An Investigation into the Use of Nano-Coated Stencils to Improve Solder Paste Printing with Small Stencil Aperture Area Ratios

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ABSTRACT
Certain types of nano-coated stencils dramatically improve the transfer efficiency of solder paste during paste printing. These nano-coatings also refine the solder paste brick shape giving improved print definition. These two benefits combine to help the solder paste printing process produce an adequate amount of solder paste in the correct position on the circuit board pads. Today, stencil aperture area ratios from 0.66 down to 0.40 are commonly used and make paste printing a challenge.

This paper presents data on small area ratio printing for component designs including 01005 Imperial (0402 metric) and smaller 03015 metric and 0201 metric chip components and 0.3 mm and 0.4 mm pitch micro BGAs. The aperture area ratios studied range from 1.06 down to 0.30. The effects of nano-coatings are studied and compared to uncoated laser cut, fine grain steel stencils. Stencil thicknesses are varied from 0.003 inch (75 µm) to 0.004 inch (100 µm) and to 0.005 inch (125 µm). Solder paste powder size is varied including IPC Types 3, 4 and 5. The effects of all of these variables are examined in relation to small aperture area ratios. Based on the results of the work a set of guidelines for stencil thickness, stencil nano-coating and solder paste type will be proposed in order to achieve good solder paste printing results.

Keywords: printing, area ratio, 01005, transfer efficiency, solder paste, stencil, nano-coating, 0402 metric, 03015 metric, 0201 metric, 0.3 mm pitch, 0.4 mm pitch

1.0 INTRODUCTION

The continuing trend for miniaturization of electronics ensures that 01005 Imperial (0402 metric – 0.4 x 0.2 mm) and smaller components will become more prevalent. 03015 metric (0.30 x 0.15 mm) components are under consideration and 0201 metric (0.20 x 0.10 mm) parts are on the horizon. The solder paste printing process becomes a limiting factor when components of this size are used as well as when pitch of the component goes down to 0.3 mm as in the case of Chip Scale Packages (CSPs). The intent of this investigation is to determine the best options for stencil design, nano-coating and solder paste type for use with micro BGAs, 01005 Imperial (0402 metric) and smaller components. It is the intention of the authors to present a set of general guidelines for use with these types of components.

This investigation is a continuation of previous work [1]. This previous work included printing studies with stencil aperture area ratios ranging from 0.30 to 0.80. A variety of solder pastes and the effects of a polymer nano-coating were studied. A 01005 Imperial (0402 metric) component layout was included to gather some initial data. In the previous work component layouts smaller than 01005 Imperial were not included. In this investigation the 01005 Imperial (0402 metric) component layout is varied to determine the best aperture design for the printing process. 03015 metric and 0201 metric component layouts are also included.

2.0 METHODOLOGY/EXPERIMENTAL

Challenging stencil designs which use standard component layouts for the small components under investigation were created. Solder paste print studies were conducted with a variety of stencil thicknesses and solder paste types. The effect of a production polymer type nano-coating was evaluated. Solder paste volumes were measured and the results were summarized and statistically compared against each other.

2.1 Equipment

The printer used was a semi-automatic printer without a cleaning system. The print parameters used are as follows.

- Print speed = 20 mm/sec
- Blade length = 300 mm (11.8 in)
- Blade material = 304 SS polished steel
- Print pressure = 0.18 kg/cm (1 lb/inch)
- Separation speed = 1.5 mm/sec
- Cleaning cycle: Underside cleaning was not performed during the print studies

The solder paste inspection system (SPI) used was a semi-automatic system. The printed solder paste volumes were measured for each print study and the data evaluated using statistical analysis software.

2.2 01005 Imperial Test Stencil

The 01005 Imperial Test Stencil (Figure 1) has several different challenging component layouts. Three micro BGA components were included with 0.3 mm, 0.4 mm and 0.5 mm pitch. The micro BGA apertures were designed as rounded squares (RSQ) and the sizes were varied accordingly at 200 µm (8 mil), 250 µm (10 mil) and 300 µm (12 mil). Three 01005 Imperial (0402 metric) component designs were included with three different RSQ aperture sizes: 150 µm (6 mil), 175 µm (7 mil) and 190 µm (7.5 mil). One 0201 Imperial (0603 metric) component design was included for comparison with a RSQ aperture size of 280 x 380 µm (11x15 mil). Whitmore [2] used similar aperture sizes in a study on 0.3mm pitch CSP devices.

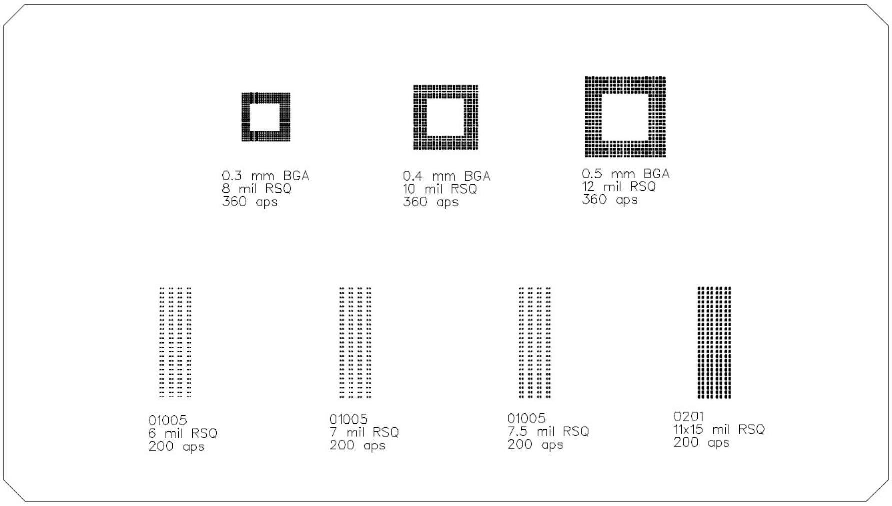

Figure 1 – 01005 Imperial Test Stencil

Three stencil thicknesses were used in this test: 75 µm (3 mil), 100 µm (4 mil) and 125 µm (5 mil). The material used for these stencils was a fine grain 304 stainless steel with 8-9 µm grain size. Two stencils of each thickness were made, and one of each was coated with a production polymer type nano-coating. The nano-coating used is a thermally cured polymer which is easily visible in the apertures and on the surface of the stencil. Figure 2 shows an example of the production polymer nano-coating (yellow) on a steel stencil.

Figure 2 – Example of the Production Polymer Nano-coating on a Steel Stencil

The aperture sizes were held constant for each stencil thickness so the area ratios (AR) varied according to stencil thickness. A complete list of the component layout, aperture sizes and area ratios for the 01005 Imperial stencil design is shown below (Table 1).

Table 1 – 01005 Imperial Test Stencil Component Layout, Aperture Size and Area Ratio

					5 mil stencil		4 mil stencil		3 mil stencil	
Component Type	Aperture Size (mils)	Aperture Shape	Aperture Area (sq. mils)	# Paste Deposits Scanned Per print	Theoretical vol (cu. mils)	AR	Theoretical vol (cu. mils)	AR	Theoretical vol (cu. mils)	AR

0.5 mm BGA	12 x 12	RSQ	144	140	720	0.60	576	0.75	432	1.00
0.4 mm BGA	10 x 10	RSQ	100	150	500	0.50	400	0.63	300	0.83
0.3 mm BGA	8 x 8	RSQ	64	150	320	0.40	256	0.50	192	0.67
01005 6 mil	6 x 6	RSQ	36	144	180	0.30	144	0.38	108	0.50
01005 7 mil	7 x 7	RSQ	49	144	245	0.35	196	0.44	147	0.58
01005 7.5 mil	7.5 x 7.5	RSQ	56	144	281	0.38	225	0.47	169	0.63
0201 Imperial	11 x 15	RSQ	165	144	825	0.63	660	0.79	495	1.06

Three different company production solder pastes were used in this investigation with the 01005 Imperial stencil design. All three were made with the same flux but with different sizes of solder powder. The company production solder pastes were all no clean, lead-free and were made with SAC305 alloy. The solder powder sizes used were IPC standard Type 3 (25-45 µm diameter), Type 4 (20-38 µm diameter) and Type 5 (15-25 µm diameter). IPC standard dictates that 80% of the solder powder must fall within these particle sizes.

<u>2.3 03015 Metric Test Stencil</u>

A second stencil was designed with apertures sized for 03015 metric (0.30 x 0.15 mm) and 0201 metric (0.20 x 0.10 mm) components (Figure 3).

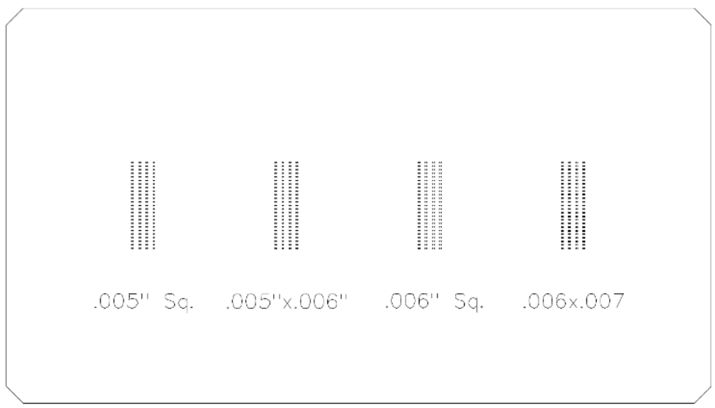

Figure 3 – 03015 Metric Test Stencil

Four different aperture sizes were used: 125 µm (0.005") square, 125 µm x 150 µm (0.005" x 0.006") rectangle, 150 µm (0.006") square, and 150 µm x 180 µm (0.006" x 0.007") rectangle. The stencils were made of fine grain 304 stainless steel with 8-9 µm grain size and 75 µm (0.003") and 100 µm (0.004") stencil thicknesses. Two stencils of each thickness were made and one stencil of each thickness was coated with a production polymer nano-coating. Print studies on the 03015 metric stencil design were conducted using no clean SAC305 Type 4 (20-38 µm) and Type 5 (15-25 µm) solder pastes which were the same solder pastes used with the 01005 Imperial test stencil.

The aperture sizes were held constant for each stencil thickness so the area ratios (AR) varied according to stencil thickness. Harter [3] used a similar area ratio range for 03015 metric components. A complete list of the component layout, aperture sizes and area ratios for the 03015 metric stencil design is shown below (Table 2).

Table 2 – 03015 Metric Test Stencil Component Layout, Aperture Size and Area Ratio

					4 mil stencil		3 mil stencil	
Component Type	Aperture Size (mils)	Aperture Shape	Aperture Area (sq. mils)	# Paste Deposits Scanned Per print	Theoretical vol (cu. mils)	AR	Theoretical vol (cu. mils)	AR
0201 metric	5 x 5	Square	25	192	100	0.31	75	0.42
0201 metric	5 x 6	Rectangle	30	192	120	0.34	90	0.45
03015 metric	6 x 6	Square	36	192	144	0.38	108	0.50
03015 metric	6 x 7	Rectangle	42	192	168	0.40	126	0.54

2.4 Print Study Details for both Stencil Designs

The circuit boards used were made of copper clad FR-4 laminate. Bare copper clad material was chosen in order to eliminate potential variations from board pad size and board pad mis-registration. The solder paste was printed directly onto the bare copper and then solder paste volume was measured using a SPI (Solder Paste Inspection) system. A 10 board print study was completed for each stencil and each solder paste and the results summarized for every component layout. No underside cleaning was carried out during the print studies. Transfer efficiency means and standard deviations were calculated and Tukey-Kramer Honest Significant Difference (HSD) statistical analysis was performed to compare the data sets developed.

3.0 RESULTS AND DISCUSSION

3.1 01005 Imperial Test Stencil Results

The transfer efficiency means and standard deviations for all fine grained uncoated (F) and fine grained nano-coated (FPN) stencils and Type 3 solder paste are shown below (Table 3).

Table 3 – Transfer Efficiency Means and Standard Deviations – Type 3 Solder Paste

Stencil	F 3			F 4			F 5		
Component	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
0.3mm BGA	69.0	16.5	0.67	30.8	4.5	0.50	19.0	3.8	0.40
0.4mm BGA	62.5	10.4	0.83	43.6	5.7	0.63	33.7	5.0	0.50
0.5mm BGA	80.6	10.2	1.00	61.0	4.5	0.75	56.3	5.9	0.60
01005 6mil	12.1	3.2	0.50	6.0	1.3	0.38	2.9	0.9	0.30
01005 7mil	21.8	4.3	0.58	12.8	2.0	0.44	7.4	2.7	0.35
01005 7.5mil	26.7	4.9	0.63	17.6	3.4	0.47	10.1	1.7	0.38
0201 Imperial	83.0	13.5	1.06	57.3	2.9	0.79	50.8	4.5	0.63
Stencil	FPN 3			FPN 4			FPN 5		
Component	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
0.3mm BGA	68.1	9.7	0.67	46.5	6.7	0.50	33.5	9.0	0.40
0.4mm BGA	72.3	7.1	0.83	64.6	6.5	0.63	57.6	5.0	0.50
0.5mm BGA	76.9	7.7	1.00	73.2	5.5	0.75	68.4	2.1	0.60
01005 6mil	20.0	5.9	0.50	14.2	5.1	0.38	6.9	1.6	0.30
01005 7mil	36.8	8.1	0.58	22.6	6.6	0.44	12.9	2.6	0.35
01005 7.5mil	43.2	7.3	0.63	28.8	6.1	0.47	18.1	5.8	0.38
0201 Imperial	74.4	7.4	1.06	71.5	4.5	0.79	66.9	3.6	0.63

The stencils were named with codes (for Tables 3, 4, and 5) which translate as follows:

- F 3 = Fine grain steel, 3 mil thick
- F 4 = Fine grain steel, 4 mil thick
- F 5 = Fine grain steel, 5 mil thick
- FPN 3 = Fine grain steel, Polymer Nano-coating, 3 mil thick
- FPN 4 = Fine grain steel, Polymer Nano-coating, 4 mil thick
- FPN 5 = Fine grain steel, Polymer Nano-coating, 5 mil thick

It is desirable to have high mean transfer efficiency percentage (TE%) and low standard deviation of the mean transfer efficiency. There is a wide spread of transfer efficiencies shown here due to the large range of area ratios under evaluation (0.30 to 1.06) due to stencil aperture size and stencil thickness differences. In general, as area ratio reduces below 0.67 down to 0.40, transfer efficiency increases for the nano-coated stencil compared with the un-coated stencil by 10% up to 24% for the Type 3 solder paste for the 3 stencil thicknesses. The data for Type 4 solder paste is shown below (Table 4).

Table 4 – Transfer Efficiency Means and Standard Deviations – Type 4 Solder Paste

Stencil	F 3			F 4			F 5		
Component	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
0.3mm BGA	57.4	8.7	0.67	33.6	5.7	0.50	19.7	3.5	0.40
0.4mm BGA	68.6	9.2	0.83	50.4	5.8	0.63	39.2	6.3	0.50
0.5mm BGA	82.5	10.1	1.00	67.2	4.6	0.75	57.5	5.3	0.60
01005 6mil	19.2	6.7	0.50	8.4	2.0	0.38	2.4	0.9	0.30
01005 7mil	28.8	7.4	0.58	16.2	2.3	0.44	6.4	1.6	0.35
01005 7.5mil	33.8	7.4	0.63	20.6	3.7	0.47	10.0	2.5	0.38
0201 Imperial	86.0	10.3	1.06	62.2	3.5	0.79	52.7	5.2	0.63
Stencil	FPN 3			FPN 4			FPN 5		
Component	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
0.3mm BGA	60.7	5.4	0.67	48.9	6.0	0.50	40.4	10.7	0.40
0.4mm BGA	72.4	6.6	0.83	62.2	3.8	0.63	61.0	5.0	0.50
0.5mm BGA	78.4	4.9	1.00	71.5	3.3	0.75	70.5	2.7	0.60
01005 6mil	25.6	7.3	0.50	15.3	6.1	0.38	8.7	2.0	0.30
01005 7mil	40.6	8.0	0.58	26.1	7.5	0.44	17.3	5.6	0.35
01005 7.5mil	44.4	7.3	0.63	31.7	6.9	0.47	21.5	6.2	0.38
0201 Imperial	75.6	2.0	1.06	66.0	3.5	0.79	67.2	4.5	0.63

In general, as area ratio reduces below 0.67 down to 0.40, transfer efficiency increases for the nano-coated stencil compared to the un-coated stencil by 5% up to 23% for the Type 4 solder paste for the 3 stencil thicknesses. The data for Type 5 solder paste is shown below (Table 5).

Table 5 – Transfer Efficiency Means and Standard Deviations – Type 5 Solder Paste

Stencil	F 3			F 4			F 5		
Component	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
0.3mm BGA	55.4	7.9	0.67	35.6	3.8	0.50	24.4	4.3	0.40
0.4mm BGA	72.0	7.4	0.83	56.9	4.1	0.63	49.2	6.9	0.50
0.5mm BGA	85.5	7.3	1.00	71.8	4.8	0.75	66.2	4.4	0.60
01005 6mil	19.7	5.4	0.50	8.8	2.5	0.38	3.5	1.0	0.30
01005 7mil	31.3	6.6	0.58	18.1	2.7	0.44	8.8	2.2	0.35
01005 7.5mil	36.4	6.8	0.63	23.4	2.2	0.47	13.4	2.8	0.38
0201 Imperial	86.3	9.4	1.06	68.5	2.9	0.79	63.0	3.8	0.63
Stencil	FPN 3			FPN 4			FPN 5		
Component	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
0.3mm BGA	66.9	3.5	0.67	55.5	4.1	0.50	54.6	8.4	0.40
0.4mm BGA	77.0	3.8	0.83	69.2	2.9	0.63	72.2	2.4	0.50
0.5mm BGA	82.7	3.4	1.00	77.3	3.0	0.75	80.4	1.8	0.60
01005 6mil	33.1	7.3	0.50	21.3	5.6	0.38	14.3	2.9	0.30
01005 7mil	47.0	7.8	0.58	32.1	5.9	0.44	22.8	4.7	0.35
01005 7.5mil	52.1	6.4	0.63	40.0	5.2	0.47	33.8	8.2	0.38
0201 Imperial	82.1	3.2	1.06	73.7	2.6	0.79	79.0	1.2	0.63

In general, as area ratio reduces below 0.67 down to 0.40, transfer efficiency increases for the nano-coated stencil compared with the un-coated stencil by 10% up to 30% for the Type 5 solder paste for the 3 stencil thicknesses.

It is difficult to see absolute trends or make more definitive comparisons between these data sets without the help of charts and statistical analysis. Bar charts showing the TE% differences between un-coated (F) and nano-coated stencils (FPN) are shown below (see Figures 4, 5, and 6). The data from all solder paste types (Types 3, 4, and 5) is averaged in these charts.

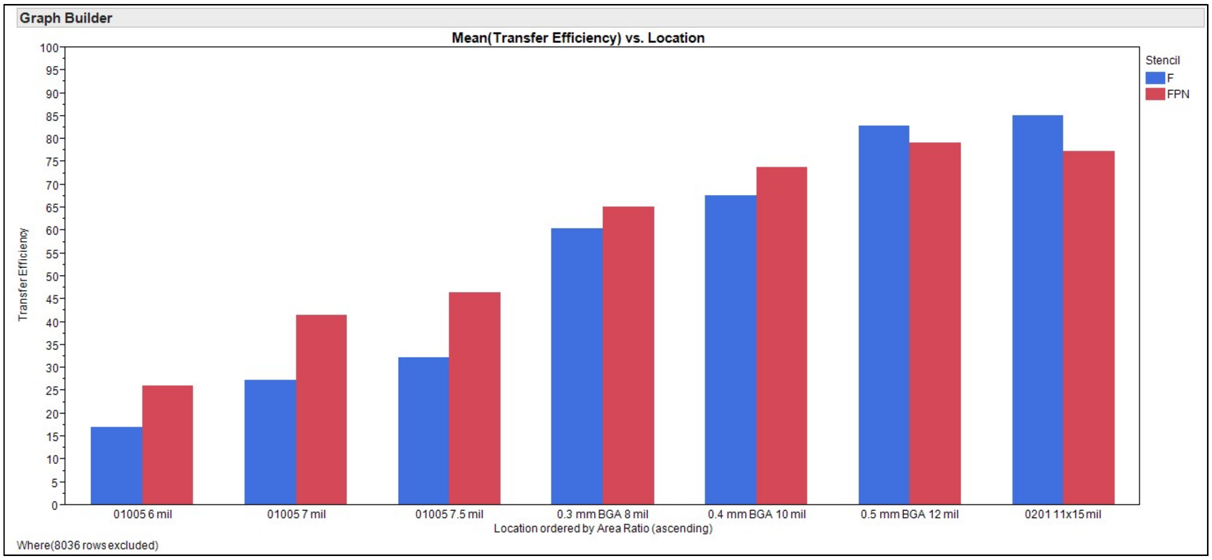

Figure 4 – Mean TE% by Location for 3 mil Thick Stencils (F-blue, FPN-red)

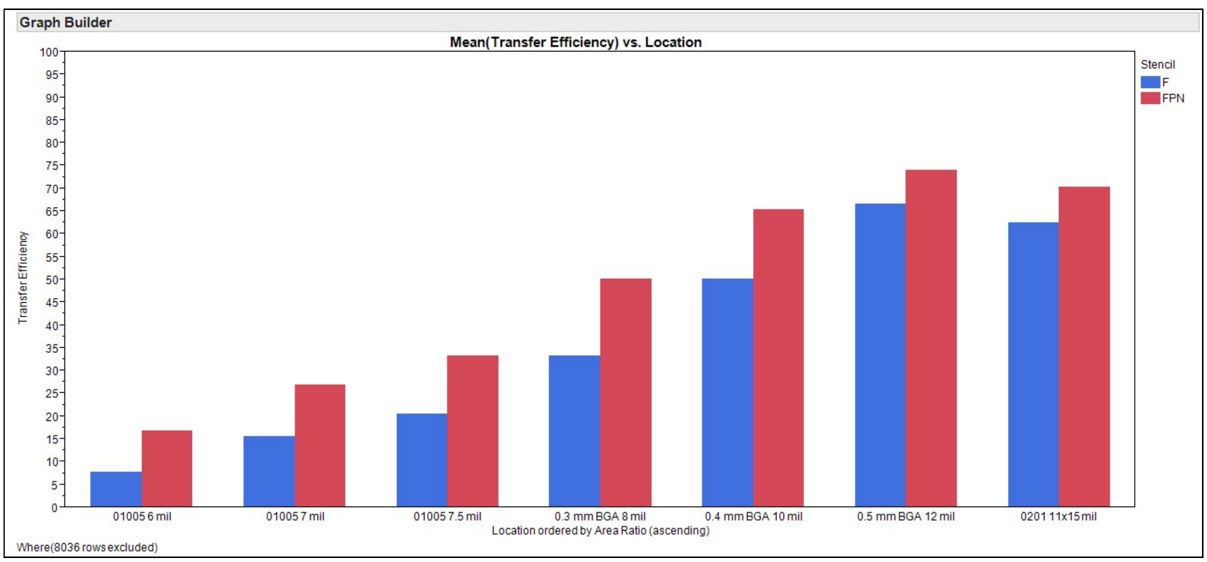

Figure 5 – Mean TE% by Location for 4 mil Thick Stencils (F-blue, FPN-red)

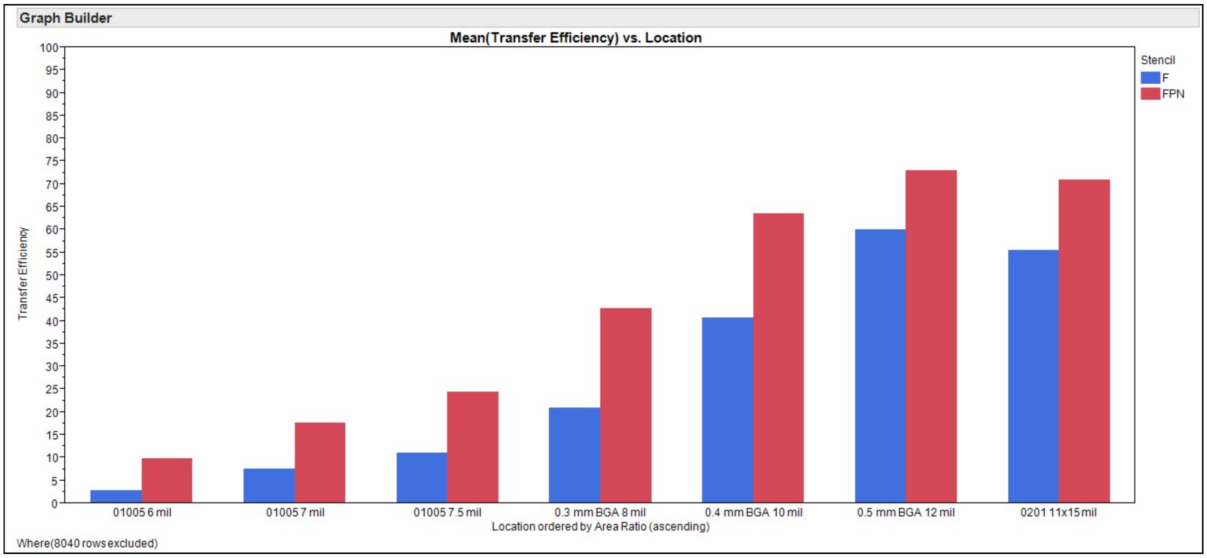

Figure 6 – Mean TE% by Location for 5 mil Thick Stencils (F-blue, FPN-red)

In general the transfer efficiencies from the 3 mil stencil are higher than the 4 mil stencil which are higher than the 5 mil stencil. This is expected due to the fact that area ratios for the 3 mil stencils (0.50 to 1.06) are higher than the area ratios for the 4 mil stencils (0.38 to 0.79) which are higher than the area ratios for the 5 mil stencils (0.30 to 0.63). Use of the polymer nano-coating shows an increase in transfer efficiency for all component layouts with the exception of the 3 mil thick stencil with 0.5 mm pitch BGA and 0201 Imperial components. Harter [3] reports a similar increase in transfer efficiency from the use of polymer type nano-coating. The uncoated stencil gave higher TE% for each of these two components than the nano-coated stencil. This is because the area ratio for these two components on the 3 mil thick stencils is high: 0.5 mm BGA (1.00 AR) and 0201 Imperial (1.06 AR). Solder paste release is not an issue with these high area ratios.

Bar charts of this data were sorted by thickness for un-coated (Figure 7) and polymer nano-coated stencils (Figure 8). These charts show the effect of stencil thickness on transfer efficiency. Again all solder paste types (Types 3, 4, and 5) are averaged in these charts.

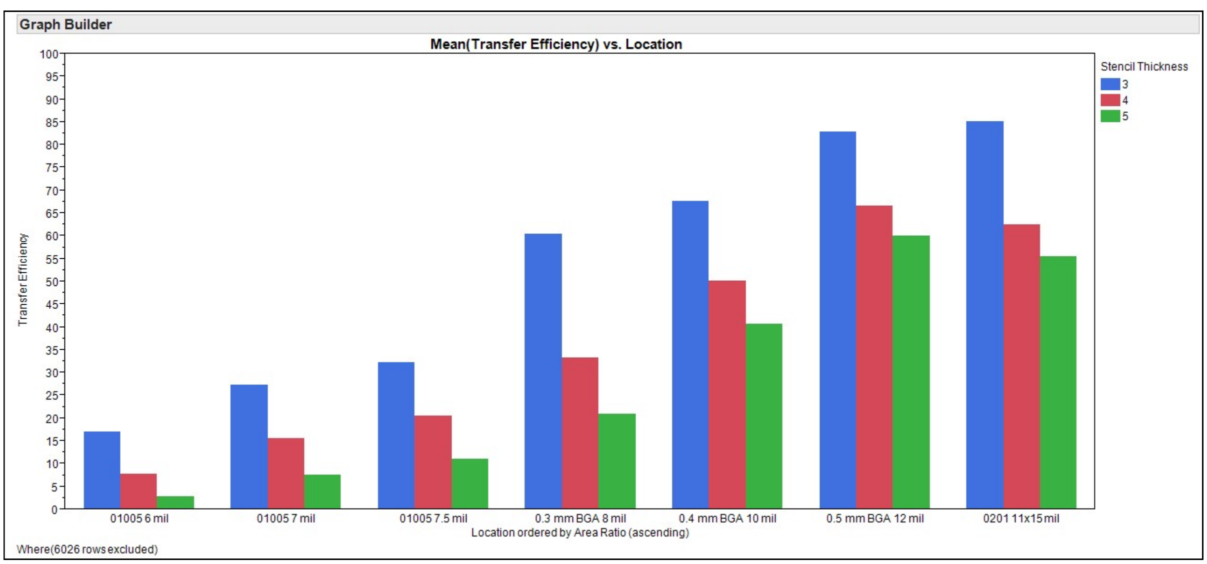

Figure 7 – Mean TE% by Location Separated by Thickness for the Uncoated Stencils (F) (3mil-blue, 4mil-red, 5mil-green)

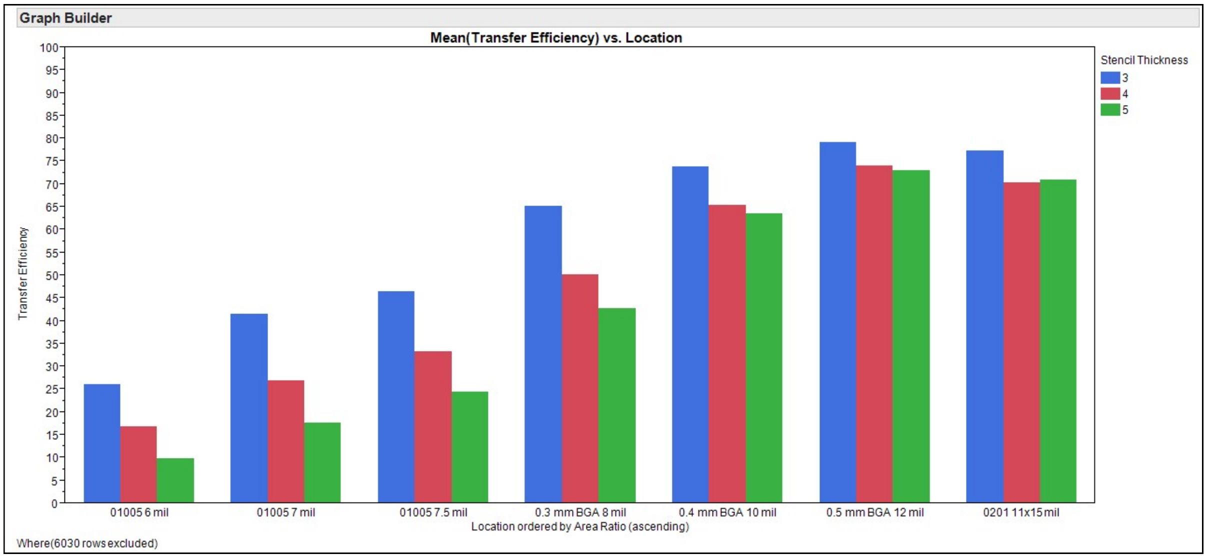

Figure 8 – Mean TE% by Location Separated by Thickness for the Nano-coated Stencils (FPN) (3mil-blue, 4mil-red, 5mil-green)

The 3 mil thick stencil produces higher TE% than the 4 and 5 mil thick stencils due to the higher area ratios. The difference between the TE% for the 3, 4 and 5 mil thick stencils is smaller when the polymer nano-coating is used versus un-coated stencils, especially for larger component area ratios (e.g. 0201 Imperial components). The polymer nano-coating improves transfer efficiency for the 4 and 5 mil thick stencils so they come closer to the transfer efficiency of the 3 mil thick stencils.

The effect of solder paste type is shown below for the 3 mil (Figure 9), 4 mil (Figure 10) and 5 mil (Figure 11) thick stencils.

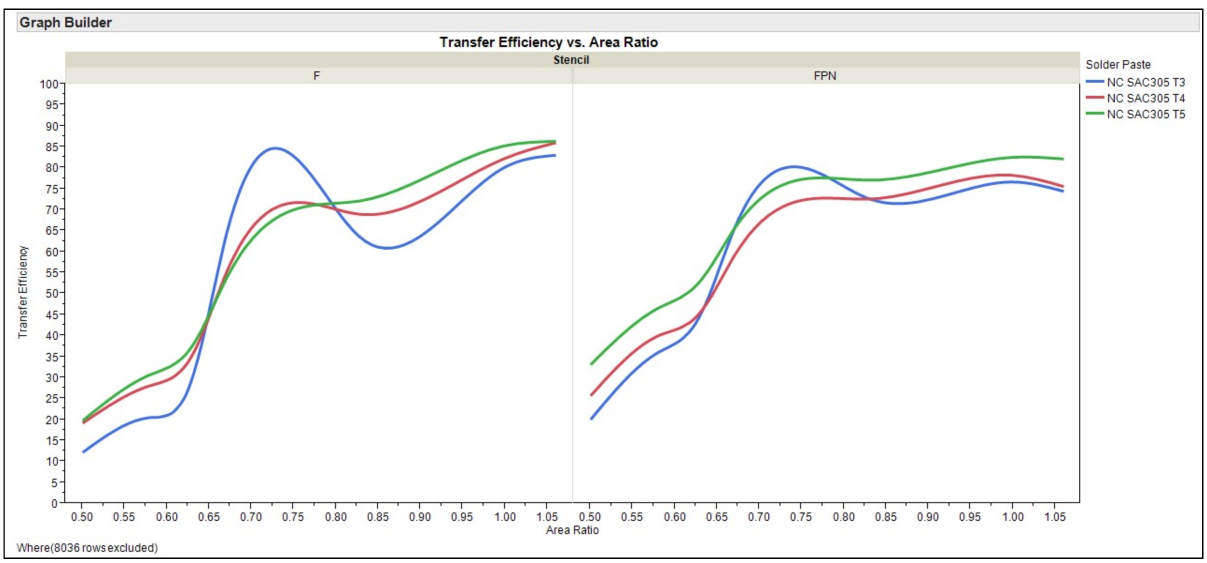

Figure 9 – Mean TE% by Area Ratio Comparing Nano and Un-Coated Stencils and Solder Paste Type - 3 mil Stencils (Blue-Type 3, Red-Type 4, Green- Type 5)

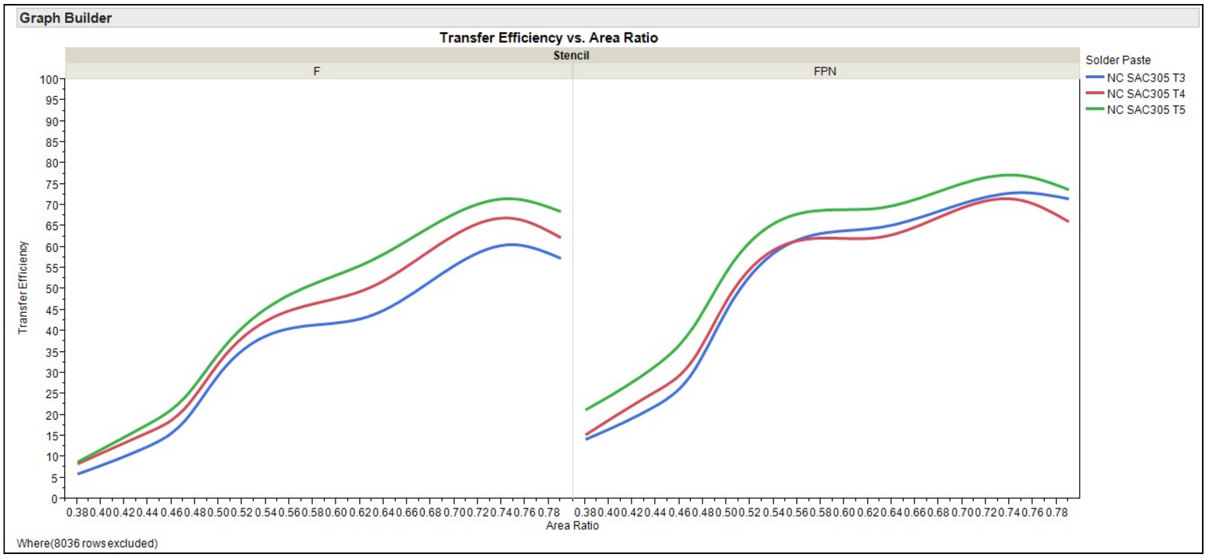

Figure 10 – Mean TE% by Area Ratio Comparing Nano and Un-Coated Stencils and Solder Paste Type - 4 mil Stencils (Blue- Type 3, Red- Type 4, Green-Type 5)

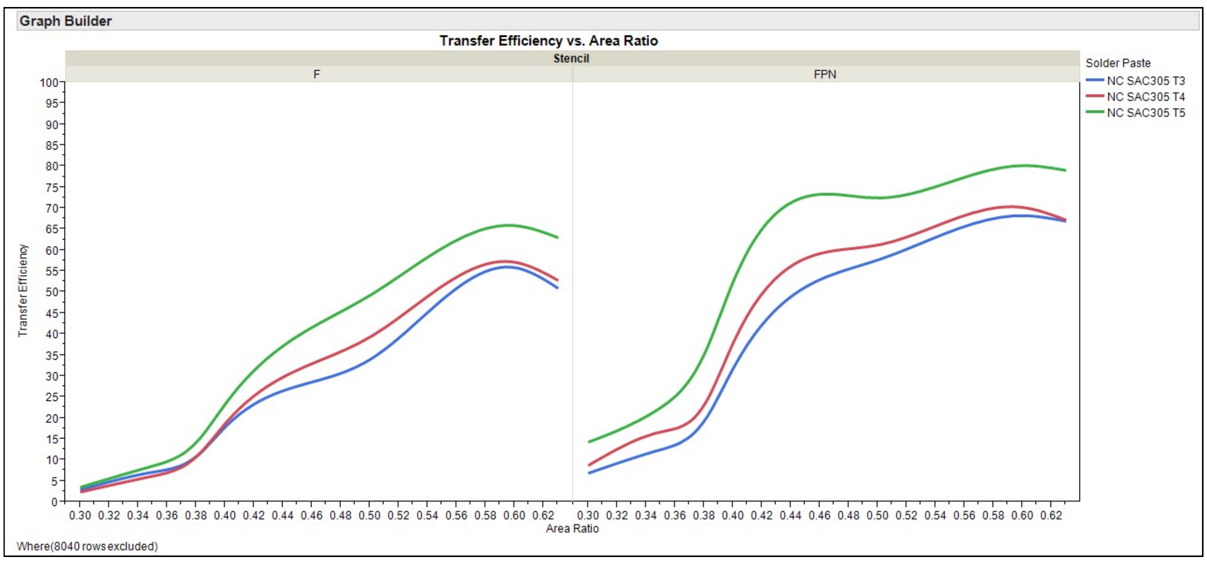

Figure 11 – Mean TE% by Area Ratio Comparing Nano and Un-Coated Stencils and Solder Paste Type - 5 mil Stencils (Blue- Type 3, Red-Type 4, Green-Type 5)

In general, the transfer efficiencies for the Type 3 solder paste (blue) are lower than for the Type 4 (red) and Type 5 solder paste (green). This is true for all 3 thicknesses of stencils. Gray [4] reported similar transfer efficiency results for laser cut, fine grain, nano-coated stencils with Type 5 solder paste. One anomaly in this data is for Type 3 solder paste on the 3 mil thick uncoated (F) stencil. In this case the Type 3 solder paste gave a much higher TE% than Types 4 and 5 for the area ratios of 0.70 to 0.75. These area ratios are not challenging for the print process and as a result all three types of solder paste produced acceptable results.

There are some trends visible in the transfer efficiency data that lend themselves to the use of micro BGAs and 01005 type components. Some of the differences in transfer efficiency are small, but further evaluation was required to understand if they were significantly different. Tukey – Kramer HSD testing was performed to determine which of the variables in this investigation had a significant effect on transfer efficiency. When the data is analyzed simply by comparing the un-coated versus polymer nano-coated stencils the following results are found (Figure 12). All other variables are averaged in this analysis.

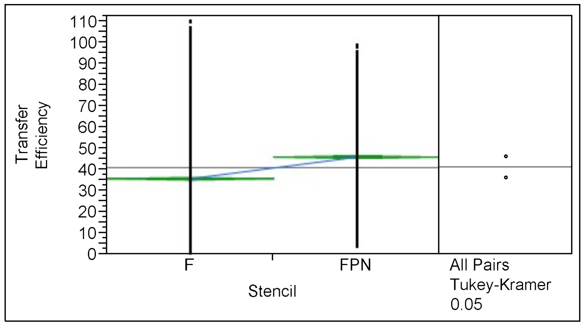

Figure 12 – Tukey-Kramer HSD by Stencil Type (Un-coated [F] versus Coated [FPN])

The statistical report for this comparison shows that the fine grain polymer nano-coated (FPN) stencils show statistically significant higher transfer efficiency than the fine grain un-coated stencils (F). This same analysis result is also seen when the stencil analysis is separated by each of the other variables.

The comparison of solder paste types is shown below (Figure 13). Again this was simplified by averaging all other variables to highlight the effects of solder paste.

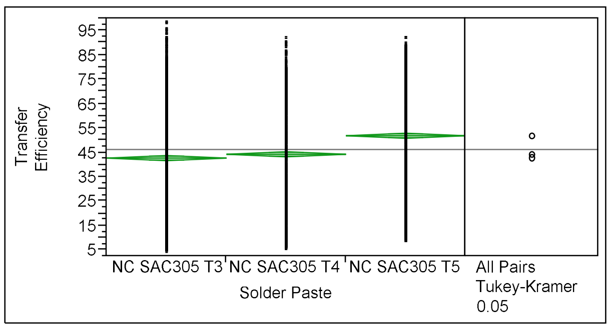

Figure 13 – Tukey-Kramer HSD by Solder Paste Type (Type 3, 4, 5) for Nano-Coated Stencils

The statistical report for this comparison shows significant differences between the solder paste types. Type 5 solder paste provides statistically significant higher transfer efficiency than Type 4 and Type 3 for the nano-coated stencils. Type 4 solder paste provides slightly higher transfer efficiency than Type 3 but this is not statistically significant. These same analysis results are seen when the solder paste type is separated by each of the other variables. A summary of the key Tukey – Kramer HSD statistics is shown below in Table 6.

Table 6 – Summary of Tukey-Kramer HSD Comparisons

Variables Compared	**Effect on TE% (0 = no effect / baseline + = increase ++ = increase over 0 and +)**
Uncoated stencils (F) Nano-coated stencils (FPN)	**0** +
Type 3 paste Type 4 paste Type 5 paste	**0** + ++
Uncoated stencils (F) with Type 3 paste Type 4 paste Type 5 paste	 **0** + ++
Nano-coated stencils (FPN) with Type 3 paste Type 4 paste Type 5 paste	 **0** **0** +

A mark of 0 indicates no statistical difference between the transfer efficiency datasets, or that it is the baseline condition in each category of variables. A mark of (+) indicates a statistically significant increase in transfer efficiency over the baseline

(0) condition. A mark of (++) indicates a statistically significant increase in transfer efficiency over that of the (+) and (0) marked items. Each category of variables was compared separately in Table 6. A rating of (+) in one category is not intended to indicate lower transfer efficiency than a rating of (++) in a different category. The ratings are intended to be compared only within each category. In general the following conclusions can be drawn from the Tukey – Kramer HSD testing.

- The polymer nano-coated stencils provide a statistically significant increase in transfer efficiency versus un-coated stencils.
- Overall Type 4 solder paste provides a statistically significant increase in transfer efficiency versus Type 3 solder paste.
- Overall Type 5 solder paste provides a statistically significant increase in transfer efficiency versus Type 4 and Type 3 solder pastes.
- When un-coated stencils are used Type 4 solder paste provides a statistically significant increase in transfer efficiency versus Type 3 solder paste.
- When un-coated stencils are used Type 5 solder paste provides a statistically significant increase in transfer efficiency versus Type 4 and Type 3 solder pastes.
- When polymer nano-coated stencils are used Type 3 and Type 4 solder pastes provide transfer efficiencies that are statistically similar.
- When polymer nano-coated stencils are used Type 5 solder paste provides a statistically significant increase in transfer efficiency versus Type 4 and Type 3 solder pastes.

3D images (Figure 14) of selected solder paste prints highlight some of the differences observed in this investigation by Area Ratio (AR).

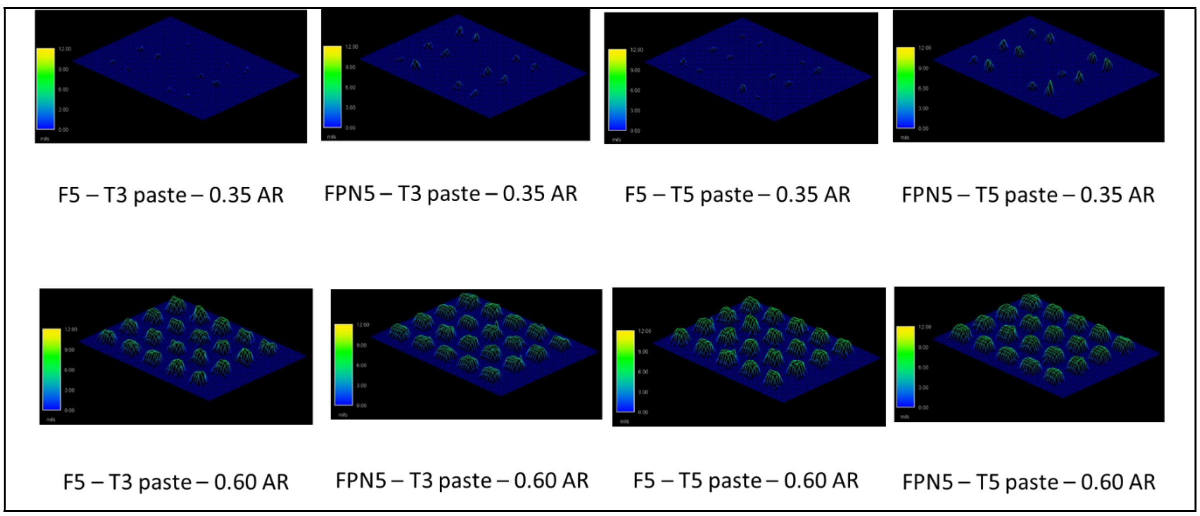

Figure 14 – 3D Images of Solder Paste Prints for the 5 mil Thick Stencils by Area Ratio (AR). Un-Coated (F) Versus Coated (FPN) Stencil Paste Deposit Images Using Type 3 (T3) and Type 5 (T5) Pastes

The 3D solder paste images show how brick definition improves with the use of the polymer nano-coated stencil. Solder paste brick definition also improves when the solder paste is changed from Type 3 to Type 5 for both the uncoated (F) and nano-coated (FPN) stencils.

<u>3.2 03015 Metric Test Stencil Results</u>

The transfer efficiency means and standard deviations for all fine grain uncoated (F) and fine grain nano-coated (FPN) 3 mil and 4 mil thick stencils and Type 4 solder paste are shown below (Table 7).

Table 7 – 03015 Metric Stencil Transfer Efficiency Means and Standard Deviations – Type 4 Solder Paste with 3 mil and 4 mil thick stencils

Stencil	F 3 (Uncoated 3 mil stencil)			F 4 (Uncoated 4 mil stencil)		
Aperture Sizes (mils)	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
5 x 5	17.7	6.9	0.42	4.2	1.7	0.31
5 x 6	25.2	7.6	0.45	6.1	1.8	0.34
6 x 6	34.8	8.2	0.50	13.0	2.4	0.38
6 x 7	40.7	7.7	0.54	17.9	2.5	0.40
Stencil	FPN 3 (Coated 3 mil stencil)			FPN 4 (Coated 4 mils stencil)		
Aperture Sizes (mils)	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
5 x 5	24.1	8.0	0.42	13.5	3.0	0.31
5 x 6	34.4	9.5	0.45	20.6	3.7	0.34
6 x 6	45.4	9.1	0.50	30.0	6.2	0.38
6 x 7	51.8	7.4	0.54	35.6	6.5	0.40

Type 4 solder paste along with 3 mil thick stencils gave high transfer efficiency means that are likely usable for the 03015 metric and 0201 metric components especially when the production polymer nano-coating is used (FPN3). The transfer efficiency means for Type 4 solder paste and the 4 mil thick un-coated stencil (F 4) are low. There were many missing solder paste deposits with this combination.

The transfer efficiency means and standard deviations for all fine grain uncoated (F) and fine grain nano-coated (FPN) 3 mil and 4 mil thick stencils and Type 5 solder paste are shown below (Table 8).

Table 8 – 03015 Metric Stencil Transfer Efficiency Means and Standard Deviations – Type 5 Solder Paste with 3 mil and 4 mil thick stencils

Stencil	F 3 (Uncoated 3 mils stencil)			F 4 (Uncoated 4 mils stencil)		
Aperture Sizes (mils)	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
5 x 5	19.8	5.7	0.42	3.0	1.5	0.31
5 x 6	25.0	4.7	0.45	4.8	1.7	0.34
6 x 6	37.4	6.4	0.50	11.1	2.6	0.38
6 x 7	44.5	6.8	0.54	14.7	3.8	0.40
Stencil	FPN 3 (Coated 3 mils stencil)			FPN 4 (Coated 4 mils stencil)		
Aperture Sizes (mils)	TE% Mean	TE% Stdev	AR	TE% Mean	TE% Stdev	AR
5 x 5	33.8	7.7	0.42	17.4	2.8	0.31
5 x 6	45.9	9.4	0.45	25.8	2.5	0.34
6 x 6	57.9	7.0	0.50	34.9	6.3	0.38
6 x 7	62.2	6.2	0.54	42.5	7.5	0.40

In general, Type 5 solder paste gave higher transfer efficiency means than Type 4 solder paste. This was not the case for the 4 mil thick un-coated stencil (F 4) which produced lower transfer efficiency means with Type 5 solder paste versus Type 4 solder paste. The polymer nano-coated 4 mil thick stencil (FPN 4) gave higher transfer efficiency means for Type 5 solder paste than Type 4 solder paste. The polymer nano-coated stencils gave higher transfer efficiencies than the un-coated stencils for both stencil thicknesses. Transfer efficiency increases for the nano-coated stencil compared with the un-coated stencil by 7% up to 18% for the Type 4 solder paste and by 14% up to 28% for the Type 5 solder paste for both stencil thicknesses.

A bar chart of mean TE% versus aperture size is shown below for the 3 mil thick un-coated (F) and polymer nano-coated (FPN) stencils and Type 5 solder paste (Figure 15).

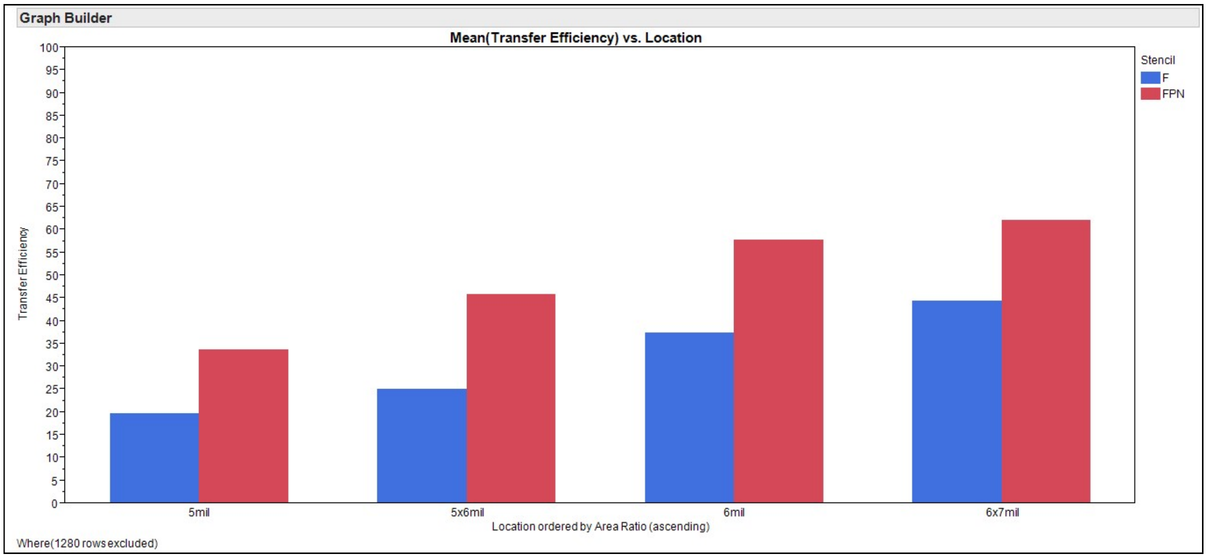

Figure 15 – 03015 Metric Stencils Mean TE% by Aperture Size, 3 mil Thick Uncoated (F) (Blue) and Nano-coated (FPN) (Red) Stencils, Type 5 Solder Paste

Overall the mean transfer efficiencies are generally acceptable for the 3 mil thick stencils and Type 5 solder paste, especially when the polymer nano-coated stencil is used.

A bar chart of mean TE% versus aperture size is shown below for the 4 mil thick uncoated (F) and nano-coated (FPN) stencils and Type 5 solder paste (Figure 16).

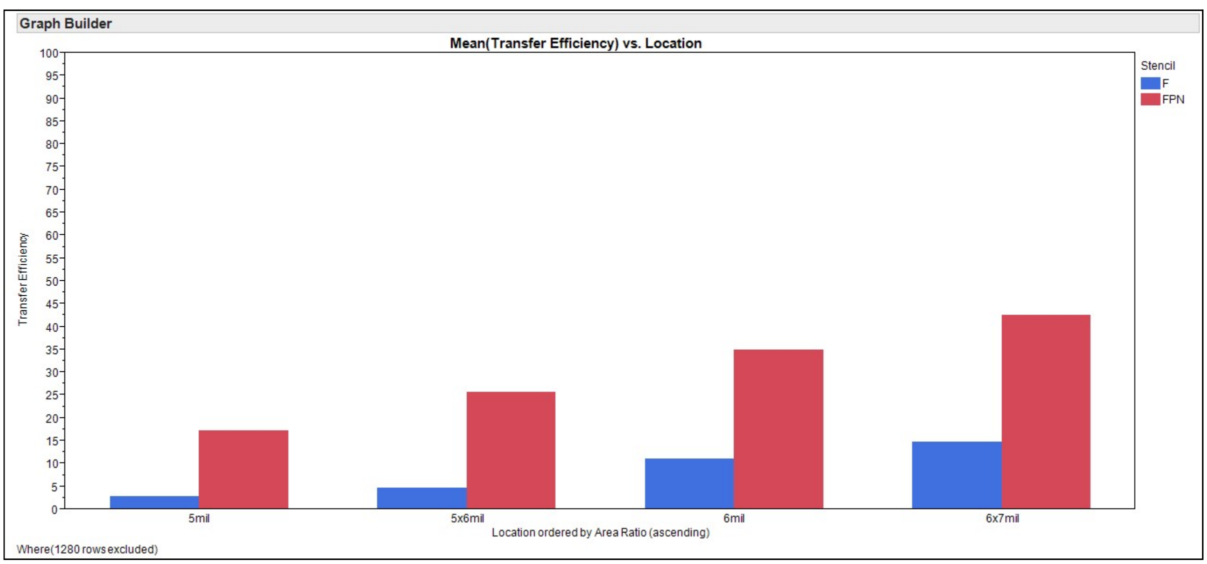

Figure 16 – 03015 Metric Stencils Mean TE% by Aperture Size, 4 mil Thick Uncoated (F) (Blue) and Nano-coated (FPN) (Red) Stencils, Type 5 Solder Paste

Overall the mean transfer efficiencies are lower for the 4 mil thick stencils and Type 5 solder paste versus 3 mil thick stencils and Type 5 solder paste. The un-coated 4 mil thick stencil (F) gave low transfer efficiency and there were many missing solder paste deposits during print testing. The production polymer nano-coating (FPN) gave an increase in TE% with this combination of 4 mil thick stencil and Type 5 solder paste. Despite the increase in the mean transfer efficiencies, the overall TE% numbers for the 4 mil thick nano-coated stencil are generally lower than desired.

The effect of the polymer nano-coating versus non-coated stencil on TE% by Area Ratio is shown below (Figure 17). The chart shows the area ratios for both 03015 metric stencil thicknesses with Type 5 solder paste.

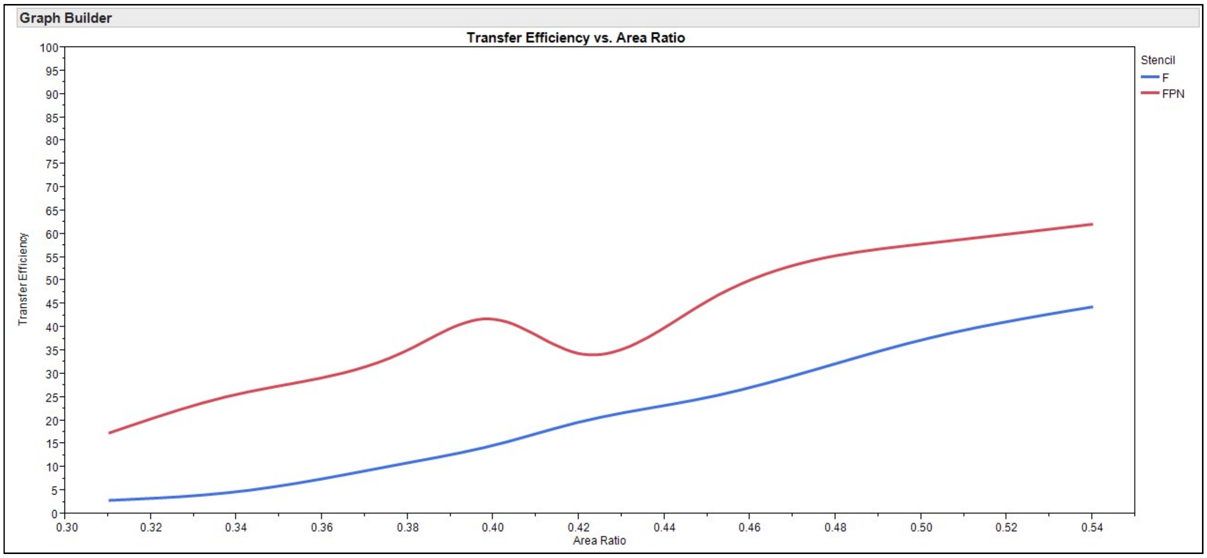

Figure 17 – 03015 Metric Uncoated (F) and Nano-coated (FPN) Stencils Mean TE% by Area Ratio for Both Stencil Thicknesses with Type 5 Solder Paste

The increase in transfer efficiency generated by the production polymer nano-coating is apparent in Figure 17. When printing solder paste through apertures of this small size and small area ratio it is important to use the correct type of solder paste and polymer nano-coated stencils. Due to the increase in transfer efficiency provided by the polymer nano-coating the solder paste printing process window is increased.

Tukey-Kramer HSD analysis of the 03015 metric stencil transfer efficiency data shows statistically significant differences in the data (Figure 18) between nano-coated and uncoated stencils.

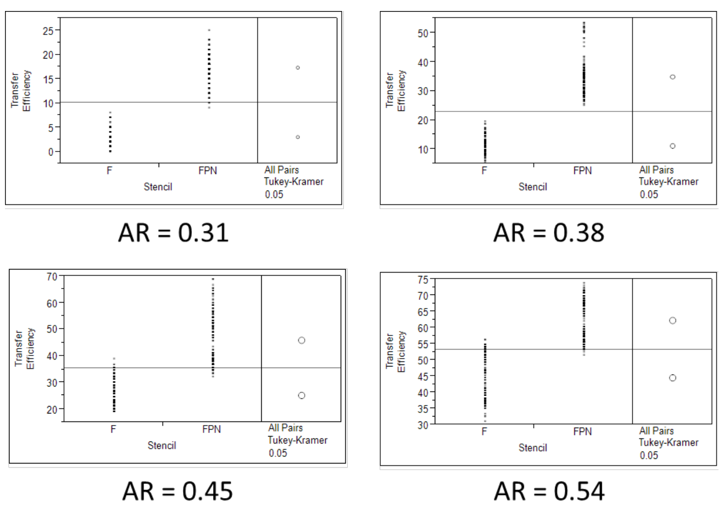

Figure 18 – Tukey-Kramer HSD Diagrams for 03015 Metric Stencils for Un-Coated (F) and Polymer Nano-Coated (FPN) Stencils. Both Types of Solder Paste are combined.

The transfer efficiencies for the polymer nano-coated stencils (FPN) are statistically higher than the transfer efficiencies for the un-coated (F) stencils for all area ratios evaluated.

<u>3.3 Guidelines</u>

In order to establish a set of guidelines, the question at hand is the ideal transfer efficiency to create a “good” solder joint. It is common to use guidelines of 70% or 80% transfer efficiency for most applications [3, 5, 6, 7, 8, 9]. This guideline does not apply as well to very small components with small area ratios. Consumer products have used transfer efficiencies of 40% which in certain cases have produced acceptable solder joints. Industry testing would have to be done to determine the effects of solder paste volume on solder joint quality and reliability which is beyond the scope of this paper.

Based on the results of this investigation a set of general recommendations can be made. These recommendations are listed by component type and category below.

3.3.1 0.3 mm pitch CSP
It is generally recommended that 3 mil thick stencils are used for 0.3 mm pitch CSP components. A polymer nano-coating improves TE% but uncoated stencils can also produce acceptable results. All three types of solder paste (IPC Type 3, 4 or 5) can be used, but Type 4 or Type 5 solder paste should be used if Type 3 solder paste gives lower than desired transfer efficiencies.

3.3.2 0.4 mm pitch CSP
The 0.4 mm pitch CSP components can be used with any of the stencils tested but not all solder paste types can be used with each stencil type. The polymer nano-coated stencils allowed for the use of all solder paste types (IPC Type 3, 4 and 5) with all stencil thicknesses. If uncoated stencils are used then Type 4 or 5 solder paste is generally recommended.

3.3.3 0.5 mm pitch CSP
The 0.5 mm pitch CSP components can be used with any of the stencils tested and the different types of solder paste (IPC Type 3, 4 or 5) due to the relatively high area ratios. The polymer nano-coated stencils improved TE% and solder paste brick definition.

3.3.4 01005 Imperial Chip Components (0402 metric)
It is generally recommended to use 7 or 7.5 mil rounded square apertures for this type of component, along with Type 5 solder paste and polymer nano-coated stencils. 3 mil thick polymer nano-coated stencils are generally preferred for this component type.

3.3.5 0201 Imperial Chip Components (0603 metric)
The 0201 Imperial component layout had the largest area ratio and nearly all combinations tested are recommended. Polymer nano-coated stencils are preferred due to improvements in TE% and solder paste brick definition. All types of solder paste (IPC Type 3, 4 and 5) produced acceptable TE% with this component layout. All stencil thicknesses produced acceptable TE%, but the paste volume requirement for this component type would determine the optimal stencil thickness used.

3.3.6 03015 Metric (0.30 x 0.15 mm) and 0201 Metric (0.20 x 0.10 mm) Chip Components
Both of these component layouts push the lower limits of aperture size and area ratios (0.31 to 0.54). Solder paste printing is very challenging for these small component types. Type 5 solder paste is generally recommended along with the 3 mil thick polymer nano-coated stencils.

3.3.7 Stencil Thickness
The thinner stencils produced higher TE% than the thicker stencils due to the higher area ratios. The 3 mil thick stencils are generally recommended for use with more combinations than the 4 or 5 mil thick stencils. The stencil with most recommended combinations is 3 mil thick with the polymer nano-coating. Stencil thickness has to be selected for the specific application to ensure that solder paste volume is adequate for all of the components used. If solder paste volumes are too high, then bridging might become a concern especially for 0.3 mm and 0.4 mm pitch component applications.

3.3.8 Nano-Coated versus Un-Coated Stencils
Polymer nano-coated stencils showed a benefit in improved transfer efficiencies by 5% up to 30% for most combinations tested. Solder paste brick definition is also improved through the use of polymer nano-coated stencils.

3.3.9 Solder Paste Type
As expected, Type 5 solder paste improved solder paste print transfer efficiency (TE%) versus Type 4 and Type 3 solder pastes. Type 5 solder paste would be of most benefit when considering use of 01005 Imperial (0402 metric), 03015 metric and 0201 metric components. This is similar to results developed by other studies [4]. Type 5 solder paste is generally more susceptible to solder reflow defects like graping because of the larger surface area of the solder powder particles than Type 4 and 3 solder pastes. The choice of solder paste powder type should be balanced between the need for improved TE% versus potential soldering issues.

4.0 CONCLUSIONS

It is possible to create a robust printing process for 01005 Imperial (0402 metric), 03015 metric, 0201 metric chip components and fine pitch (0.3 mm and 0.4 mm) CSPs with laser-cut fine-grain stainless steel stencils using polymer nano-coatings, and different solder paste types. Aperture area ratios down to 0.30 can be used and adequate solder paste transfer efficiency can be obtained. Fine grain laser-cut nano-coated stainless stencils work well for small chip components and fine pitch components when paired with solder pastes made with smaller sized solder powders (e.g. Type 4 or 5 solder powder). A statistically significant increase in transfer efficiency can be obtained through the use of a production polymer nano-coating on the stencils with transfer efficiencies increasing from 5% to 30% over non-coated stencils. Use of a polymer nano-coated stencil along with Type 5 solder paste gave the overall highest transfer efficiencies. General guidelines for the use of 01005 Imperial and smaller components and fine pitch CSPs have been established and are reported in the results and discussion section of this paper.

5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES

[1] T. Lentz, "Performance Enhancing Nano-Coatings: Changing the Rules of Stencil Design", Proceedings of SMTA International, 2014.

[2] M. Whitmore, J. Schake, "The Development of a 0.3mm Pitch CSP Assembly Process Part 2: Assembly & Reliability", Proceedings of SMTA International, 2015.

[3] S. Harter, J. Franke, C. Lantzsch, "Evaluation of the Stencil Printing for Highly Miniaturized SMT Components with 03015MM in Size", Proceedings of SMTA International, 2015.

[4] R. Gray, "Development of a Robust 03015 Process", Proceedings of IPC Apex Expo, 2015.

[5] C. Ashmore, "Big Ideas on Miniaturisation", Proceedings of IPC Apex Expo, 2013.

[6] E. Moen, "Advances in Stencil Technology to Facilitate Ultra-Fine Pitch Printing", Intermountain Expo and Tech Forum, 2014.

[7] R. Bennett, E. Hanson, "Low Surface Energy Coatings, Rewrites the Area Ratio Rules", Proceedings of IPC Apex Expo, 2013.

[8] R. Short, W. Coleman, J. Perault, "Print Performance Studies Comparing Electroform and Laser-Cut Stencils", Proceedings of IPC Apex Expo, 2014.

[9] L. Bruno, T. Johnson, "Printing of Solder Paste – A Quality Assurance Methodology", Proceedings of IPC Apex Expo, 2014.

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