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 electrpolishing 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

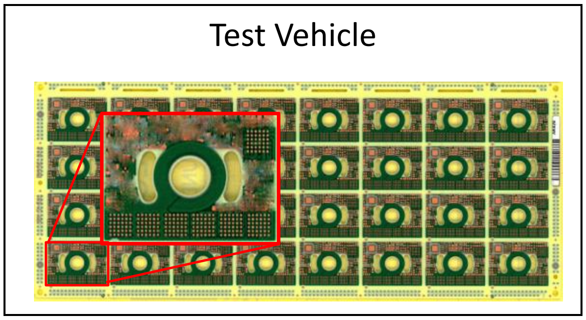

Figure 1. Test Vehicle (non-BGA circuitry on closeup is intentionally blurred)

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^{o}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 electropolised 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%
	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%

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
	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

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

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

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

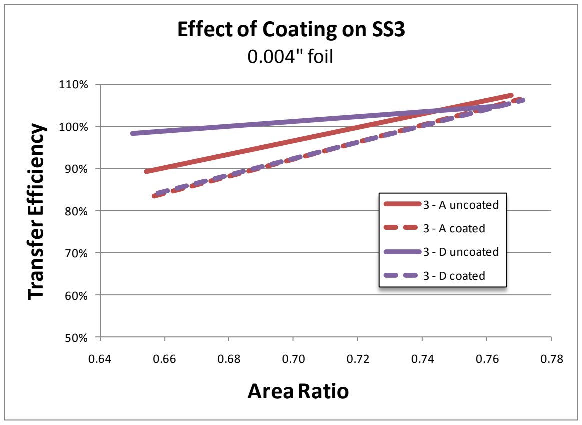

Figure 2. Comparison of print performance of SS #3 stencils from two suppliers with and without coating

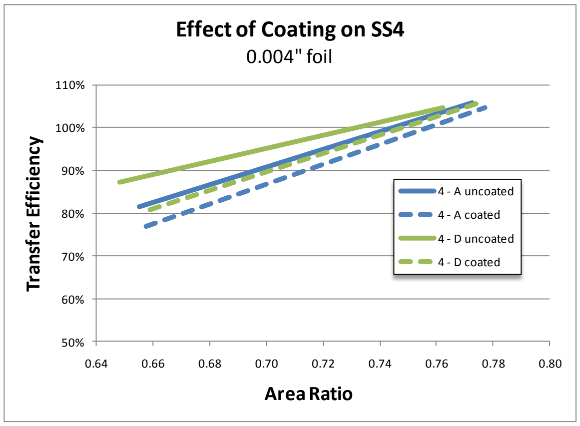

Figure 3. Comparison of print performance of SS #4 stencils from two suppliers with and without coating

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.

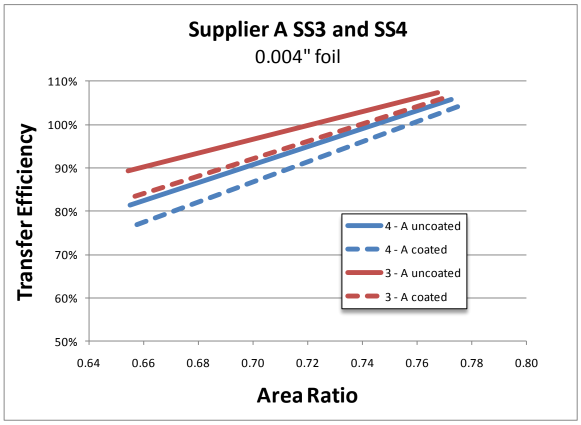

Figure 4. Comparison of print performance of SS #3 and SS #4 from same supplier

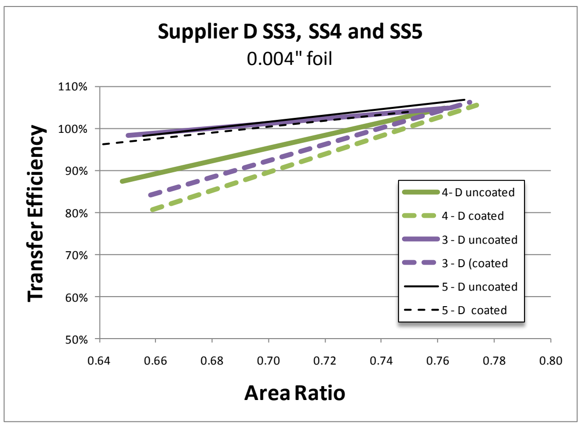

Figure 5. Comparison of three types of SS from the same supplier

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.

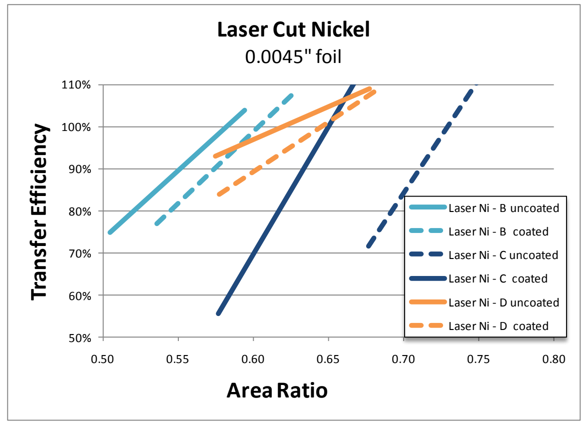

Figure 6. Comparison of print performance of laser-cut nickel foils from three different suppliers

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.

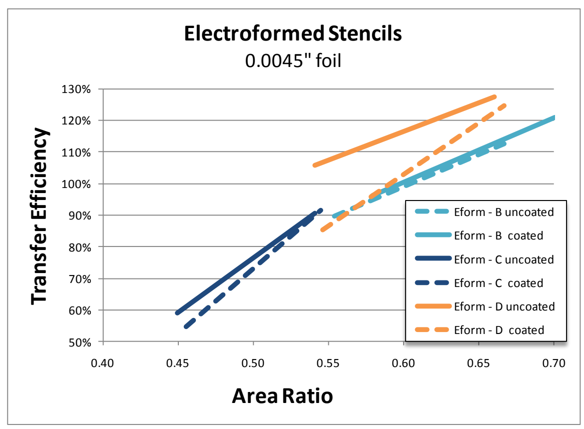

Figure 7. Comparison of print performance of electroformed stencils from three different suppliers.

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 Cpks based on the control limits used in production. BGA Cpks were all above 1.67. All 0201 Cpks, 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	0.58	96%	3.85	2.55	100
		0201	0.70	121%			
9	1 - B not coated	BGA	0.55	90%	3.63	2.24	70
		0201	0.67	113%			
10	1 - B coated	BGA	0.60	67%	3.8	1.68	100
		0201	0.71	95%			
11	1 - B not coated	BGA	0.66	81%	2.75	1.85	30
		0201	0.78	109%			
4	1 - C coated	BGA	0.46	55%	1.94	1.71	0
		0201	0.54	91%			
14	1 - C not coated	BGA	0.45	59%	2.27	1.88	0
		0201	0.54	91%			
17	1 - D coated	BGA	0.55	85%	2.88	1.92	10
		0201	0.67	125%			
27	1 - D not coated	BGA	0.54	106%	3.34	2.25	20
		0201	0.66	127%			
3	2 - B coated	BGA	0.55	68%	2.94	1.7	80
		0201	0.65	98%			
2	2 - B not coated	BGA	0.55	81%	3.34	2.18	80
		0201	0.64	97%			
15	2 - B coated	BGA	0.54	77%	3.25	2.3	40
		0201	0.63	109%			
16	2 - B not coated	BGA	0.51	75%	3.25	2.23	20
		0201	0.59	104%			
13	2 - C coated	BGA	0.58	56%	2.04	0.79	100
		0201	0.69	122%			
12	2 - C not coated	BGA	0.68	72%	2.26	0.97	60
		0201	0.81	143%			
19	2 - D coated	BGA	0.58	84%	2.04	2.37	60
		0201	0.68	108%			
18	2 - D not coated	BGA	0.58	93%	2.75	2.59	0
		0201	0.68	109%			
5	3 - A coated	BGA	0.66	77%	3.01	2.03	100
		0201	0.78	105%			
1	3 - A not coated	BGA	0.66	81%	3.15	2.13	100
		0201	0.77	106%			
23	3 - D coated	BGA	0.66	81%	2.97	1.76	100
		0201	0.77	106%			
22	3 - D not coated	BGA	0.65	87%	3.21	2.04	30
		0201	0.76	105%			
6	4 - A coated	BGA	0.66	83%	3.44	2.06	100
		0201	0.77	106%			
7	4 - A not coated	BGA	0.65	89%	3.7	2.3	80
		0201	0.77	107%			
21	4 - D coated	BGA	0.66	84%	3.11	1.91	100
		0201	0.77	106%			
20	4 - D not coated	BGA	0.65	98%	3.02	2.36	60
		0201	0.76	105%			
25	5 - D coated	BGA	0.64	96%	3.27	2.28	90
		0201	0.75	104%			
24	5 - D not coated	BGA	0.66	98%	3.17	2.32	80
		0201	0.77	107%			

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.

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