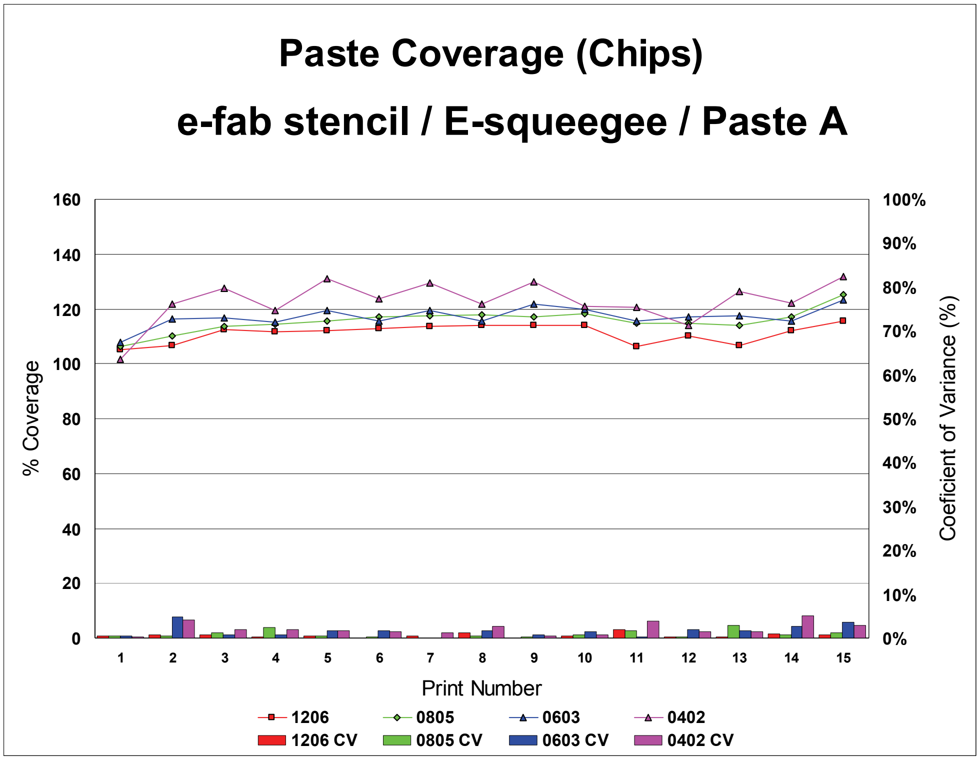


Figure 1a – Paste Coverage on Chip Components e-fab Stencil

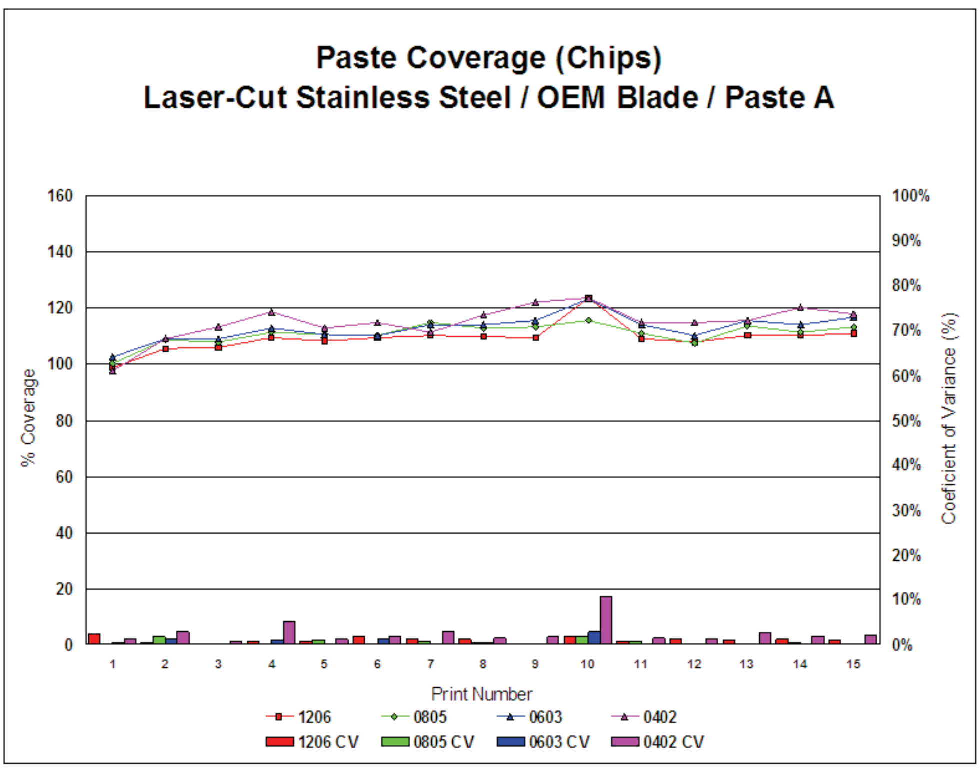


Figure 1b – Paste Coverage on Chip Components Laser-Cut Stainless Steel Stencil

Figure 2a and 2b show the paste coverage for the 0201's for the same stencil / paste / squeegee blade combination as Figure 1a and 1b. Paste coverage and CV are significantly better for the e-fab stencil / Paste (A) / E-squeegee combination compared to the Laser-Cut / Paste (A) / OEM blade combination.

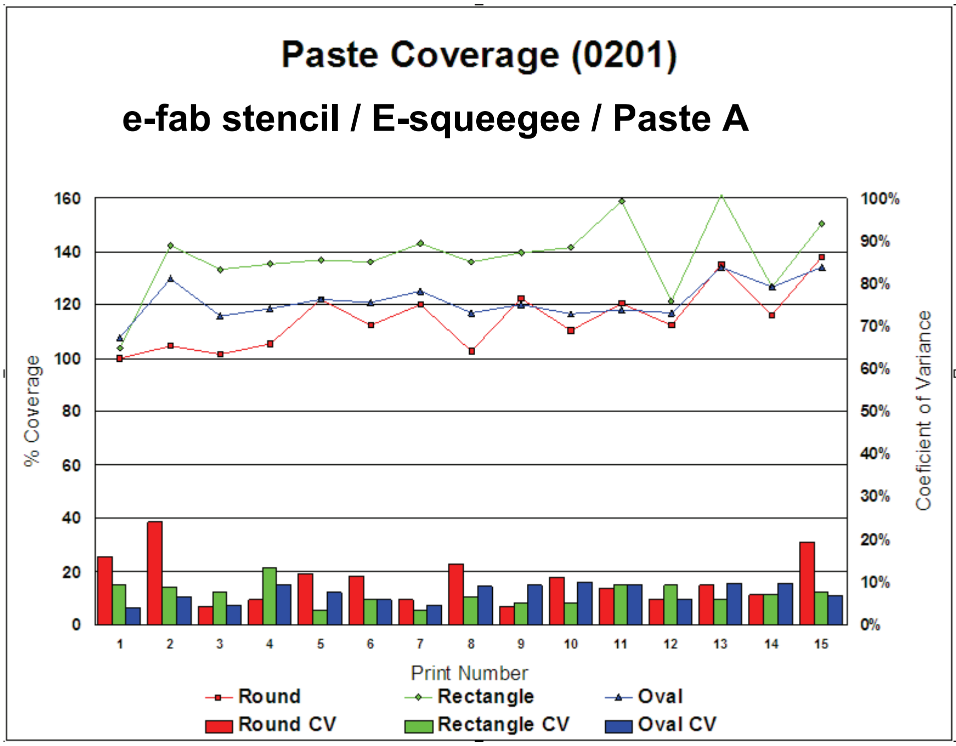


Figure 2a – Paste Coverage 0201 Chip e-Fab Stencil

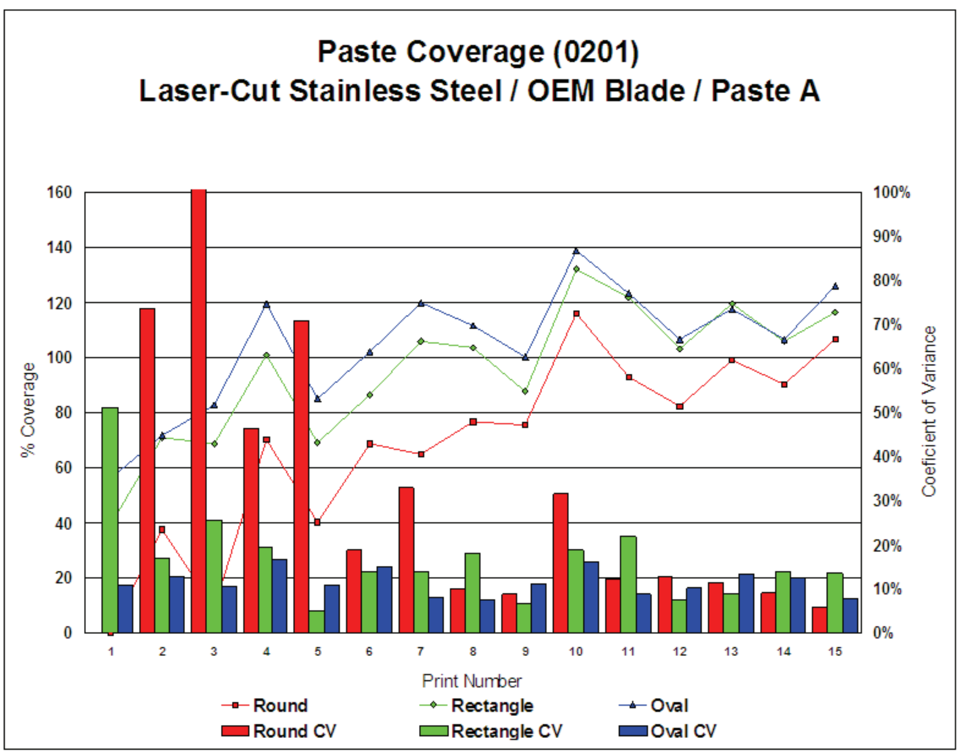


Figure 2b – Paste Coverage 0201 Chip Components Laser-Cut Stainless Stencil

Figure 3a and 3b show paste coverage for the .8mm and 1mm BGA's for the same combination as Figure 1a and 1b. The e-fab has better paste coverage and lower CV then the Laser-Cut combination.

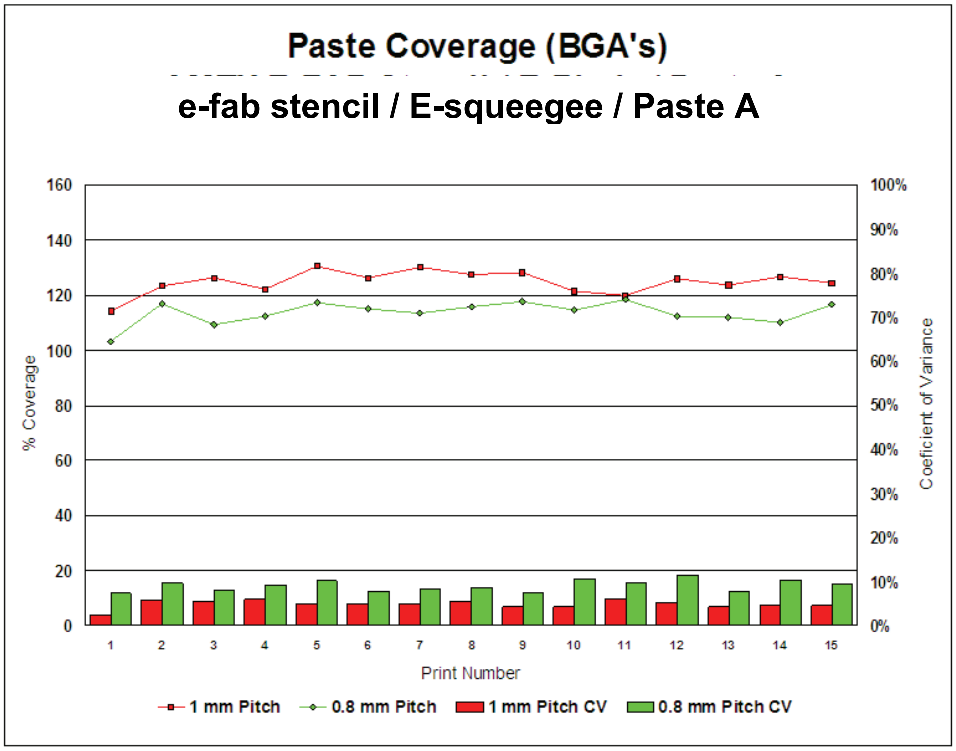


Figure 3a – Paste Coverage BGA's e-fab Stencil

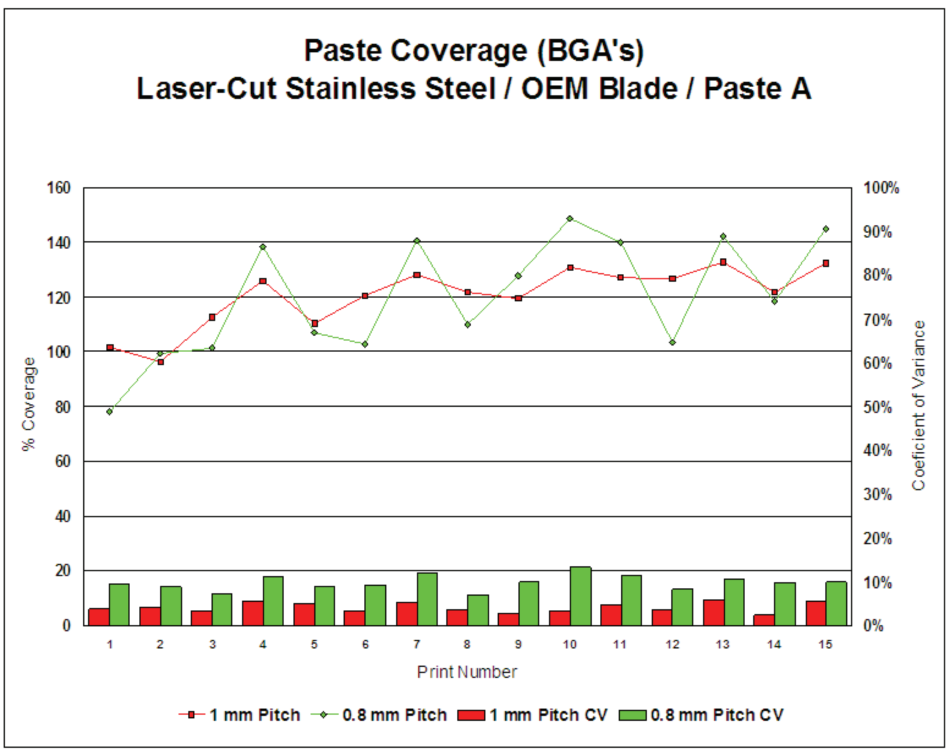


Figure 3b – Paste Coverage BGA's Laser-Cut Stainless Steel Stencil

Figure 4a and 4b show the aperture blockage for the 0201's for the same combination as Figure 1a and 1b. The e-fab combination has almost no aperture blockage while the Laser-Cut combination has significant blockage.

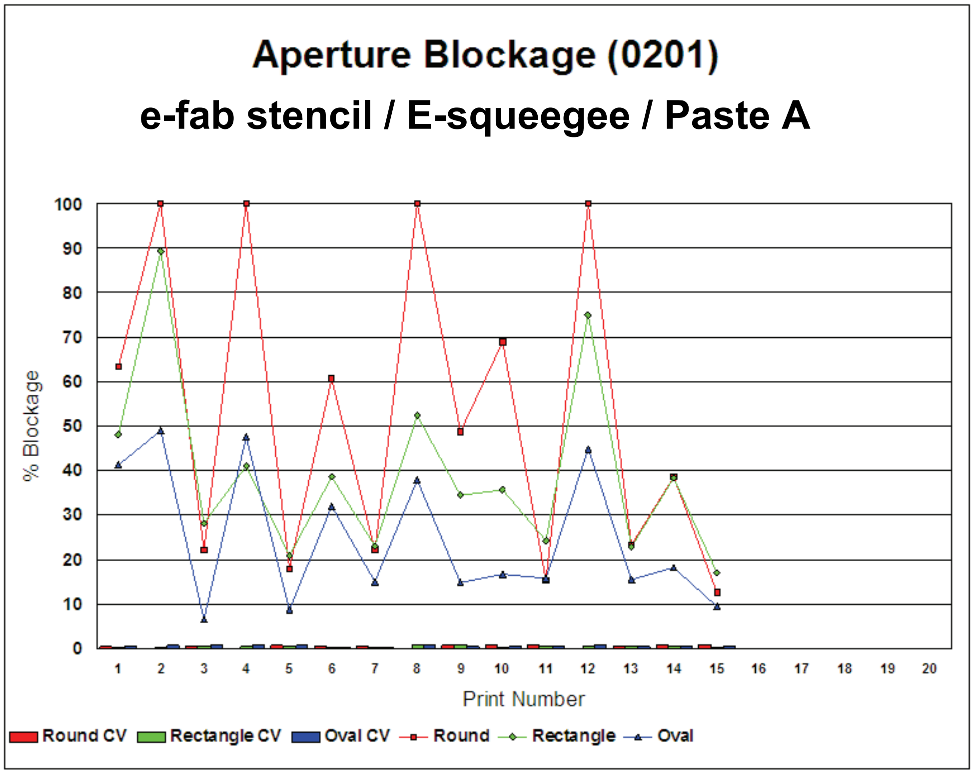


Figure 4a – Aperture Blockage 0201 e-Fab Stencil

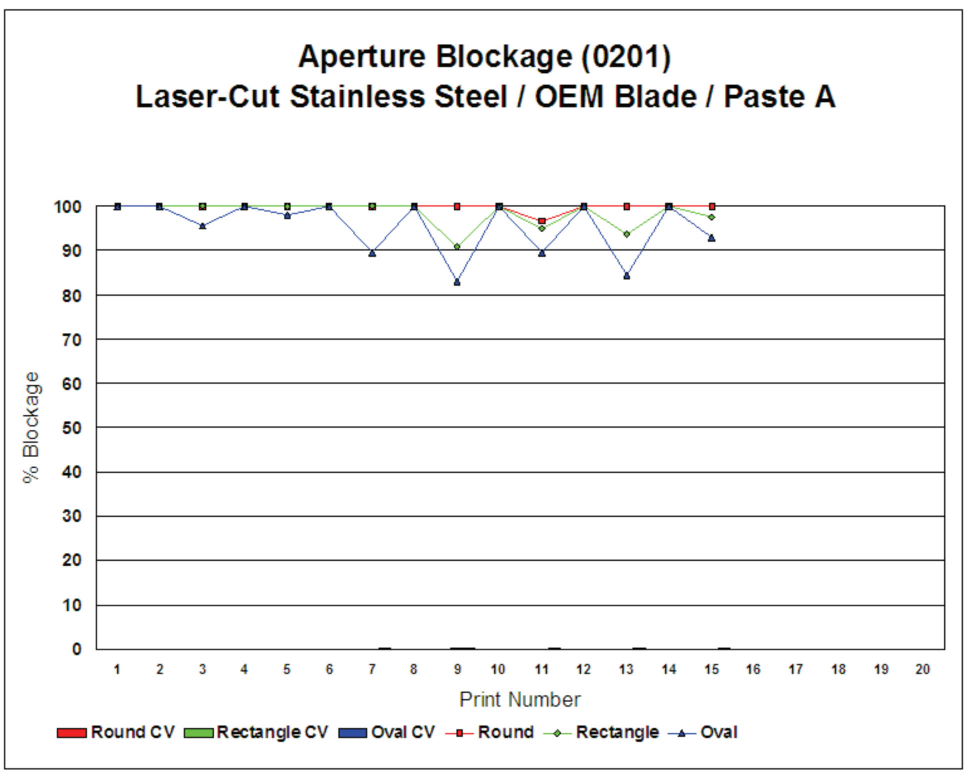


Figure 4b – Aperture Blockage 0201 Laser-Cut Stainless Stencil

Figure 5a and 5b show smearing of paste around the apertures in mm^2 for all components for the same combination as Figure 1a and 1b. Smearing for the e-fab combination is lower than the Laser-Cut combination.

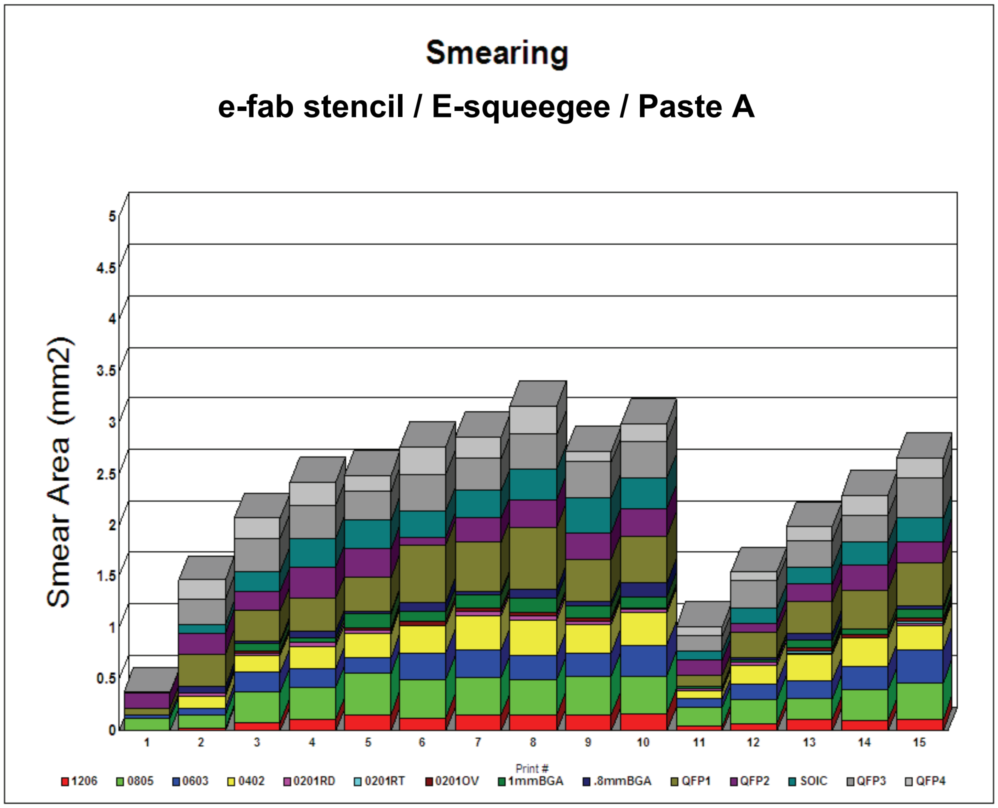


Figure 5a – Smearing of All Components e-Fab Stencil

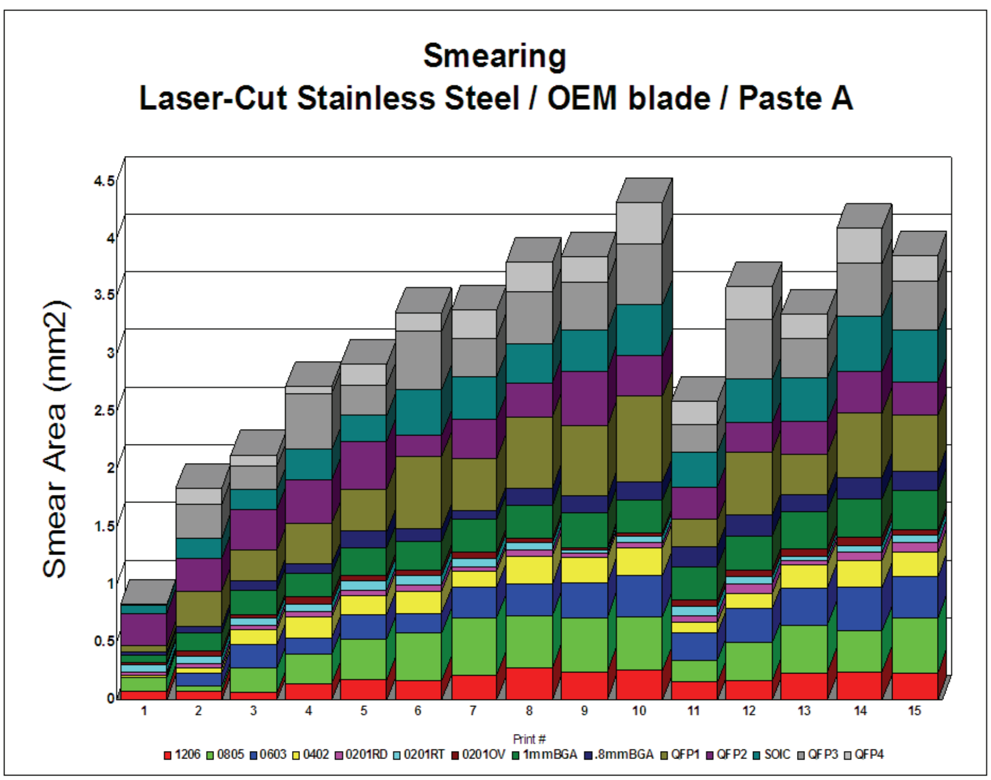


Figure 5b – Smearing of All Components Laser-Cut Stainless Stencil

Visual inspection

Visual inspection was performed on 5 boards of the 15 boards printed for each of the stencil / paste / squeegee blade combinations. The 2nd, 5th, 9th, 10th, and 15th print are used in the visual inspection test. There are three separate visual inspections defined below, the aperture test, the spread test, and the paste release test.

Aperture Test

The aperture test is designed to test for shorts and opens for a set of specific fine pitch apertures not specifically representative of any SMD components. There are 10 groups of fine pitch apertures on each substrate. Each group has apertures horizontal, vertical and at a 45° angle to the squeegee travel direction. Each group also has an array of circular apertures. The apertures in each group have the same width and spacing ranging from 120µ to 300µ in 20µ steps. These 10 groups are collectively called the aperture test. For each direction (vertical, horizontal, and diagonal) in each group, all 5 of the saved test substrates are inspected for line breaks or shorts at 25X. A short is defined as a bridge of two adjacent lines of solder paste. As little as 2 particles of solder touching each other at up to 25X magnification constitutes a short. A line break is the incomplete transfer of solder paste to the substrate. Any missing solder (including the ends of the aperture) that reduce the height by more than 75% are considered a line break. Just one defect (short or line break) is required to constitute a defect for a given group of apertures. After looking at all 5 boards for each of the stencil / paste / squeegee blade combinations the group without any opens or shorts in all three dissections (vertical, horizontal, and diagonal) is recorded. This summary is shown in Table 2.

Spread Test

There is a section of the Benchmarker II design that has 6 rows of large 25 X 50 mil pads. Each row of pads has a different gap between the pads ranging from 4 mils to 12 mils. For this test count how many shorts were found in the row for each pad gap for each of the 5 prints. Inspect for shorts at 25X. A short is defined as a bridge of two adjacent pads of solder paste. As little as 2 particles of solder touching each other at up to 25X magnification constitutes a short. There are (38) 4 mil gaps, (36) 6 mil gaps, (34) 8 mil gaps, (32) 10 mil gaps and (30) 12 mil gaps for each board. Since 5 boards are inspected this gives a possible of 850 total shorts if all the gaps were shorted. The total number of shorts for all 5 boards for each stencil / paste / squeegee blade combination is recorded and shown in Table 2.

Table 2 - Summary of Results for Benchmarker II Visual Inspection

Stencil	Paste Type	Blade Type	Spread Results	Aperture Results	Paste Transfer
Laser-Cut A42 step Laser-Cut-SS e-fab stencil	A A A	OEM OEM OEM	570 409 390	>300 260 240	220 240 200
Laser-Cut A42 step e-fab Stencil	A A	E-squeegee E-squeegee	568 385	280 260	220 180
A42 step e-fab Stencil	B B	E-squeegee E-squeegee	524 501	240 220	220 140
A42 step e-fab Stencil	C C	E-squeegee E-squeegee	670 521	>300 280	N/A N/A

Table Definition

Spread test – How many bridges between apertures spaced 4, 6, 8, 10, 12 mils apart

Aperture Test – Which aperture configuration bridges (Horizontal, Vertical, Diagonal). Spacing is 120, 140, 160, 180, 200, 220, 240, 260, 280, 300 micron apart for the combination of prints 2, 5, 9, 10, 15

Paste Transfer – Paste transfer for circle apertures of 120, 140, 160, 180 200, 240, 260, micron diarmeter looking at only the second print.

Release Test

The array of circular apertures ranging from 120 microns up to 300 micron was inspected for this test. The lowest aperture size without voids or insufficients was recorded for each stencil / paste / squeegee blade combination. Results are summarized in Table 2. In addition Figure 6a shows the solder bricks for the 140 micron aperture array for the combination e-fab Stencil, paste A, and OEM blade while Figure 6b shows the same combination for the 160 micron aperture array. Figure 7a shows the solder bricks for the 140 micron aperture array for the combination e-fab Stencil, paste B, and E-squeegee blade while Figure 7b shows the same combination for the 160 micron aperture array. Figure 8a shows the solder bricks for the 140 micron aperture array for the combination Laser-Cut Alloy 42 step Stencil, paste A, and OEM blade while Figure 8b shows the same combination for the 160 micron aperture array. Figure 9a shows the solder bricks for the 140 micron aperture array for the combination Laser-Cut Stainless Steel Stencil, paste A, and OEM blade while Figure 9b shows the same combination for the 160 micron aperture array. As expected the e-fab Stencil demonstrates better paste release for the small circular apertures. However, both Blade type and Paste type influence overall paste release for the small apertures.

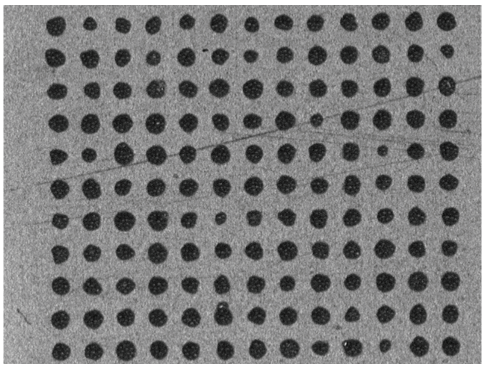


Figure 6a – Solder Brick for 140 Micron Aperture Paste A, OEM Blade e-fab Stencil

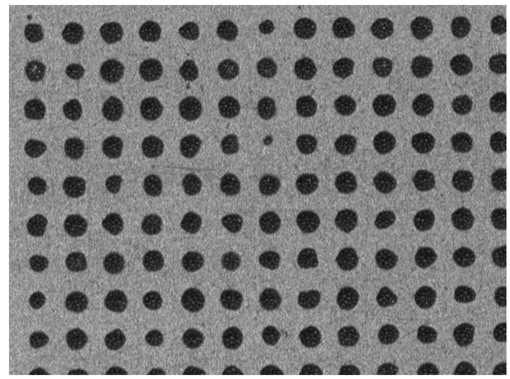


Figure 6b – Solder Brick for 160 Micron Aperture Paste A, OEM Blade e-fab Stencil

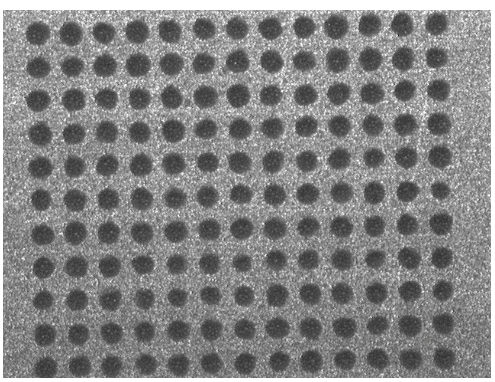


Figure 7a – Solder Brick for 140 Micron Aperture Paste B, E-squeegee e-fab Stencil

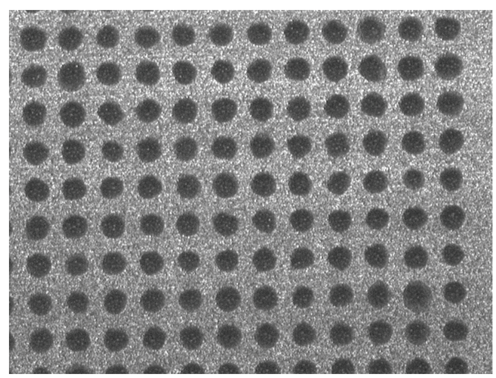
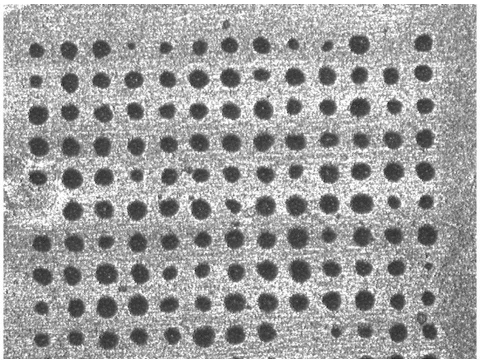


Figure 7b – Solder Brick for 160 Micron Aperture Paste B, E-squeegee e-fab Stencil

Figure 8 shows the solder brick results for the Laser-Cut Alloy 42 step stencil for 140 and 160 micron apertures. Figure 9 shows the solder brick results for the Laser-Cut Stainless Steel stencil for 140 and 160 micron apertures. Both stencils use Paste A and the OEM Squeegee blade.



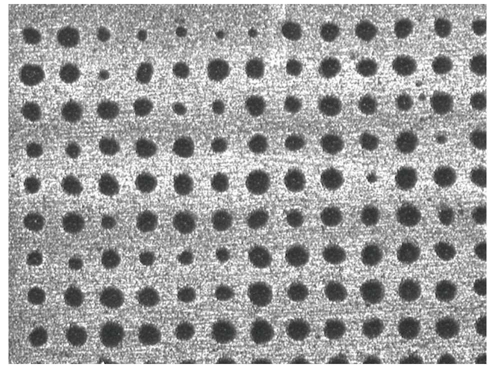
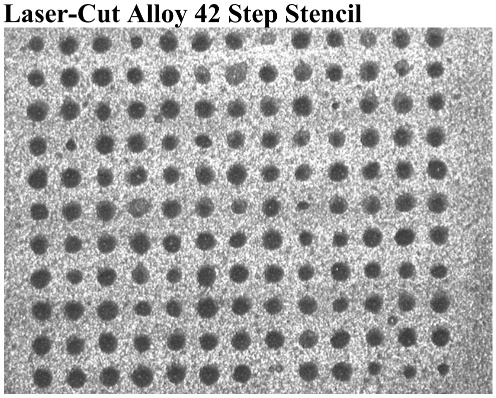


Figure 8a – Solder Brick for 140 Micron Aperture Paste A, OEM-Blade Laser-Cut Alloy 42 Step Stencil

Figure 8b – Solder Brick for 160 Micron Aperture Paste A, OEM-Blade Laser-Cut Alloy 42 Step Stencil



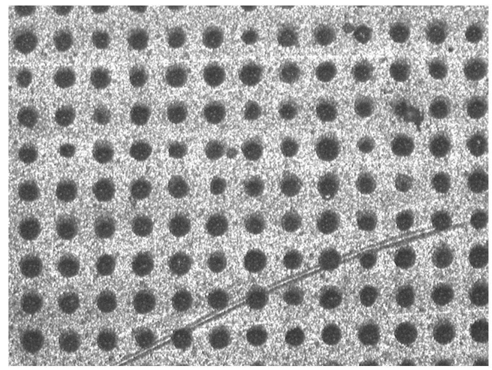


Figure 9a – Solder Brick for 140 Micron Aperture Paste A, OEM-Blade Laser-Cut Stainless Steel Stencil

Figure 9b – Solder Brick for 160 Micron Aperture Paste A, OEM-Blade Laser-Cut Stainless Steel Stencil

Squeegee blade Studies

Two different Squeegee Blade evaluations were performed. One test involver two blade types (OEM Blade and the E-squeegee blade) using 3 different solder paste types and three stencil types. The other test involved 5 different blade types and one solder paste (Type B).

Two Blades with 3 stencils and 3 solder pastes

The minimum squeegee pressure to achieve clean wiping of the solder paste in both forward and reverse directions was recorded for the stencil / paste / blade combinations. The squeegee speed was held constant for all tests at 50 mm/sec. Results are summarized in Table 3. AS seen Stencil type, Paste type, and Squeegee Blade type all play a roll in determining the minimum squeegee pressure.

Table 3 - Minimum Squeegee Pressure for Clean Paste Wipe

Blade Type	Paste Type	Stencil Type	Pressure Kgms/cm
OEM	A	Laser A42 step	0.80
E-squeegee	C	Laser A42 step	0.80
OEM	A	Laser SS	0.48
OEM	A	e-fab	0.44
E-squeegee	C	e-fab	0.44
E-squeegee	A	Laser A42 step	0.43
E-squeegee	A	e-fab	0.31
E-squeegee	B	Laser A42 step	0.24
E-squeegee	B	e-fab	0.14

Five Blades with 1 stencil and 1 solder paste

In this case the e-fab stencil and solder paste B was used for all five-squeegee blades. The five squeegee blades were described earlier in the test. Results are summarizes in Figure 10 and Figure 11. Figure shows the minimum pressure for the 5 blades while Figure 11 shows the residue solder paste left on the blades after printing. There is considerable variation in minimum Squeegee Blade pressure varying on the low end from 0.144 Kgms per centimeter of blade length for the E-squeegee to 0.4 Kgms per centimeter for the Nickel coated blade with a Teflon coating. The amount of paste left on the blades varied from a low of 9.5 grams to a high of 17.1 grams. In no case was there enough paste left on the blade to rise up onto the blade holder. It was contained on the blade where it present no problem to the print operation due to paste drying on the blade holder and falling back into the solder paste reservoirs on the stencil.

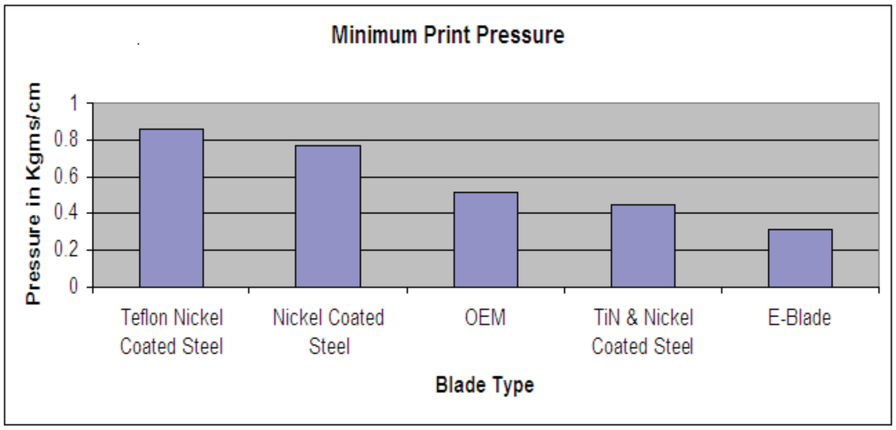


Figure 10 – Minimum Squeegee Blade Pressure to Achieve Clean Wipe of Solder Paste

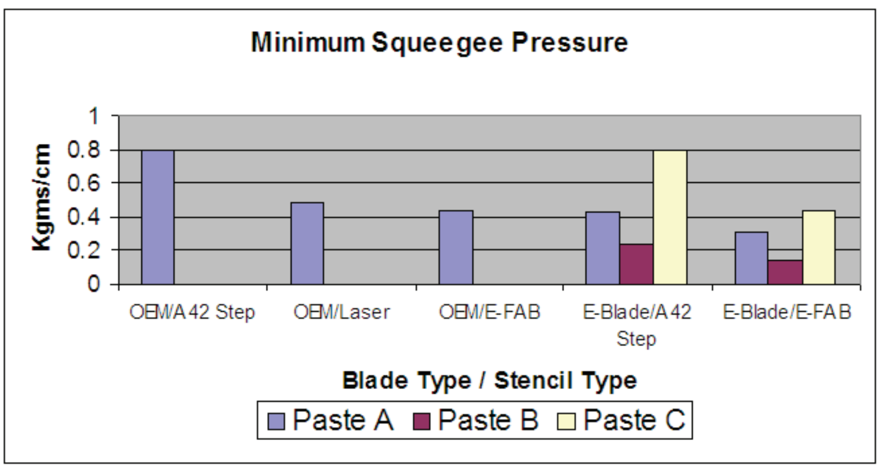


Figure 11 – Minimum Squeegee Blade Pressure to Achieve Clean Wipe of Solder Paste

Conclusions

Paste coverage for fine pitch components like 0201's and small apertures (140 microns) is significantly better for the e-fab stencil compared to the Laser-Cut stencil for Lead Free Solder pastes. This was also the case for Lead solder paste as shown in prior publications [1,2].

Paste smearing was lower for the e-fab stencil using the electroformed E-squeegee compared to the Laser-Cut stencil using the OEM blade, in both cases Paste A was used.

- The best Spread Test results (minimum bridging between solder bricks) was achieved for the e-fab stencil / Paste A / E-squeegee combination.
- The best Aperture Test results (bridging / opens) was achieved for the e-fab stencil / Paste B / E-squeegee combination.
- The best Paste Transfer results was achieved for the e-fab stencil / Paste B / E-squeegee combination.

- The E-squeegee demonstrated the lowest squeegee pressure for all combinations except for Laser-Cut / Paste C.
- Paste B with the E-squeegee demonstrated the lowest squeegee pressure at .14 Kgms/cm.

- When comparing the five different squeegee blade types the E-squeegee provided the lowest squeegee pressure of any in the group.

- When comparing the residue paste left on the squeegee blade after printing it was found there is very little variation from blade to blade. The variation was 10 grams up to 17 grams. Even at 17 grams there was not nearly enough paste to get on the blade holder where it could be a problem.

References

(1) "Solder Paste Volume Studies for Measuring the Performance of electroformed and Laser Stencils" William E. Coleman, APEX Proceedings 2001

(2) "Stencil Printing Studies" William E. Coleman, APEX Proceedings 2001