

EVALUATION OF STENCIL FOIL MATERIALS, SUPPLIERS AND COATINGS

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ABSTRACT

The past few years have brought PCB assemblers a multitude of choices for SMT stencil materials and coatings. In addition to the traditional laser-cut stainless steel (SS) or electroformed nickel, choices now include SS that has been optimized for laser cutting, SS with smaller grain structures, and laser cut nickel. Available post-cutting processes include electropolishing and nano-coating.

Each option touts advantages over the others. To identify the best options for the real-world application of a highly miniaturized, very densely populated SMT product, an experiment was devised. It included different materials, manufacturing methods and suppliers. Stencils were tested in pairs in order to capture the effects of a new hydrophobic coating. The surface treatment was applied to one stencil of each pair, allowing for direct comparison of print performance with and without the coating.

Output variables included print yields, transfer efficiencies on 0.5mm BGAs and 0201s, volume repeatabilities on BGAs and 0201s, and dimensional accuracy of the stencils.

INTRODUCTION

The goal of stencil printing is to get the right amount of paste in the right location, every time. To support that goal, a number of analytical techniques are available to characterize, quantify, and monitor the inputs and outputs of the process. They are all based on the ability to accurately measure the volumes of individual solder paste deposits.

Paste deposit volumes can be measured by a variety of methods; the currently available best-in-class method uses structured white light in a process known as Moire, phase shift, or white light interferometry. Paste volume readings can then be manipulated in a variety of ways to analyze the process from different perspectives.

Basic statistics are calculated:

- Average (mean) volume
- Standard deviation of volume

Variability is examined:

- Coefficient of Variation (CV%), is the standard deviation expressed as a percent of the mean volume. Generally speaking, a CV of less than 10% indicates a repeatable process.
- Cpk, the process capability index, compares the process output to its control limits. Typical benchmarks include 1.33, 1.67 and 2.0, indicating 4, 5 and 6-sigma process quality, respectively.

The paste-stencil relationship is characterized:

- Aperture Area Ratio (AR), is calculated as the area of the aperture's PCB-side opening divided by the area of the aperture walls, and is an indicator of the relative adhesive forces on the solder paste deposit during separation from the stencil. As area ratios decrease, so does the amount of paste transferred. The minimum acceptable area ratio is often considered to be 0.66 for typical SMT purposes.
- Transfer Efficiency (TE), is the percentage of paste that is actually transferred to the PCB, as opposed to that left inside the stencil aperture.¹ It is calculated as the average paste deposit volume divided by the aperture's volume, and expressed as a percent. A common benchmark is 80% TE.

ARs and TE's may be either theoretical or actual. Theoretical ARs and TEs are calculated from the stencil specification, whereas actual ARs and TEs are based on actual measurements.

In addition to derived indices, production yields, when available, are the ultimate indicator of process capability and fitness for use.

- Print test yields are measured at the PCB level, not the per-deposit level. In the case of 10,000 deposits per print, all 10,000 must fall within their control limits.
- An output of 1 bad deposit and 9,999 good ones on a PCB would not be considered a 100 ppm process; it would be considered a zero yield process.

Each of these metrics can be applied to the stencil printing process to characterize the relationship between process inputs and outputs. In the following study, they are used to select the best stencil options for a high volume, production operation.

EXPERIMENTAL SETUP

Test Vehicle

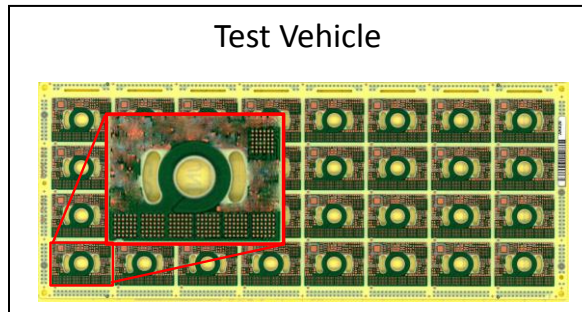


Figure 1. Test Vehicle (non-BGA circuitry on closeup is intentionally blurred)

The PCB shown in fig 1 is a typical high-volume production product. Each 32-up array measures approximately 3x7 inches, and has nearly 15,000 SMT pads. Of the 14,468 pads, roughly 8500 are mask-defined (SMD) BGA pads and 1900 are metal-defined (NSMD) 0201 pads. The same set of 10 PCBs were used for all tests.

For each stencil, 10 prints were taken, providing roughly 85,000 BGA paste deposit measurements and 19,000 0201 deposit measurements. The test prints were produced sequentially on a well maintained and calibrated 2009 DEK horizon stencil printer using, both front-to-back and back-to-front squeegee strokes, with an automatic dry wipe after each print. Print parameters were:

- Print speed: 15 mm/sec
- Print pressure: 5 kg (250mm blades)
- Separation speed: 20mm/sec

The solder paste used in all tests was Indium 3.2 HF Type 3, water soluble, lead-free, halogen-free, lot # 37310. Fresh paste was used on each stencil. The paste was not kneaded; 2 dummy prints were produced before measurements were taken. The 27 stencils were print tested in a climate controlled NPI manufacturing area over 5 different runs. During the tests the climate ranged from 23.0 to 25.5°C, and relative humidity ranged from 32.9 to 46.9%.

The PCB was supported with a flat, non-vacuum tooling plate and edge clamps. Deposit volume measurements were taken with a Koh Young 3030VAL.

Stencils

Each supplier was invited to submit stencils in pairs. One stencil was printed in the as-received condition; the other had a hydrophobic nanocoating applied before printing.

Suppliers A & D applied the coating at their sites, prior to shipping the stencils. The same coating product was applied to stencils provided by suppliers B & C after arriving at the Vicor facility.

Test Matrix

Four suppliers, coded A-D, submitted stencils in a variety of configurations. Materials, coded 1-5, included:

- Electroformed stencils (#1)
- Electroformed nickel foils that were laser cut (#2)
- Standard 301SS (#5)
- 304SS designed for laser cutting (#3)
- 301SS with modified grain size (#4)

Thicknesses of the foils included 0.0045” and 0.004”. The current production standard is 0.0045” laser cut nickel foils. 0.004” is under consideration because the preferred 0.0045” is not available in rolled steel.

Electropolished stencils were not tested in this evaluation, because not all suppliers provide electropolishing capability, and while electropolished apertures have been reported to release higher volumes of paste due to their rounded corners,² they have also reported to produce higher rates of variation in volume consistency.³

Table 1. Experimental Matrix

No.	Supplier	Material	Nano Coat	Thickness
1	A	4	N	4.0
2	B	2	N	4.0
3	B	2	Y	4.0
4	C	1	Y	4.5
5	A	4	Y	4.0
6	A	3	Y	4.0
7	A	3	N	4.0
8	B	1	Y	4.5
9	B	1	N	4.5
10	B	1	Y	4.0
11	B	1	N	4.0
12	C	2	N	4.5
13	C	2	Y	4.5
14	C	1	N	4.5
15	B	2	Y	4.5
16	B	2	N	4.5
17	D	1	Y	4.5
18	D	2	N	4.5
19	D	2	Y	4.5
20	D	3	N	4.0
21	D	3	Y	4.0
22	D	4	N	4.0
23	D	4	Y	4.0
24	D	5	N	4.0
25	D	5	Y	4.0
26	D	1	N	4.5
27	D	1	N	4.5

Not all suppliers provided all combinations of materials and thicknesses. The matrix of submitted and tested stencils is shown in table 1. The single unpaired stencil, labeled number 26, was an experimental run by one of the suppliers to investigate the effects of a process change.

RESULTS

Aperture Measurements

Table 2. Average Aperture measurement

Material	No.	Supplier	BGA Dia	0201 Width	0201 Length
1	4	C	10.1	11.0	13.1
	8	B	9.9	11.0	13.0
	9	B	10.0	11.1	13.1
	10	B	10.5	11.6	13.5
	11	B	10.4	11.4	13.3
	14	C	10.0	11.0	13.2
	17	D	9.5	10.7	12.7
	26	D	9.5	10.7	12.6
	27	D	9.4	10.6	12.5
2	2	B	10.2	11.1	13.1
	3	B	10.2	11.1	13.0
	12	C	9.9	10.9	12.9
	13	C	9.9	10.9	12.8
	15	B	10.1	11.0	13.0
	16	B	10.1	11.0	12.9
	18	D	10.4	11.3	13.2
	19	D	10.4	11.3	13.3
3	6	A	10.5	11.4	13.4
	7	A	10.5	11.4	13.3
	20	D	10.5	11.5	13.4
	21	D	10.5	11.5	13.4
4	1	A	10.5	11.5	13.5
	5	A	10.5	11.6	13.5
	22	D	10.5	11.5	13.4
	23	D	10.5	11.5	13.4
5	24	D	10.5	11.4	13.3
	25	D	10.4	11.4	13.3
		SPEC	10.8	11.8	13.8
		average	10.2	11.2	13.1

Thickness Measurements**Table 3.** Foil Thickness Measurements

Material	No.	Supplier	Thcknss Spec	Thcknss Avg	% Diff
1	4	C	4.5	5.5	23%
	8	B	4.5	4.3	6%
	9	B	4.5	4.5	0%
	10	B	4.0	4.4	9%
	11	B	4.0	3.9	2%
	14	C	4.5	5.6	24%
	17	D	4.5	4.4	3%
	26	D	4.5	4.4	2%
	27	D	4.5	4.4	3%
2	2	B	4.0	4.7	16%
	3	B	4.0	4.6	16%
	12	C	4.5	3.7	19%
	13	C	4.5	4.3	4%
	15	B	4.5	4.7	5%
	16	B	4.5	5.0	11%
	18	D	4.5	4.5	0%
3	6	A	4.0	4.0	0%
	7	A	4.0	4.0	0%
	20	D	4.0	4.1	1%
	21	D	4.0	4.0	0%
4	1	A	4.0	4.0	0%
	5	A	4.0	4.0	0%
	22	D	4.0	4.1	1%
	23	D	4.0	4.0	0%
5	24	D	4.0	4.0	0%
	25	D	4.0	4.1	2%

KEY:

0-3%

4-10%

>10%

To calculate actual transfer efficiencies and area ratios, the stencils' apertures and thicknesses were measured. The apertures were measured on the PCB side with a Microvue automated vision system; 20 of each aperture size were measured per stencil and the average is reported in table 2. The foil thicknesses were measured at all four corners of the print area with a Mitotoyo 12" throat micrometer; their averages are reported in table 3. The average figures reported in the tables are used to calculate the apertures' actual volumes and area ratios.

Paste Volumes**Table 4.** Paste volumes in cubic mils

Material	No.	Supplier	BGA Paste Volume	0201 Paste Volume
1	4	C	281	626
	8	B	306	667
	9	B	255	571
	10	B	241	588
	11	B	267	599
	14	C	290	619
	17	D	308	665
	26	D	312	691
	27	D	315	689
2	2	B	251	576
	3	B	267	608
	12	C	200	487
	13	C	185	454
	15	B	260	665
	16	B	293	642
	18	D	296	647
3	6	A	352	741
	7	A	320	665
	20	D	347	724
	21	D	293	622
4	1	A	306	670
	5	A	282	598
	22	D	339	711
	23	D	337	711
5	24	D	313	750
	25	D	321	635

The measured solder paste volumes, shown in table 4, are the averages of the individual measurements for each feature. Standard deviations and coefficients of variation were also calculated but not shown. Most CVs for the BGAs were less than 10%; the highest CVs were 16%.

Transfer Efficiencies

Table 5. Theoretical and actual transfer efficiencies

Material	No.	Supplier	BGA Transfer Efficiency			0201 Transfer Efficiency		
			Theo	Act	Diff	Theo2	Act2	Diff2
1	4	C	68%	55%	-13%	85%	91%	6%
	8	B	74%	96%	22%	91%	121%	30%
	9	B	62%	90%	28%	78%	113%	35%
	10	B	66%	67%	1%	90%	95%	5%
	11	B	73%	81%	8%	92%	109%	17%
	14	C	70%	59%	-11%	84%	91%	6%
	17	D	75%	85%	11%	91%	125%	34%
	26	D	76%	101%	25%	94%	124%	30%
2	27	D	77%	106%	29%	94%	127%	33%
	2	B	68%	81%	13%	88%	97%	8%
	3	B	73%	68%	-5%	93%	98%	5%
	12	C	49%	72%	23%	66%	143%	76%
	13	C	45%	56%	11%	62%	122%	60%
	15	B	63%	77%	14%	91%	109%	18%
	16	B	71%	75%	4%	88%	104%	16%
	18	D	72%	93%	21%	88%	109%	21%
3	19	D	64%	84%	20%	87%	108%	22%
	6	A	96%	83%	-13%	114%	106%	-7%
	7	A	87%	89%	2%	102%	107%	5%
	20	D	95%	98%	4%	111%	105%	-6%
4	21	D	80%	84%	4%	95%	106%	11%
	1	A	84%	81%	-2%	103%	105%	3%
	5	A	77%	77%	0%	92%	104%	13%
	22	D	93%	87%	-5%	109%	105%	-4%
5	23	D	92%	81%	-11%	109%	106%	-3%
	24	D	85%	98%	13%	115%	108%	-7%
	25	D	88%	96%	8%	97%	104%	7%

Actual TEs were calculated. The aperture volumes used in the TE calculations are based on the averages of the measured aperture sizes and foil thickness. The use of the actual sizes versus theoretical sizes was essential to this analysis, which compares different stencils. Print studies that use the same stencil throughout, i.e. those that examine pastes or print parameters, can usually use theoretical area ratios and transfer efficiencies, because the stencil remains constant and any deviation in the stencil will apply equally to all measurements. When different stencils with varying dimensions are used, however, measured values are necessary to properly characterize their behavior. Table 5 shows the differences between theoretical and actual transfer efficiencies for the stencils used in this study, and illustrates the necessity of using measured values to get accurate results.

Transfer Efficiencies, Cpks and Yields

Table 6 shows the ARs, TEs and Cpks for the BGA and 0201 components, and the overall print yields.

The Cpks are based on the theoretical aperture volumes and the following control limits:

- BGA: 20 to 139% of theoretical volume
- 0201: 50 – 200% of theoretical volume

Yields are based on the ten print tests used to gather the volume data. Each print counts as 10% of the yield.

Table 6. Transfer efficiencies, Cpks, and Yields

Stencil No.	Stencil Type	Component	AR	TE	BGA Cpk	0201 Cpk	YIELD
1	3 - A not coated	BGA 0201	0.66 0.77	81% 106%	3.15	2.13	100
2	2 - B not coated	BGA 0201	0.55 0.64	81% 97%	3.34	2.18	80
3	2 - B coated	BGA 0201	0.55 0.65	68% 98%	2.94	1.7	80
4	1 - C coated	BGA 0201	0.46 0.54	55% 91%	1.94	1.71	0
5	3 - A coated	BGA 0201	0.66 0.78	77% 105%	3.01	2.03	100
6	4 - A coated	BGA 0201	0.66 0.77	83% 106%	3.44	2.06	100
7	4 - A not coated	BGA 0201	0.65 0.77	89% 107%	3.7	2.3	80
8	1 - B coated	BGA 0201	0.58 0.70	96% 121%	3.85	2.55	100
9	1 - B not coated	BGA 0201	0.55 0.67	90% 113%	3.63	2.24	70
10	1 - B coated	BGA 0201	0.60 0.71	67% 95%	3.8	1.68	100
11	1 - B not coated	BGA 0201	0.66 0.78	81% 109%	2.75	1.85	30
12	2 - C not coated	BGA 0201	0.68 0.81	72% 143%	2.26	0.97	60
13	2 - C coated	BGA 0201	0.58 0.69	56% 122%	2.04	0.79	100
14	1 - C not coated	BGA 0201	0.45 0.54	59% 91%	2.27	1.88	0
15	2 - B coated	BGA 0201	0.54 0.63	77% 109%	3.25	2.3	40
16	2 - B not coated	BGA 0201	0.51 0.59	75% 104%	3.25	2.23	20
17	1 - D coated	BGA 0201	0.55 0.67	85% 125%	2.88	1.92	10
18	2 - D not coated	BGA 0201	0.58 0.68	93% 109%	2.75	2.59	0
19	2 - D coated	BGA 0201	0.58 0.68	84% 108%	2.04	2.37	60
20	4 - D not coated	BGA 0201	0.65 0.76	98% 105%	3.02	2.36	60
21	4 - D coated	BGA 0201	0.66 0.77	84% 106%	3.11	1.91	100
22	3 - D not coated	BGA 0201	0.65 0.76	87% 105%	3.21	2.04	30
23	3 - D coated	BGA 0201	0.66 0.77	81% 106%	2.97	1.76	100
24	5 - D not coated	BGA 0201	0.66 0.77	98% 107%	3.17	2.32	80
25	5 - D coated	BGA 0201	0.64 0.75	96% 104%	3.27	2.28	90
26	1 - D* not coated	BGA 0201	0.54 0.66	101% 124%	3.17	2.29	10
27	1 - D not coated	BGA 0201	0.54 0.66	106% 127%	3.34	2.25	20

OBSERVATIONS

Dimensional accuracy

The measurements shown in tables 2 and 3 are grouped by material type. The electroformed stencils exhibited the greatest amount of variation in aperture size, with a range of approximately 0.001"; the laser cut nickel foils showed about half that at 0.0005", and the laser cut SS foils showed about one-tenth the size variation of the electroformed apertures, with a 0.0001" spread from smallest to largest measured sizes.

Thickness variation also trended with material type. The electroformed foils showed more thickness variation than the rolled foils. Of the electroformed stencils, supplier C's foils showed the greatest deviation from its specification, measuring almost 25% thicker than desired. Of the electroformed foils that were laser cut, both supplier B's and C's submissions showed considerable deviation from the specification (4–19%). Supplier D's stencils did not demonstrate as much thickness variation in the electroformed materials as the other electroformed samples. Supplier A did not submit any electroformed samples. All SS foils showed extremely low thickness variation.

Positional accuracy was not measured on the stencils, but paste print offsets were measured and recorded as part of the solder paste inspection routine.

Transfer Efficiencies and Area Ratios

Plotting TE against Area Ratio (AR) is an industry-accepted method of measuring the release characteristics of a stencil. For all stencils, the two data points generated by the BGA and 0201 measurements form the endpoints of the trend line and the basis for the comparison. The BGA ARs are designed to be in the 0.60 to 0.66 range, depending on foil thickness; the 0201 ARs are designed to be in the 0.71 to 0.80 range, again depending on foil thickness.

All the data was plotted and reviewed. The more notable comparisons include:

- Comparisons of release performance with and without surface coatings
- Comparisons of two specialized stainless steel alloys
- Comparison of electroformed and laser cut nickel stencils

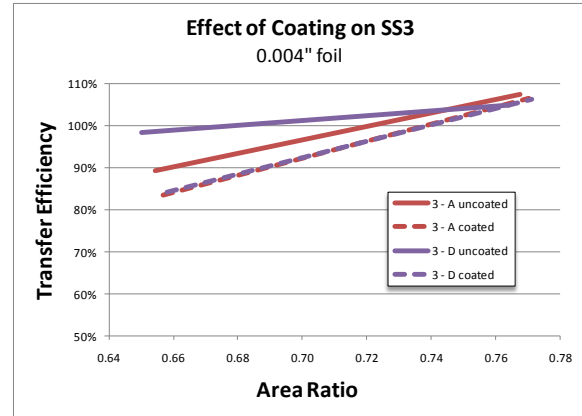


Figure 2. Comparison of print performance of SS #3 stencils from two suppliers with and without coating

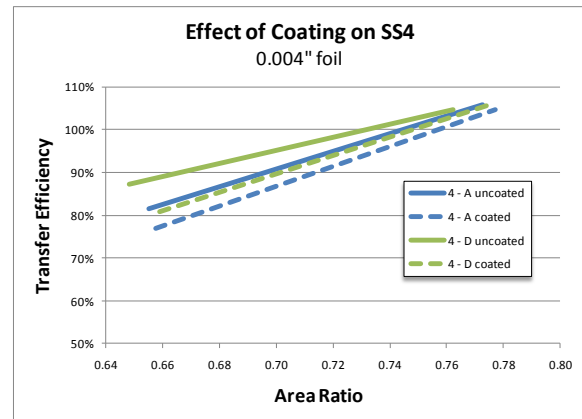


Figure 3. Comparison of print performance of SS #4 stencils from two suppliers with and without coating

When comparing the release characteristics of each stencil, performance differentiation is noted for the low area ratios associated with the BGA, but the release properties all appear to converge at the higher area ratios associated with the 0201s. This trend was seen in all data sets.

Also seen in all datasets were the slightly lower transfer efficiencies of the coated stencils on the low AR (BGA) deposits, regardless of the material type, as seen in figures 2 and 3. This trend appears to counter popular beliefs about the coating's ability to improve transfer efficiency, but is consistent on all 13 pairs of stencil tests.

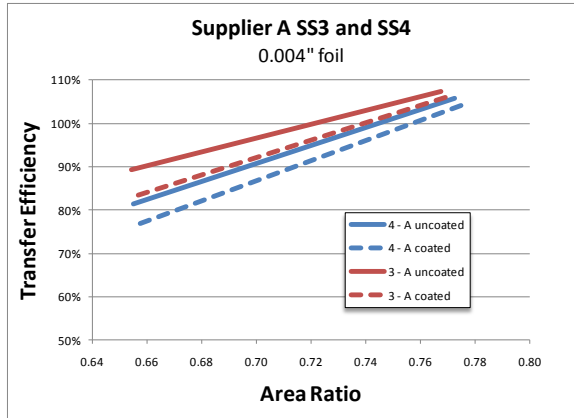


Figure 4. Comparison of print performance of SS #3 and SS #4 from same supplier

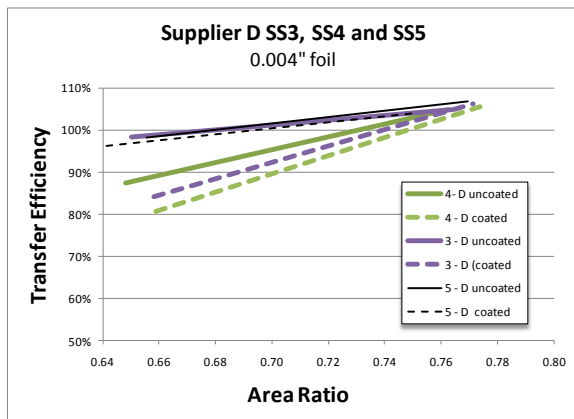


Figure 5. Comparison of three types of SS from the same supplier

Of the two specialized stainless steels, the one with the smaller grain size did not appear to release as much material as the one with the coarser grain size. Replotting the data by supplier (figures 4 and 5) shows the trend more clearly. Regardless of the stencil provider, the foils with the larger grain size released approximately 10% more solder paste than the stencil with the smaller grain size, and stencils without coatings released 8-10% more than stencils with coatings. Supplier D also submitted a pair of stencils produced with non-specialized SS alloy. Its performance is plotted with the specialized foil alloys in figure X. It appears to perform as well as one of the specialized alloys, regardless of coating.

Due to their relatively larger AR differences, the electroformed foils cannot be compared as directly as the steel foils, but provide interesting observations when plotted.

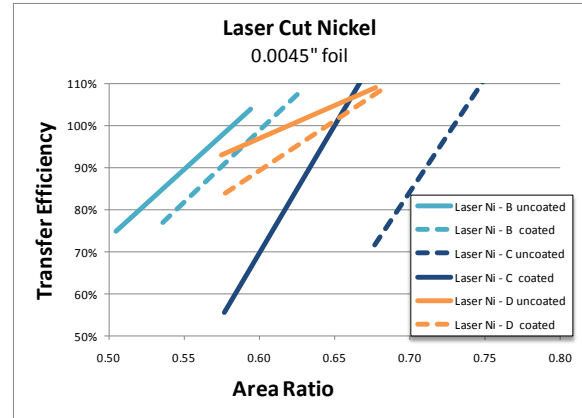


Figure 6. Comparison of print performance of laser cut nickel foils from three different suppliers

Thickness variation in pairs of stencils is the primary driver for differing ARs on submissions from suppliers B and C, as seen in figure 6. Supplier C's 0.0045" foils measured 0.0047" and 0.0050"; supplier B's measured 0.0037" and 0.0043". Consistent thickness on supplier D's stencils maintained very close AR's between the two foils. Again, at similar area ratios, the uncoated stencil appears to stencil release more solder paste than the coated one.

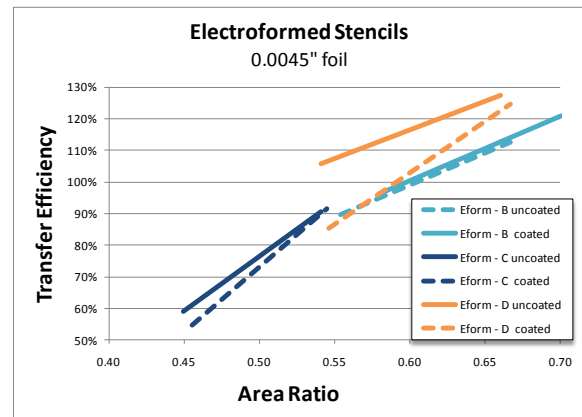


Figure 7. Comparison of print performance of electroformed stencils from three different suppliers.

As with the laser-cut nickel stencils, varying foil thicknesses drove varying AR's. Both of supplier C's stencils measured about 0.001" too thick, and their apertures measured nearly 0.001" too small, driving area ratios down to the 0.45 range, which is considered unacceptable. Supplier B's stencil thicknesses also varied; one measured 0.0002" thicker than the other, creating the AR offset seen in figure 7. A similar offset due to a 0.0005" thickness difference was also observed on the same supplier's 0.004" electroformed stencils. Again, supplier D's foils showed very little variation, and followed trends

similar to the SS foils with respect to transfer efficiency differences between coated and uncoated foils on BGA ARs.

The electroformed foils, despite having low area ratios, appeared to deposit more volume than expected, exhibiting 100% or better transfer efficiency for a BGA with an AR of 0.55 and >120% for 0201s with ARs of 0.65. Those are relatively high numbers that merited further investigation. A potential reason for the excess volumes could be poor gasketing between stencil and the PCB caused by misalignment, so positional accuracy of the prints from suppliers C & D was queried in the SPI database.

Table 7. Average print offsets

Stencil No.	Stencil Type	Offset X (in)	Offset Y (in)
23	4-D	-0.0001	-0.0013
22	4-D	0.0005	-0.0007
21	3-D	0.0004	-0.0006
20	3-D	0.0006	-0.0005
25	5-D	0.0007	-0.0008
24	5-D	0.0004	-0.0006
17	Eform - D	0.0004	-0.0017
26	Eform - D	-0.0001	-0.0011
19	Laser Ni - D	0.0004	-0.0006
18	Laser Ni - D	0.0005	-0.0001
10	Eform - B	0.0018	-0.0018
11	Eform - B	0.0016	-0.0017
8	Eform - B	0.0006	-0.0021
9	Eform - B	0.0005	-0.0020
15	Laser Ni - B	-0.0001	-0.0020
16	Laser Ni - B	0.0001	-0.0023
3	Laser Ni - B	0.0004	0.0000
2	Laser Ni - B	0.0003	-0.0007

Table 7 shows the average print offset of stencils as reported by the SPI machine. The majority of the prints from the SS stencils are displaced from the centers of their pads by less than 0.001". The electroformed stencils' prints are all displaced by more than 0.001"; half of them are displaced by 0.002" or more. While the measured positional offsets are not conclusively the root cause of excessively high solder volumes, it is probable that an average aperture-pad misalignment of 0.002" would cause excessive paste to be deposited on the PCBs. Note that supplier C's stencils are not included in this portion of the analysis; the products were eliminated from contention prior to the investigation of positional accuracy.

Process Capabilities

Most of the stencils tested produced acceptable Cpk's based on the control limits used in production. BGA Cpk's were all above 1.67. All 0201 Cpk's, except those associated with a pair of laser-cut nickel stencils from supplier C, also met the 5-sigma threshold.

Yields

Table 8. Yield comparison

Stencil No.	Stencil Type	Component	AR	TE	BGA Cpk	0201 Cpk	YIELD
8	1 - B coated	BGA 0201	0.58 0.70	96% 121%	3.85	2.55	100
9	1 - B not coated	BGA 0201	0.55 0.67	90% 113%	3.63	2.24	70
10	1 - B coated	BGA 0201	0.60 0.71	67% 95%	3.8	1.68	100
11	1 - B not coated	BGA 0201	0.66 0.78	81% 109%	2.75	1.85	30
4	1 - C coated	BGA 0201	0.46 0.54	55% 91%	1.94	1.71	0
14	1 - C not coated	BGA 0201	0.45 0.54	59% 91%	2.27	1.88	0
17	1 - D coated	BGA 0201	0.55 0.67	85% 125%	2.88	1.92	10
27	1 - D not coated	BGA 0201	0.54 0.66	106% 127%	3.34	2.25	20
3	2 - B coated	BGA 0201	0.55 0.65	68% 98%	2.94	1.7	80
2	2 - B not coated	BGA 0201	0.55 0.64	81% 97%	3.34	2.18	80
15	2 - B coated	BGA 0201	0.54 0.63	77% 109%	3.25	2.3	40
16	2 - B not coated	BGA 0201	0.51 0.59	75% 104%	3.25	2.23	20
13	2 - C coated	BGA 0201	0.58 0.69	56% 122%	2.04	0.79	100
12	2 - C not coated	BGA 0201	0.68 0.81	72% 143%	2.26	0.97	60
19	2 - D coated	BGA 0201	0.58 0.68	84% 108%	2.04	2.37	60
18	2 - D not coated	BGA 0201	0.58 0.68	93% 109%	2.75	2.59	0
5	3 - A coated	BGA 0201	0.66 0.78	77% 105%	3.01	2.03	100
1	3 - A not coated	BGA 0201	0.66 0.77	81% 106%	3.15	2.13	100
23	3 - D coated	BGA 0201	0.66 0.77	81% 106%	2.97	1.76	100
22	3 - D not coated	BGA 0201	0.65 0.76	87% 105%	3.21	2.04	30
6	4 - A coated	BGA 0201	0.66 0.77	83% 106%	3.44	2.06	100
7	4 - A not coated	BGA 0201	0.65 0.77	89% 107%	3.7	2.3	80
21	4 - D coated	BGA 0201	0.66 0.77	84% 106%	3.11	1.91	100
20	4 - D not coated	BGA 0201	0.65 0.76	98% 105%	3.02	2.36	60
25	5 - D coated	BGA 0201	0.64 0.75	96% 104%	3.27	2.28	90
24	5 - D not coated	BGA 0201	0.66 0.77	98% 107%	3.17	2.32	80

Table 8 orders the stencils to allow for easy comparison of like pairs. Of the 13 pairs of stencils that were compared, 7 of the coated ones produced 100% yields, while only 1 of the uncoated ones produced the same.

In 11 of 13 cases, the coated stencils produced higher yields than uncoated stencils. The only situations where the coating did not improve yields were on poorly formed stencils with ARs below 0.55 and yields at 20% or lower.

DISCUSSION AND CONCLUSIONS

The stencil technology selected for this production operation is stainless steel with two-part nanocoating applied. Only small differences were noted between types of SS and suppliers in terms of print volumes and transfer efficiencies, but substantial yield improvements were observed on stencils with the surface treatment.

The SS foils offered the best dimensional accuracy. Electroformed nickel foils and stencils varied considerably more than SS in both thickness and aperture size. The positional accuracy of the electroformed stencils also appears poorer than that of the SS stencils, introducing more alignment error into the printing process.

The overall print performance of the SS foils were better than that of the electroformed ones. The actual differences between the optimized SS with different grain sizes need to be further quantified, as the experimental results from them are very close.

Nanocoatings did not improve the transfer efficiency of small apertures with area ratios in the 0.6 to 0.66 range. In fact, all the stencils with the coatings released less paste at this AR than their uncoated counterparts. The paste release for ARs in the 0.70 - 0.80 range were similar with and without the coatings. Nanocoatings improved yields dramatically. The improvement in yields afforded by the coated stencils equates to an undeniable boost in productivity.

The slightly lower transfer efficiencies of coated stencils, and of specialized stainless steel has not been investigated. It is speculated that crisper print definition may account for the small differentials, but no formal analysis has been performed to date.

Concerns of depositing adequate solder volume with a thinner stencil were addressed. Laser-cut nickel stencils with 0.0045" foil thicknesses deposited an average of 250 cubic mils, whereas the SS stencils

with 0.004" foil thicknesses deposited an average of 322 cubic mils. Furthermore, the 0.004" SS stencils showed less variation in the volumes than the laser-cut nickel stencils. 0.004" SS foils with modified grain size and surface coating are now used in production for assembly of the test vehicle PCB and many similar products.

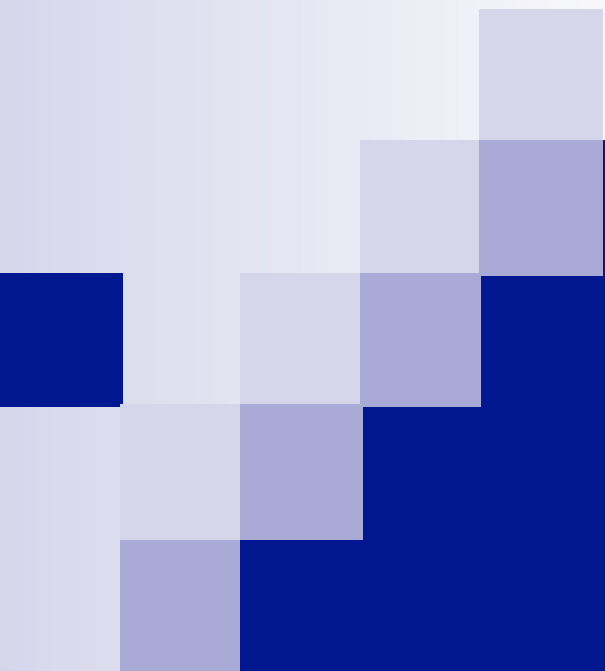
ACKNOWLEDGEMENTS

The authors would like to thank the four stencil providers for their participation in this study. They would also like to recognize their colleagues who assisted in executing the tests:

- Karan Barabde
- John Zalaket

REFERENCES

- [1] Shea, C., et al, "Characterizing Transfer Efficiencies and the Fine Feature Stencil Printing Process," Proceedings of SMTA International, 2005
- [2] Mohanty, R., et al, "Effect of Nano Coated Stencil on 01005 Printing," Proceedings of IPC-APEX 2011
- [3] Shea, C. et al, "Quantitative Evaluation of New Stencil Materials," Proceedings of IPC-APEX 2011

A decorative graphic on the left side of the slide consisting of several overlapping squares in various shades of blue and purple, arranged in a stepped, staircase-like pattern.

Evaluation of Stencil Foil Materials, Suppliers and Coating

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Agenda

- **Introduction & New Technology**
- **Stencil Selection Experiment**
- **Measurement and Analysis Methods**
- **Results & Discussion**
- **Questions**



Advances in SMT Stencil Technology

■ Materials

- ☒ Stainless steel optimized for laser cutting
- ☒ Stainless steel with smaller grain size
- ☒ Electroformed nickel

■ Laser Cutters

- ☐ New models offer more control over cutting params

■ Nano-coatings

- ☐ Applied only by stencil manufacturer
- ☒ Applied by manufacturer or user

The Experiment

- All about the stencils

- ☐ 4 suppliers
- ☐ 4 material/manufacturing methods
- ☐ 2 thicknesses
- ☐ Nano-coating Y or N

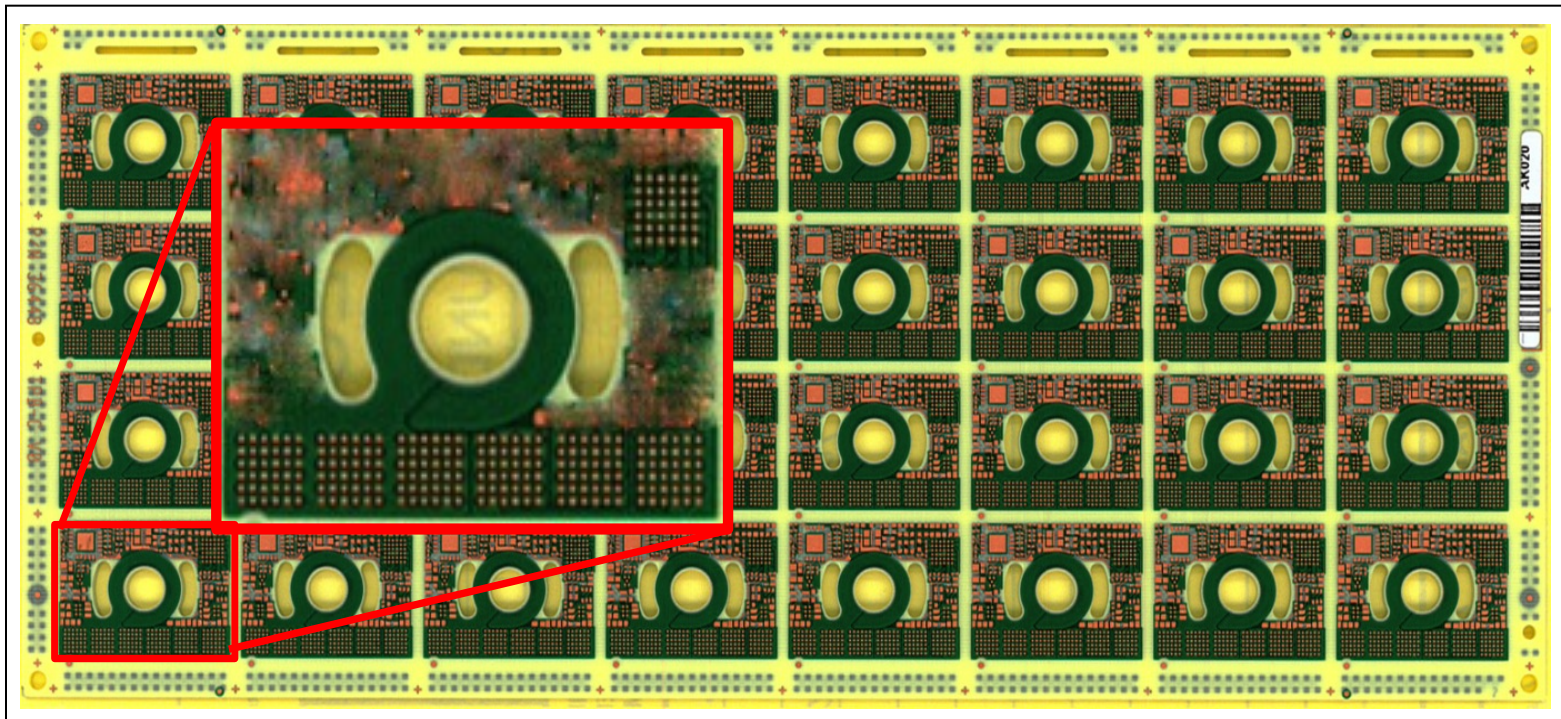
- Tests used:

- Same lot of water-soluble, lead-free, halide free solder paste, fresh for each stencil with 2 dummy prints
- Same 10 PCBs
- 10 consecutive prints off of same printer and tooling
- Koh Young 3030VAL to measure print volumes

Objective: *Identify the best stencil technology for production of densely populated SMT assemblies*

Test Vehicle

- Production PCB
- 32-up panel
- 3" x 7"
- 14,468 pads
- 8500 BGA pads
- 1900 0201 pads



(non-BGA pads intentionally blurred)



Materials/Mfg Process

■ Materials

- Fully electroformed foils and apertures
- Electroformed nickel with laser cut apertures
- “Premium” 304SS designed for laser cutting
- “Premium” 301SS with finer grain structures
- “Standard” 301SS (1 set, control)

■ Thicknesses

- Eform & Laser Ni: 4.0 and 4.5mils
- SS: 4.0 mils only

Experimental Matrix

- Suppliers invited to submit as many samples as they wanted
- Not a full factorial
- Test stencils submitted in pairs; nano-coating applied to one of each pair
- Tested over five sessions on NPI line
- Foil thicknesses and aperture size measurements recorded

No.	Supplier	Material	Nano Coat	Thickness
1	A	4	N	4.0
2	B	2	N	4.0
3	B	2	Y	4.0
4	C	1	Y	4.5
5	A	4	Y	4.0
6	A	3	Y	4.0
7	A	3	N	4.0
8	B	1	Y	4.5
9	B	1	N	4.5
10	B	1	Y	4.0
11	B	1	N	4.0
12	C	2	N	4.5
13	C	2	Y	4.5
14	C	1	N	4.5
15	B	2	Y	4.5
16	B	2	N	4.5
17	D	1	Y	4.5
18	D	2	N	4.5
19	D	2	Y	4.5
20	D	3	N	4.0
21	D	3	Y	4.0
22	D	4	N	4.0
23	D	4	Y	4.0
24	D	5	N	4.0
25	D	5	Y	4.0
26	D	1	N	4.5
27	D	1	N	4.5



Basic Metrics in Stencil Printing

- Based on measured deposit volumes
- Simple statistics
 - Mean
 - Standard deviation
 - CV% (std deviation as % of mean)
- Process measurements
 - Cpk
 - Yield
- Paste Transfer Efficiency
- Aperture Area Ratio

Transfer Efficiency & Area Ratio

Transfer Efficiency, TE

$$\% \text{ TE} = \left[\frac{\text{Volume of paste deposited}}{\text{Volume of stencil aperture}} \right] \times 100$$

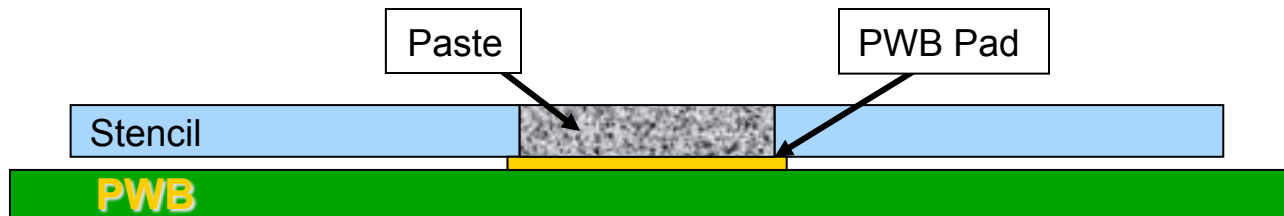
Area Ratio, AR

$$\text{AR} = \frac{\text{Area of circuit side opening}}{\text{Area of aperture walls}}$$

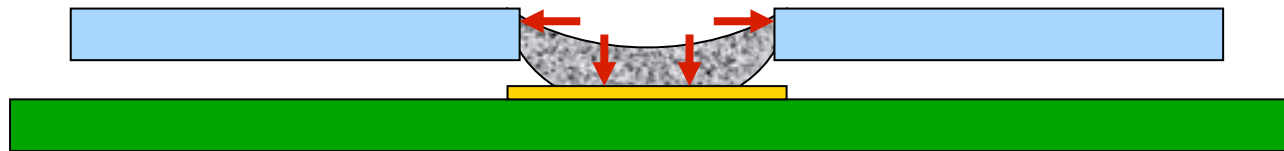
ARs and TEs can be *theoretical* or *actual*:

- Theoretical are based on specified dimensions
 - Sufficient for paste or print parameter tests that use the same stencil
- Actual are based on measured dimensions
 - Needed when different stencils are used
 - Shortcut AR formula: **AR = D/4t**
where D = circle's dia or square's side, t = foil thickness

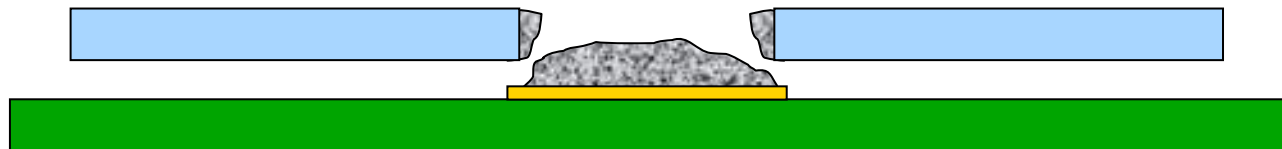
Transfer Efficiency & Area Ratio



After the aperture is filled, the solder paste sets up and sticks to both the stencil walls and the pads.



At separation, the forces holding the deposit to the pad must overcome the forces holding the deposit to the stencil walls



Depending on area ratio, a portion of the paste will release to the PWB, while some will stay in the aperture

The smaller the AR, the lower the TE



Results

Foil Thickness

Material	No.	Supplier	Thcknss Spec	Thcknss Avg	% Diff
1	4	C	4.5	5.5	23%
	8	B	4.5	4.3	6%
	9	B	4.5	4.5	0%
	10	B	4.0	4.4	9%
	11	B	4.0	3.9	2%
	14	C	4.5	5.6	24%
	17	D	4.5	4.4	3%
	26	D	4.5	4.4	2%
	27	D	4.5	4.4	3%
2	2	B	4.0	4.7	16%
	3	B	4.0	4.6	16%
	12	C	4.5	3.7	19%
	13	C	4.5	4.3	4%
	15	B	4.5	4.7	5%
	16	B	4.5	5.0	11%
	18	D	4.5	4.5	0%
	19	D	4.5	4.5	0%
3	6	A	4.0	4.0	0%
	7	A	4.0	4.0	0%
	20	D	4.0	4.1	1%
	21	D	4.0	4.0	0%
4	1	A	4.0	4.0	0%
	5	A	4.0	4.0	0%
	22	D	4.0	4.1	1%
	23	D	4.0	4.0	0%
5	24	D	4.0	4.0	0%
	25	D	4.0	4.1	2%

KEY:

0-3%

4-10%

>10%

■ Measured at four corners of print area

■ Materials:

□ 1: Electroform

□ 2: Laser Ni

□ 3: 304SS, premium

□ 4: 301SS, premium, smaller grain

□ 5: 301SS standard

■ Greatest thickness variations seen in electroformed foils and from suppliers B and C

Aperture Sizes

- 20 of each aperture size were measured

- Averages in table

- Laser cut SS had best aperture size accuracy

- Electroformed had the worst size accuracy

- Laser Ni mixed

- Suppliers A and D most repeatable

Material	No.	Supplier	BGA Dia	0201 Width	0201 Length
1	4	C	10.1	11.0	13.1
	8	B	9.9	11.0	13.0
	9	B	10.0	11.1	13.1
	10	B	10.5	11.6	13.5
	11	B	10.4	11.4	13.3
	14	C	10.0	11.0	13.2
	17	D	9.5	10.7	12.7
	26	D	9.5	10.7	12.6
	27	D	9.4	10.6	12.5
2	2	B	10.2	11.1	13.1
	3	B	10.2	11.1	13.0
	12	C	9.9	10.9	12.9
	13	C	9.9	10.9	12.8
	15	B	10.1	11.0	13.0
	16	B	10.1	11.0	12.9
	18	D	10.4	11.3	13.2
	19	D	10.4	11.3	13.3
3	6	A	10.5	11.4	13.4
	7	A	10.5	11.4	13.3
	20	D	10.5	11.5	13.4
	21	D	10.5	11.5	13.4
4	1	A	10.5	11.5	13.5
	5	A	10.5	11.6	13.5
	22	D	10.5	11.5	13.4
	23	D	10.5	11.5	13.4
5	24	D	10.5	11.4	13.3
	25	D	10.4	11.4	13.3
SPEC			10.8	11.8	13.8
average			10.2	11.2	13.1

Paste Volumes

Material	No.	Supplier	BGA Paste Volume	0201 Paste Volume
1	4	C	281	626
	8	B	306	667
	9	B	255	571
	10	B	241	588
	11	B	267	599
	14	C	290	619
	17	D	308	665
	26	D	312	691
	27	D	315	689
2	2	B	251	576
	3	B	267	608
	12	C	200	487
	13	C	185	454
	15	B	260	665
	16	B	293	642
	18	D	296	647
	19	D	263	635
3	6	A	352	741
	7	A	320	665
	20	D	347	724
	21	D	293	622
4	1	A	306	670
	5	A	282	598
	22	D	339	711
	23	D	337	711
5	24	D	313	750
	25	D	321	635

- Each value is the average of 85,000 BGA deposit volumes and 19,000 0201 deposit volumes
- 2 factors contribute to the volume variations in materials 1 and 2:
 - 2 different specified stencil thicknesses; 4.0 and 4.5
 - Thickness and aperture size deviations from spec
- All SS had consistent foil thicknesses and aperture sizes; SS volumes are very consistent.

Actual vs. Theoretical TE

Material	No.	Supplier	BGA Transfer Efficiency			0201 Transfer Efficiency		
			Theo	Act	Diff	Theo2	Act2	Diff2
1	4	C	68%	55%	-13%	85%	91%	6%
	8	B	74%	96%	22%	91%	121%	30%
	9	B	62%	90%	28%	78%	113%	35%
	10	B	66%	67%	1%	90%	95%	5%
	11	B	73%	81%	8%	92%	109%	17%
	14	C	70%	59%	-11%	84%	91%	6%
	17	D	75%	85%	11%	91%	125%	34%
	26	D	76%	101%	25%	94%	124%	30%
	27	D	77%	106%	29%	94%	127%	33%
2	2	B	68%	81%	13%	88%	97%	8%
	3	B	73%	68%	-5%	93%	98%	5%
	12	C	49%	72%	23%	66%	143%	76%
	13	C	45%	56%	11%	62%	122%	60%
	15	B	63%	77%	14%	91%	109%	18%
	16	B	71%	75%	4%	88%	104%	16%
	18	D	72%	93%	21%	88%	109%	21%
	19	D	64%	84%	20%	87%	108%	22%
3	6	A	96%	83%	-13%	114%	106%	-7%
	7	A	87%	89%	2%	102%	107%	5%
	20	D	95%	98%	4%	111%	105%	-6%
	21	D	80%	84%	4%	95%	106%	11%
4	1	A	84%	81%	-2%	103%	105%	3%
	5	A	77%	77%	0%	92%	104%	13%
	22	D	93%	87%	-5%	109%	105%	-4%
	23	D	92%	81%	-11%	109%	106%	-3%
5	24	D	85%	98%	13%	115%	108%	-7%
	25	D	88%	96%	8%	97%	104%	7%

■ Actual varies from theoretical by:

■ -13% to + 13% for laser cut SS

■ -5% to +76% for laser cut Ni

■ -13% to +35% for Eform

■ Small deviations in aperture size and foil thickness make big deviations in volumes, area ratios and TEs.



Nano-Coating

- Material

- ☐ 2-part system that can be applied by stencil supplier or user
- ☐ Applied to stencils from suppliers A and D at their manufacturing facility
- ☐ Applied to stencils from suppliers B and C at Vicor manufacturing facility

- Evaluated TEs, Cpks and print yields

Nano-Coating: TEs, Cpks, Yields

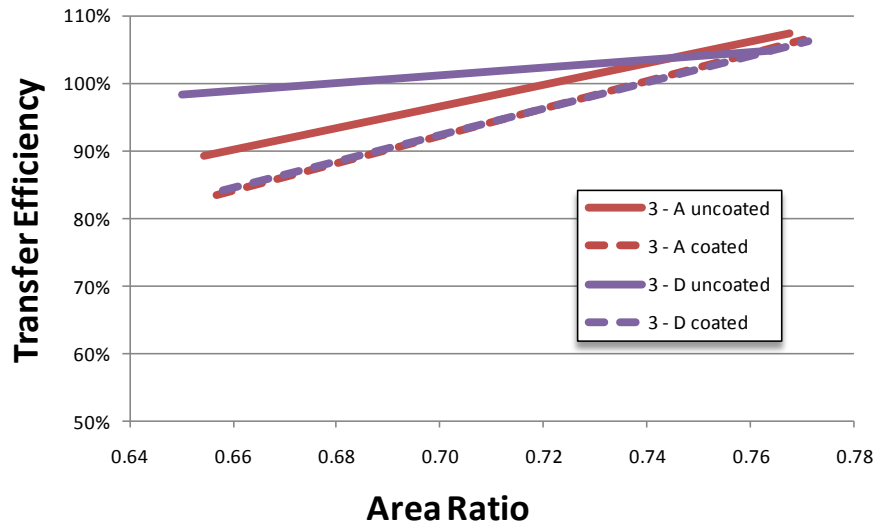
Stencil Stencil No. Component Actual AR Actual TE BGA Cpk 0201 Cpk YIELD	1 - B coated		1 - B not coated		1 - B coated		1 - B not coated		1 - C coated		1 - C not coated		1 - D coated		1 - D not coated		← E-form
	8		9		10		11		4		14		17		27		
	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	
	0.58	0.70	0.55	0.67	0.60	0.71	0.66	0.78	0.46	0.54	0.45	0.54	0.55	0.67	0.54	0.66	
	96%	121%	90%	113%	67%	95%	81%	109%	55%	91%	59%	91%	85%	125%	106%	127%	
	3.85		3.63		3.8		2.75		1.94		2.27		2.88		3.34		
	2.55		2.24		1.68		1.85		1.71		1.88		1.92		2.25		
	100		70		100		30		0		0		10		20		

Stencil Stencil No. Component Actual AR Actual TE BGA Cpk 0201 Cpk YIELD	2 - B coated		2 - B not coated		2 - B coated		2 - B not coated		2 - C coated		2 - C not coated		2 - D coated		2 - D not coated		←Laser Ni
	3		2		15		16		13		12		19		18		
	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	
	0.55	0.65	0.55	0.64	0.54	0.63	0.51	0.59	0.58	0.69	0.68	0.81	0.58	0.68	0.58	0.68	
	68%	98%	81%	97%	77%	109%	75%	104%	56%	122%	72%	143%	84%	108%	93%	109%	
	2.94		3.34		3.25		3.25		2.04		2.26		2.04		2.75		
	1.7		2.18		2.3		2.23		0.79		0.97		2.37		2.59		
	80		80		40		20		100		60		60		0		
																	SS

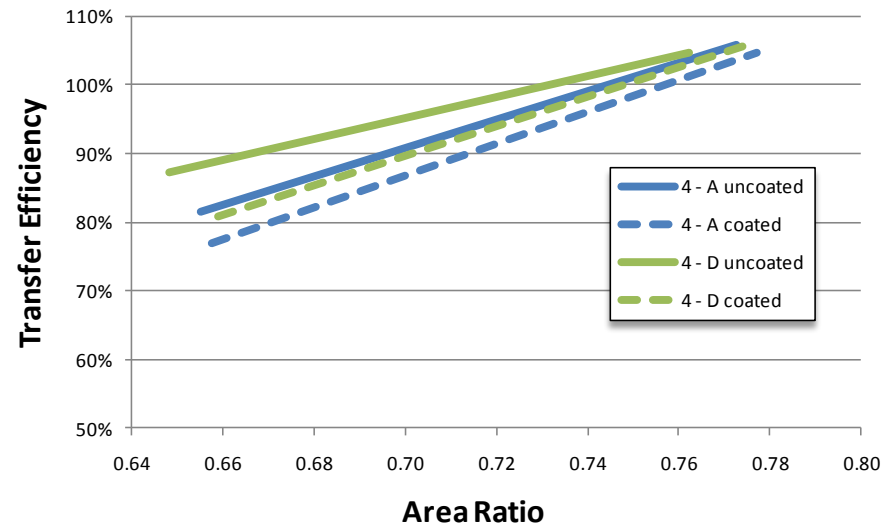
Stencil Stencil No. Component Actual AR Actual TE BGA Cpk 0201 Cpk YIELD	3 - A coated		3 - A not coated		3 - D coated		3 - D not coated		4 - A coated		4 - A not coated		4 - D coated		4 - D not coated		5 - D coated		5 - D not coated	
	5		1		23		22		6		7		21		20		25		24	
	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201
	0.66	0.78	0.66	0.77	0.66	0.77	0.65	0.76	0.66	0.77	0.65	0.77	0.66	0.77	0.65	0.76	0.64	0.75	0.66	0.77
	77%	105%	81%	106%	81%	106%	87%	105%	83%	106%	89%	107%	84%	106%	98%	105%	96%	104%	98%	107%
	3.01		3.15		2.97		3.21		3.44		3.7		3.11		3.02		3.27		3.17	
	2.03		2.13		1.76		2.04		2.06		2.3		1.91		2.36		2.28		2.32	
	100		100		100		30		100		80		100		60		90		80	

Did the Coating Improve TE?

Effect of Coating on SS3
0.004" foil



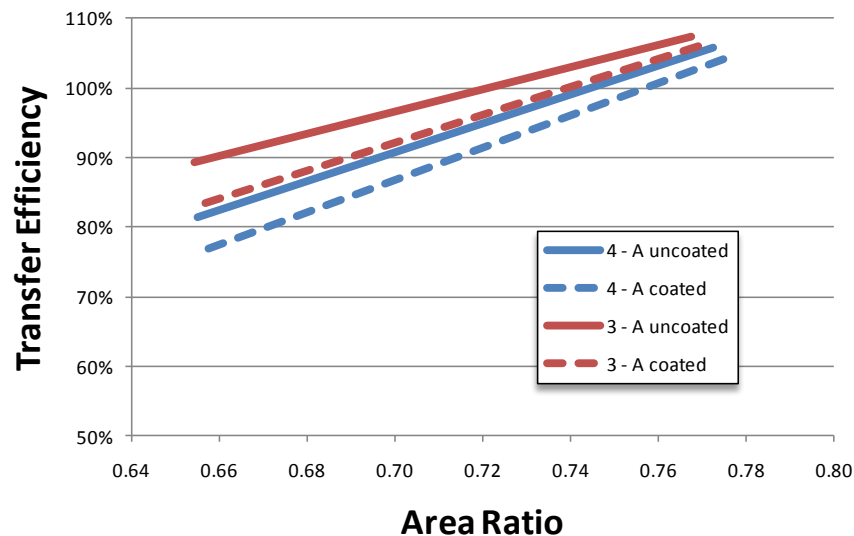
Effect of Coating on SS4
0.004" foil



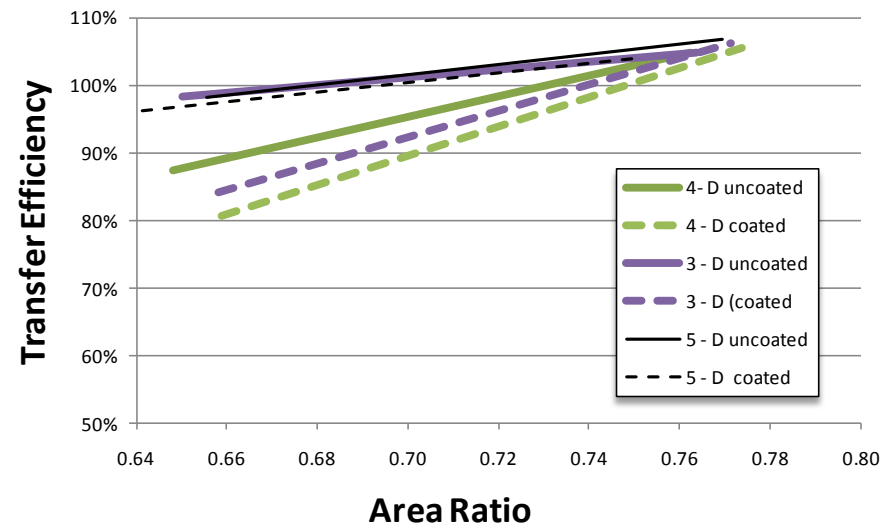
- Plots based on two data points: BGA and 0201 (ARs 0.66 and 0.77)
- On both premium SS types, from two different suppliers, the nano-coating lowered the TE at AR's ~0.66.
- TEs were comparable at 0.77

Did the Coating Improve TE?

Supplier A SS3 and SS4
0.004" foil

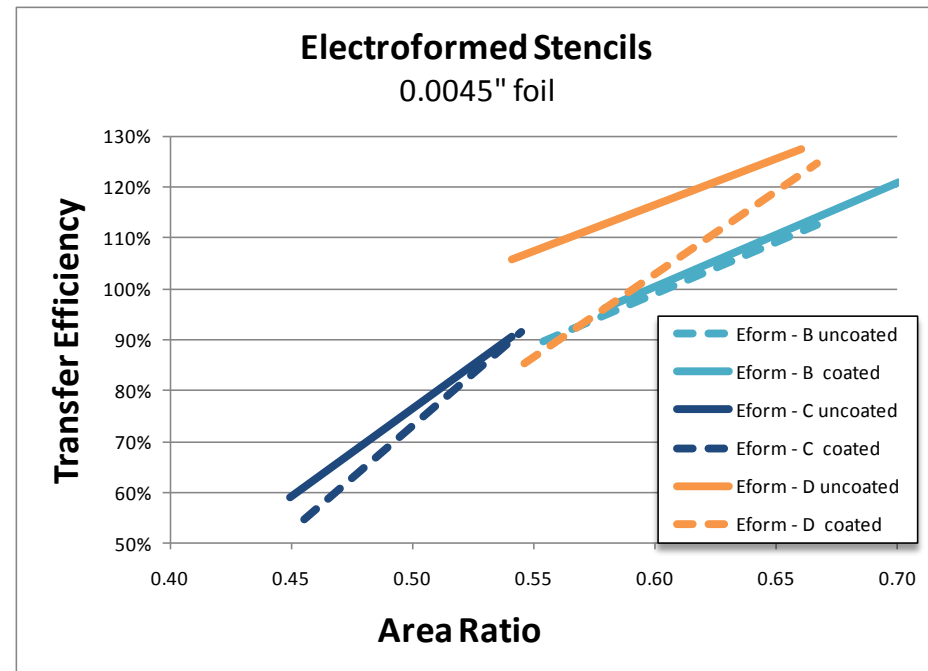
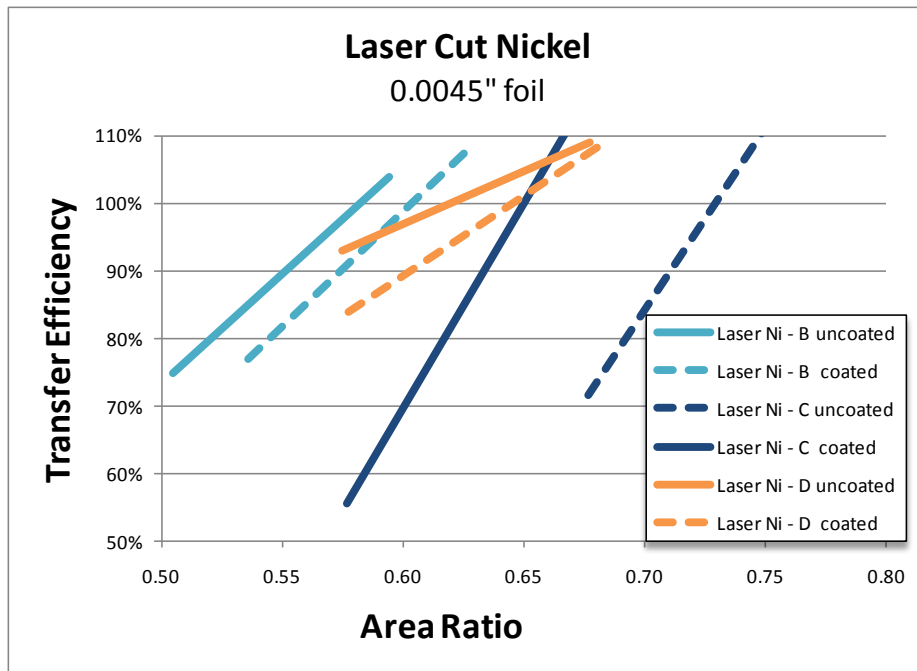


Supplier D SS3, SS4 and SS5
0.004" foil



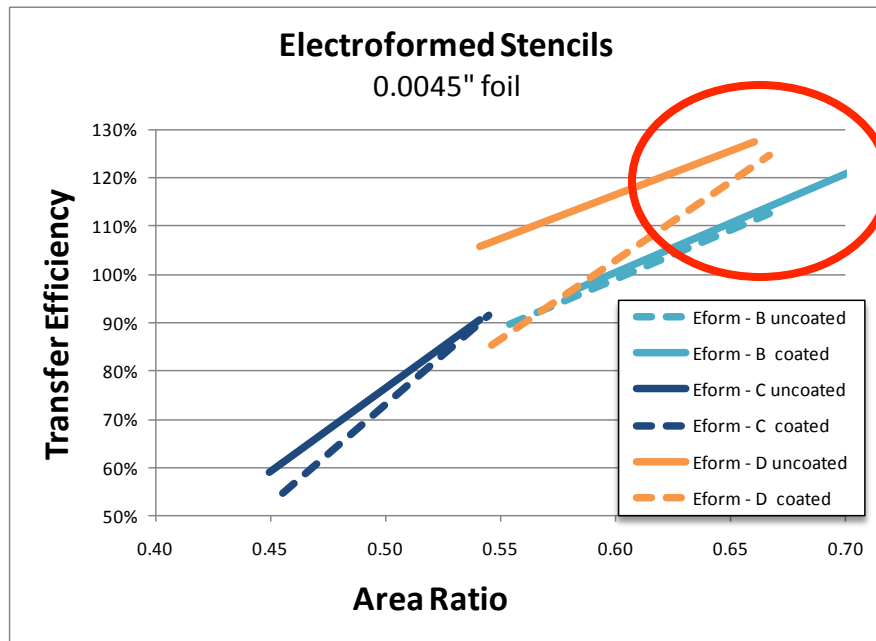
- Using 80% as a benchmark for good release at low ARs, all SS stencils with and without coating performed well.
- From supplier A, SS3 slightly outperformed SS4; Supplier D, vice versa
- SS5 was comparable to SS4; release did not appear to be affected by coating

Did the Coating Improve TE?



- Supplier C's stencils ridiculously out of spec; not considered valid data
- Supplier B's foil thicknesses varied to the extent that the stencils were not really similar and can't be compared
- Supplier D's stencils showed trends similar to SS: lower TE at the BGA AR, similar TE at the 0201 AR

High Release Numbers for Eform?



Stencil No.	Stencil Type	Offset X (in)	Offset Y (in)
23	4-D	-0.0001	-0.0013
22	4-D	0.0005	-0.0007
21	3-D	0.0004	-0.0006
20	3-D	0.0006	-0.0005
25	5-D	0.0007	-0.0008
24	5-D	0.0004	-0.0006
17	Eform - D	0.0004	-0.0017
26	Eform - D	-0.0001	-0.0011
19	Laser Ni - D	0.0004	-0.0006
18	Laser Ni - D	0.0005	-0.0001
10	Eform - B	0.0018	-0.0018
11	Eform - B	0.0016	-0.0017
8	Eform - B	0.0006	-0.0021
9	Eform - B	0.0005	-0.0020
15	Laser Ni - B	-0.0001	-0.0020
16	Laser Ni - B	0.0001	-0.0023
3	Laser Ni - B	0.0004	0.0000
2	Laser Ni - B	0.0003	-0.0007

- 110 – 130% TE at ARs of 0.66 raised suspicions
- Positional accuracy was investigated
 - Looked at paste deposit offsets in SPI database
- Electroformed apertures with high release showed average offsets of 1-2 mil

Did Coating Improve Repeatability?

- Only one pair of stencils showed Cpks less than 1.67.
- Spec limits fairly wide:
 - BGA: 20 to 139% of theoretical volume
 - Vol = 366 or 412mil³ for 4.0 and 4.5mil foils respectively
 - 0201: 50 – 200% of theoretical volume
 - Vol = 652 or 733mil³ for 4.0 and 4.5mil foils respectively
- All BGA standard deviations were within 15% of mean
 - Most within 10%
- No huge variations seen to begin with
- Most Cpks from pairs of stencils are close
- No considerable repeatability improvements documented

Did Coating Improve Yields?

Stencil Stencil No. Component Actual AR Actual TE BGA Cpk 0201 Cpk YIELD	1 - B coated		1 - B not coated		1 - B coated		1 - B not coated		1 - C coated		1 - C not coated		1 - D coated		1 - D not coated		E-form ←
	8		9		10		11		4		14		17		27		
	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	
	0.58	0.70	0.55	0.67	0.60	0.71	0.66	0.78	0.46	0.54	0.45	0.54	0.55	0.67	0.54	0.66	
	96%	121%	90%	113%	67%	95%	81%	109%	55%	91%	59%	91%	85%	125%	106%	127%	
	3.85		3.63		3.8		2.75		1.94		2.27		2.88		3.34		
	2.55		2.24		1.68		1.85		1.71		1.88		1.92		2.25		
	100		70		100		30		0		0		10		20		

Stencil Stencil No. Component Actual AR Actual TE BGA Cpk 0201 Cpk YIELD	2 - B coated		2 - B not coated		2 - B coated		2 - B not coated		2 - C coated		2 - C not coated		2 - D coated		2 - D not coated		Laser Ni ←
	3		2		15		16		13		12		19		18		
	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	
	0.55	0.65	0.55	0.64	0.54	0.63	0.51	0.59	0.58	0.69	0.68	0.81	0.58	0.68	0.58	0.68	
	68%	98%	81%	97%	77%	109%	75%	104%	56%	122%	72%	143%	84%	108%	93%	109%	
	2.94		3.34		3.25		3.25		2.04		2.26		2.04		2.75		
	1.7		2.18		2.3		2.23		0.79		0.97		2.37		2.59		
	80		80		40		20		100		60		60		0		

Stencil Stencil No. Component Actual AR Actual TE BGA Cpk 0201 Cpk YIELD	3 - A coated		3 - A not coated		3 - D coated		3 - D not coated		4 - A coated		4 - A not coated		4 - D coated		4 - D not coated		SS ↙
	5		1		23		22		6		7		21		20		
	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	BGA	0201	
	0.66	0.78	0.66	0.77	0.66	0.77	0.65	0.76	0.66	0.77	0.65	0.77	0.66	0.77	0.65	0.76	
	77%	105%	81%	106%	81%	106%	87%	105%	83%	106%	89%	107%	84%	106%	98%	105%	
	3.01		3.15		2.97		3.21		3.44		3.7		3.11		3.02		
	2.03		2.13		1.76		2.04		2.06		2.3		1.91		2.36		
	100		100		100		30		100		80		100		60		

5 - D coated		5 - D not coated		5 - D coated		5 - D not coated	
25		24		25		24	
BGA	0201	BGA	0201	BGA	0201	BGA	0201
0.64	0.75	0.66	0.77	0.64	0.75	0.66	0.77
96%	104%	98%	107%	96%	104%	98%	107%
3.27		3.17		3.27		3.17	
2.28		2.32		2.28		2.32	
90		80		90		80	

■ Of the 13 pairs of stencils tested:

- 7 of the coated produced 100% yields
- Even a Supplier C stencil got a 100% yield!
- 1 of the uncoated produced 100% yields
- Yields went up for all but one case (1-D)



Effects of Coating

- Dramatically improved yields
- Did not impact repeatability
- Lowered transfer efficiency at AR ~ 0.66
- Comparable transfer efficiency at AR ~ 0.77
- Can even make bad stencils perform better (print yields)

Effects of Material, Manufacturing Process and Foil Thickness

- SS had better overall print yields
- SS more dimensionally stable than Eform or Laser Ni
 - Thickness, aperture size and position
 - Superior dimensional accuracy, regardless of supplier
- SS had better overall volume repeatability
 - Repeatability thickness, aperture size and position
 - Process outputs very dependent on these inputs
- No alloy was clear winner in SS category
- SS produced higher average volumes, even with thinner foils
 - For BGAs, 4mil foils deposited an average of 322 mil³ of solder paste; 4.5mil laser Ni deposited an average of 250mil³ (theoretical is 366 mil³)

Results & Discussion

- Previous stencil choice for operations were laser cut Ni, based on tests performed before premium SS and nano-coating were available
- New stencil choice for operation are premium SS with nano-coating
- Print yields up approximately 5 points in production
- With Type 3, water-soluble solder paste, print process is capable of
 - 0.5mm BGAs with ARs of 0.66
 - >80% TE at ARs of 0.66
 - Cpk's >3.0 for BGAs and >2.0 for 0201s



Thank You!

Questions?

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