PERFORMANCE ENHANCING NANO-COATINGS: CHANGING THE RULES OF STENCIL DESIGN

Tony Lentz
FCT Assembly
Greeley, CO, USA
tlentz@fctassembly.com

ABSTRACT
Nano-coatings are applied to solder paste stencils with the intent of improving the solder paste printing process. Do they really make a noticeable improvement? The effect of Nano-coatings on solder paste print performance was investigated. Transfer efficiencies were studied across aperture sizes ranging from 0.30 to 0.80 area ratio. Also investigated were the effects of Nano-coatings on transfer efficiencies of tin-lead, lead-free, water soluble, no-clean, and type 3, 4, and 5 solder pastes. Solder paste print performance for each Nano-coating was summarized with respect to all of these variables.

Standard industry rules for stencil aperture design suggest that area ratios be kept above 0.66 for acceptable transfer efficiency. The intent of this rule is to ensure that solder paste volume is adequate for an acceptable process window. Nano-coatings, however, are changing this rule. Guidelines for stencil design are recommended based on the performance of Nano-coatings.

Key words: Nano-coating, Stencil Design, Area Ratio, Solder Paste Volume, Transfer Efficiency

INTRODUCTION
Nano-coatings for stencils have been in use for a few years. They have been shown to provide both benefits and negative impacts to the solder paste printing process [1]. The goal of this paper is to challenge nano-coatings with a wider range of aperture sizes than previously tested. The area ratios studied range from 0.30 up to 0.80. The ongoing trend for miniaturization of electronics [2, 3] ensures that aperture sizes will continue to get smaller. What effect do nano-coatings have on printing through apertures smaller than what is commonly used today?

It is accepted that different types of solder pastes print and release from the stencil differently. The effects of type of solder paste on the printed volume were studied. The effects of nano-coatings in combination with different types of solder paste were also examined.

The current guidelines for stencil design [4] were established to help the user to achieve adequate soldering. This assumes that printing through a specified size and shape of aperture will produce a certain solder paste volume and result in adequate soldering. Nano-coatings and solder paste type both affect printed solder paste volume. Some nano-coatings have been shown to increase solder paste volume [1]. Nano-coatings and solder paste type should be taken into account in future guidelines for stencil design.

EXPERIMENTAL METHODOLOGY
A test stencil was designed with the intent of challenging the nano-coatings, and the solder pastes used in this study. The stencil design includes a range of aperture surface area ratios from 0.30 to 0.80. The stencil design contains several types of components including QFP's, BGA's, micro BGA's, micro CSPs, 0201, and 01005 components.

Three nano-coatings were tested and an uncoated stencil was used as the baseline. Two of the nano-coatings are supplied as wipe-on coatings. These coatings are named B and C in this study. One of the nano-coatings is supplied as a spray on and thermally cured coating. This coating is labeled as D in this study. In prior work [1], a second spray and thermal cure type coating was evaluated. That particular coating was labeled as A. Coating A was not included in this study. In an effort to maintain consistency with nomenclature in prior work, Coatings B, C, and D are the same materials as were tested previously.

Solder pastes were varied in this study to include both water soluble and no clean chemistries, leaded and lead-free solders, and solder powder size variations between type 3, 4, and 5. The solder pastes tested include:

No clean, SAC 305 Type 3, 4, and 5
Water soluble, SAC 305 Type 3
No clean, Sn63/Pb37 Type 3
Water soluble, Sn63/Pb37 Type 3

The intent was to determine if these variations in solder paste show differences in printed solder paste volumes. The effects of the nano-coatings along with these changes in solder paste were also examined.

Each variation was tested using a 10 print study. The circuit boards used were copper clad material without any kind of pads. This was done in order to eliminate any chance of error due to misalignment of the stencil to the pads. No underside cleaning was done on the stencils between prints. Solder paste volumes were measured and transfer efficiency percentages (TE) were calculated for each area ratio of aperture. The data was averaged for each area ratio throughout all 10 prints.

TE (%) = (volume of solder paste printed) ÷ (volume of stencil aperture) x 100%

Equipment and Materials
The equipment and materials used for this study are detailed below.

Essemtec printer
Print speed = 20 mm/sec
Print pressure = 0.18 kg/cm (1 lb/inch)
Separation speed = 1.5 mm/sec

ASC International solder paste inspection
Vision Master AP212 with an ASCan Ultra VM150 sensor

Solder pastes
No clean, SAC 305 Type 3, 4, and 5
Water soluble, SAC 305 Type 3
No clean, Sn63/Pb37 Type 3
Water soluble, Sn63/Pb37 Type 3

Circuit boards
0.059 inch thick (1.5 mm) FR4, 0.5/0.5 oz copper, 6.0" x 3.75" size (15.2 cm x 9.5 cm).

Stencils
0.005 inch thick (127 microns), 304 stainless steel, Datum PhD. All stencils were made on the same day, using the same laser.

Stencil design
The Surface Area Ratio (SAR) stencil design is shown below (Figure 1). The design includes many different types of components commonly used. A picture of the printed solder paste (Figure 2) shows that release is possible, even through apertures with area ratios as low as 0.30.

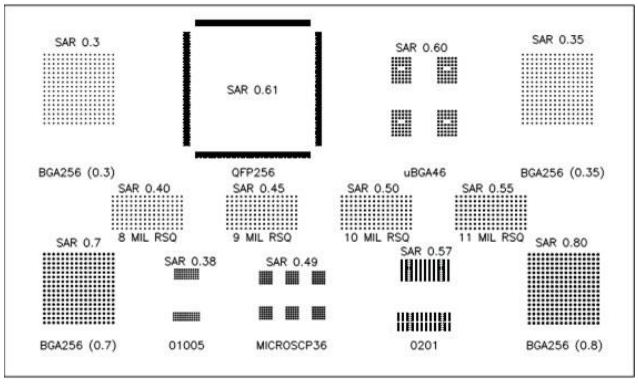

Figure 1: SAR Test Stencil

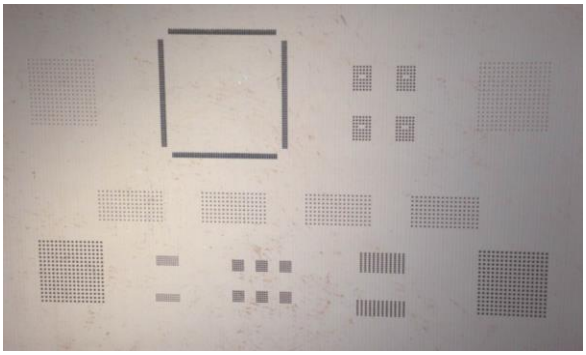
Figure 2: Printed solder paste on copper clad

The complete list of area ratios (SAR), components, aperture sizes, shapes, volumes, and number of measurements taken is shown below (Table 1). The aperture size and volumes are taken from the stencil design files and are not measured values. In most cases, rounded square (RSQ) apertures were used, which is standard practice for the stencil supplier that made the test stencils. The number of solder paste bricks measured is the total for 1 print. The total number measured for each variation in this study is 10 times that number.

Table 1: Aperture and component list for SAR test

Area Ratio (SAR)	Component	Aperture Size (mils)	Aperture Shape	Aperture Volume (mil³)	# Bricks Measured
0.300	BGA	6	RSQ	180	128
0.350	BGA	7	RSQ	245	128
0.380	01005	7.5	RSQ	281	103
0.400	BGA	8	RSQ	320	128
0.450	BGA	9	RSQ	405	128
0.490	microCSP	9.8	RSQ	480	108
0.500	BGA	10	RSQ	500	128
0.550	BGA	11	RSQ	605	128
0.570	0201	10x13	Rectangle	650	103
0.600	uBGA	12	RSQ	720	184
0.610	QFP	50x7	Rectangle	1750	128
0.700	BGA	14	RSQ	980	128
0.800	BGA	16	RSQ	1280	128

Surface area ratio [5] is calculated in the same manner as area ratio (Figure 3).

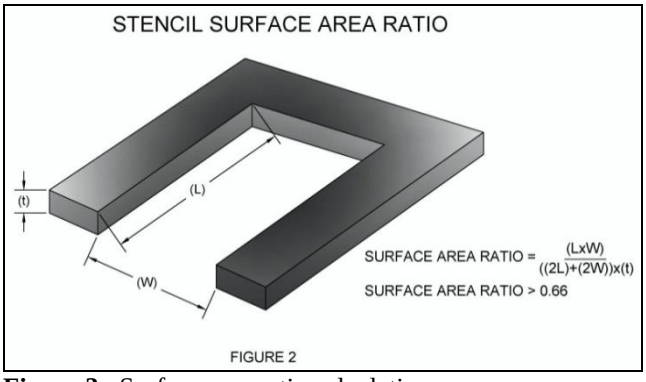

Figure 3: Surface area ratio calculation

The term Surface Area Ratio is abbreviated as SAR in this paper. This abbreviation is preferable over an abbreviation of area ratio (AR), which may be confused with Aspect Ratio. Aspect ratio is an entirely different calculation, and is not used in this paper.

RESULTS

The results of this evaluation are listed by general topic followed by discussion of the results of each test. The results are based on transfer efficiency percentages for each SAR averaged out over ten prints. The effects of nano-coatings are presented first, followed by solder powder size variations, then a comparison of no-clean and water soluble solder pastes, and finally a comparison of leaded and lead-free solder pastes.

Nano-Coating Effects

All nano-coatings were studied initially using a no-clean, SAC305 Type 3 solder paste. The data is presented in a chart of Transfer Efficiency % vs. Component in order of increasing SAR (Figure 4). The bars show the average transfer efficiency. The colors of the bars represent each stencil coating: coating B is blue, coating C is red, coating D is green, and uncoated is silver/gray.

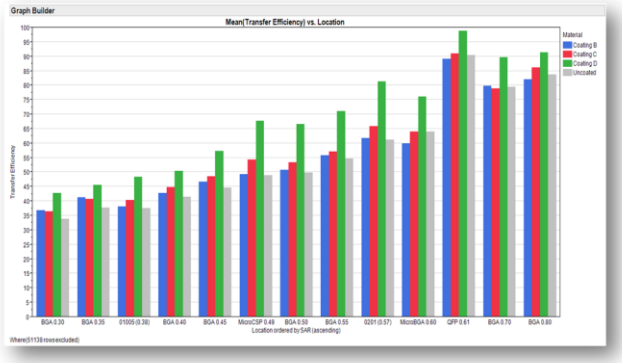

Figure 4: Nano-coating effect on solder paste volumes using no-clean, SAC305 Type 3 solder paste

As expected, transfer efficiency increases with increasing SAR from left to right. The QFP with 0.61 SAR gave higher solder paste volumes than any other component. This is due to the large rectangular aperture design (50x7 mils). Coating C gave a slightly higher TE than coating B. Coating B gave a similar TE to the uncoated stencil. Coating D gave a much higher TE than the other coatings for all aperture SARs. The effect of thermally cured nano-coatings, like Coating D, has been reported by Ferrell and Shea [6] and Short, Coleman, and Perault [7].

Condensing the data for all aperture sizes into an overall average TE gives an idea of nano-coating performance (Figure 5).

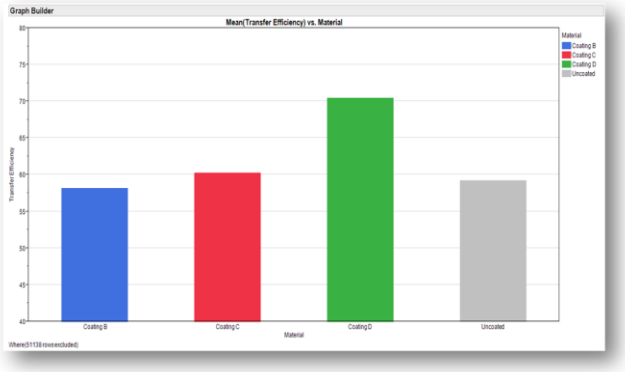

Figure 5: Overall summary of nano-coating effect on solder paste volumes. No-clean, SAC305 Type 3 solder paste.

SAC305 Type 3 no clean paste, overall transfer efficiency numbers:

Coating B: 58%
Coating C: 60%
Coating D: 71%
Uncoated stencil: 59%

The nano-coated stencils were tested again with no-clean, SAC305 Type 4 solder paste (Figure 6).

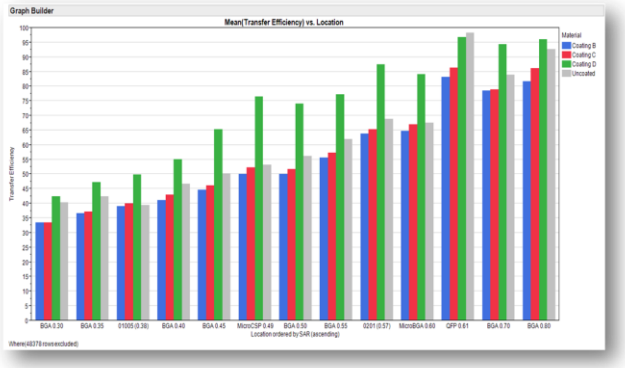

Figure 6: Nano-coating effect on solder paste volumes using no-clean, SAC305 Type 4 solder paste

The same basic trends are displayed with type 4 solder paste as were seen with type 3 solder paste. Again, there is an anomaly in the results for the QFP with 0.61 SAR. The uncoated stencil gave higher volume than all of the coated stencils at 0.61 SAR. This does not follow the basic trends visible in the data. Overall, coatings B and C both gave slightly lower transfer efficiencies than the uncoated stencil. This is consistent with results found by Shea and Whittier [8]. Coating D again gave much higher transfer efficiencies than the other coatings.

The effect of the nano-coatings on transfer efficiency becomes readily apparent when the data is condensed into an overall average (Figure 7).

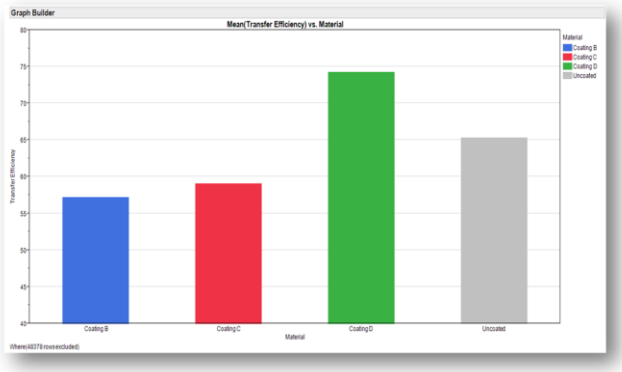

Figure 7: Overall summary of nano-coating effect on solder paste volumes. No-clean, SAC305 Type 4 solder paste.

The overall transfer efficiency numbers for SAC305 Type 4 no clean paste are listed below.

Coating B: 57%
Coating C: 59%
Coating D: 74%
Uncoated stencil: 65%

Transfer efficiency is decreased by coatings B and C, while coating D gives a large increase as compared to the uncoated stencil.

The nano-coated stencils were tested again with no-clean, SAC305 Type 5 solder paste (Figure 8).

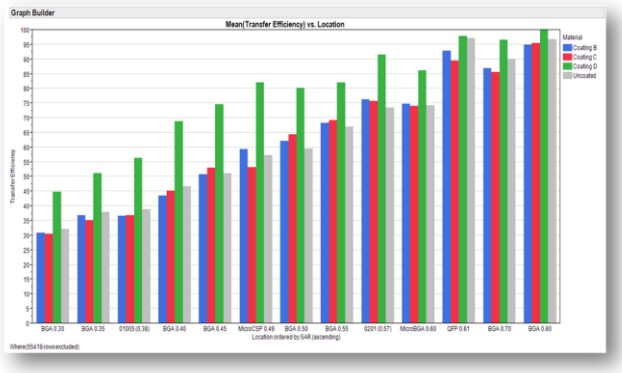

Figure 8: Nano-coating effect on solder paste volumes using no-clean, SAC305 Type 5 solder paste

Trends with Type 5 solder paste follow those seen with Type 3 and Type 4 solder pastes. The difference in transfer efficiency between coatings B, C, and D becomes smaller with increasing SAR. This follows with the general understanding that solder paste releases more easily from larger area ratio apertures. Farrell and Shea [9] reported similar trends for both Type 4 and Type 5 solder pastes.

The overall average transfer efficiency numbers for Type 5 solder paste are shown below (Figure 9).

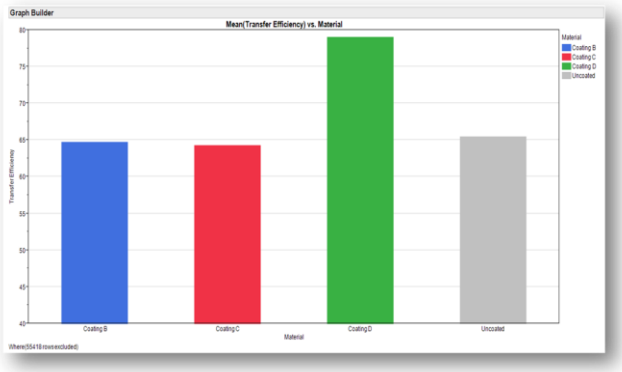

Figure 9: Overall summary of nano-coating effect on solder paste volumes. No-clean, SAC305 Type 5 solder paste.

The overall transfer efficiency numbers for SAC305 Type 5 no clean paste are listed below.

Coating B: 65%
Coating C: 64%
Coating D: 78%
Uncoated stencil: 65%

In this case, coatings B and C produced little change on the transfer efficiency, while coating D again gave a large increase.

Print stroke direction can cause variation in measured solder paste volume [2]. The printer used for this study is no exception. In this case, the odd number print direction is towards the operator, and the even number print direction is away from the operator. The transfer efficiency was condensed into an overall average for each print, and was charted by print number (Figure 10).

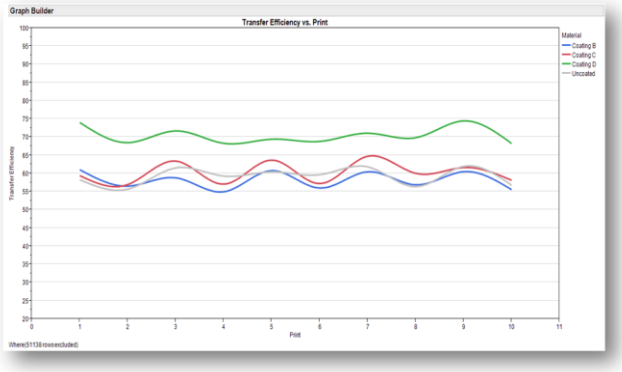

Figure 10: Print stroke effect on transfer efficiency, using no clean, SAC305 Type 3 solder paste

The odd numbered prints gave higher transfer efficiencies than the even numbered prints. The amplitude of the peaks to valleys for the uncoated stencil is fairly low, especially in the middle section of prints. The amplitude for coating B is slightly lower than that of coating C. Both coatings B and C show larger print stroke differences than the uncoated

stencil. Coating D reduced the differences in TE due to print stroke direction especially for the middle section of prints.

This paper was not intended to study the effects of print stroke on solder paste volumes. It is an interesting side note that nano-coatings have an effect on these differences. This might bear future study.

Coefficients of variation (CV) were calculated for the no clean, SAC 305 Type 3 print studies. The coefficient of variation is a percentage calculated as standard deviation divided by the mean transfer efficiency. The data is presented in order of increasing aperture SAR (Figure 11). Each color of bar represents the type of nano-coating on the stencil.

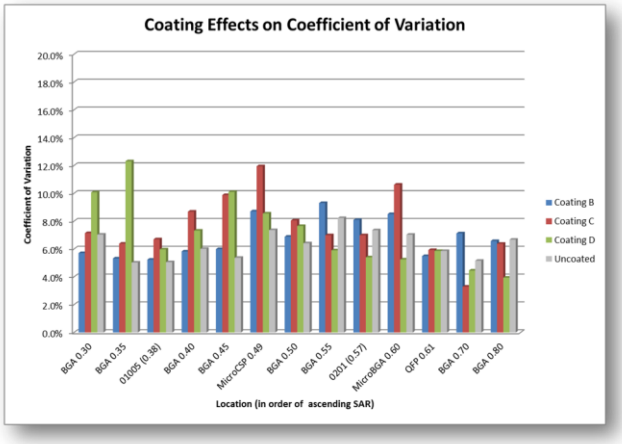

Figure 11: Coefficients of variation, using no clean, SAC305 Type 3 solder paste and the uncoated stencil

A coefficient of variation below 10% is a guideline for good print repeatability [6, 9]. The nano-coatings produced CV values greater than 10% for certain apertures. Coating D produced a CV > 10% for the lower SAR apertures (0.30 and 0.35 SAR). Coating C produced a CV > 10% at 0.49 and 0.60 SARs. The CV data was condensed into a mean result for each stencil and is listed below.

Uncoated: 6.4% mean coefficient of variation
Coating B: 6.9%
Coating C: 7.7%
Coating D: 7.1%

In general, nano-coatings increase CV slightly as compared to an uncoated stencil. The mean CV for each stencil is well below 10% indicating good overall print repeatability.

Solder Powder Size Variations (Type)
The effects of changing the solder powder size can be seen by examining the data for the uncoated stencil (Figure 12).

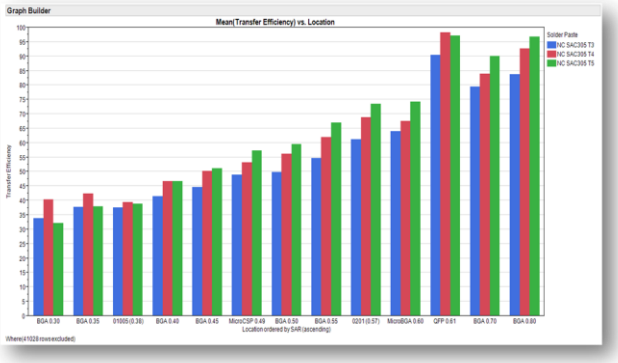

Figure 12: Transfer efficiency data for the uncoated stencil and no-clean, SAC305 Type 3, 4, and 5 solder pastes

In general, the transfer efficiency increases as solder powder type increases (powder size decreases). The difference in TE becomes minimal with decreasing aperture size. This is counter-intuitive. One would expect smaller solder powder sizes to give higher volumes through the smaller SAR apertures. Type 4 solder paste produced higher volumes than type 5 at the lowest SARs of 0.30 and 0.35.

Condensing the data into an overall TE average for each solder paste type shows some unexpected results (Figure 13).

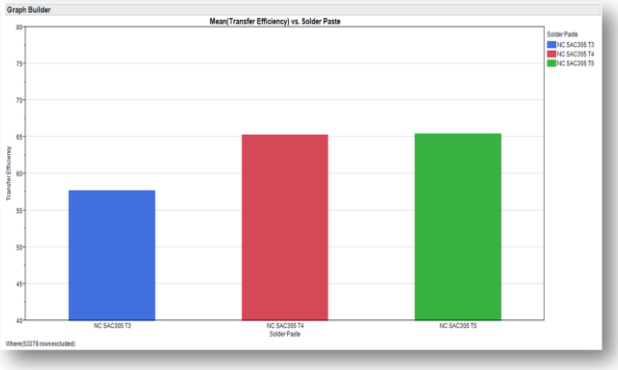

Figure 13: Overall summary of transfer efficiency for the uncoated stencil. No-clean, SAC305 Type 3, 4, and 5 solder pastes.

No-clean, SAC305 Type 3 solder paste produced an overall average TE of 58%. Type 4 and Type 5 versions of this solder paste produced the same overall average TE of 65%. This might indicate that the range of SARs chosen for this study are not challenging enough to differentiate between type 4 and 5 solder pastes. This result bears further investigation.

No-Clean vs. Water Soluble Solder Pastes
No-clean and water soluble, SAC305 Type 3 solder pastes were both printed through the uncoated stencil. The transfer efficiency results are shown below (Figure 14).

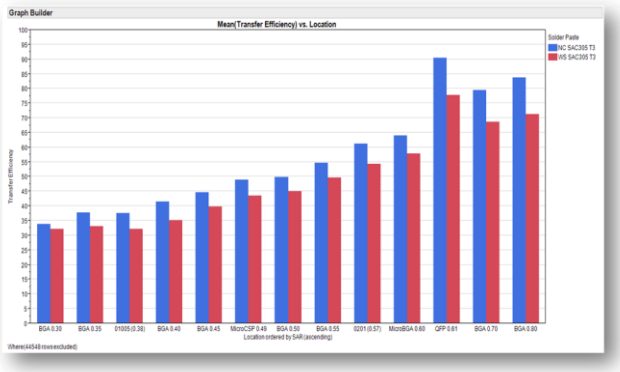

Figure 14: Transfer efficiencies of no clean vs. water soluble, SAC305 Type 3 solder pastes and the uncoated stencil

In general, the no clean solder paste produced higher transfer efficiencies than the water soluble paste. This difference increased with an increasing SAR value.

The same comparison was done with no clean and water soluble, Sn63/Pb37 Type 3 solder pastes (Figure 15).

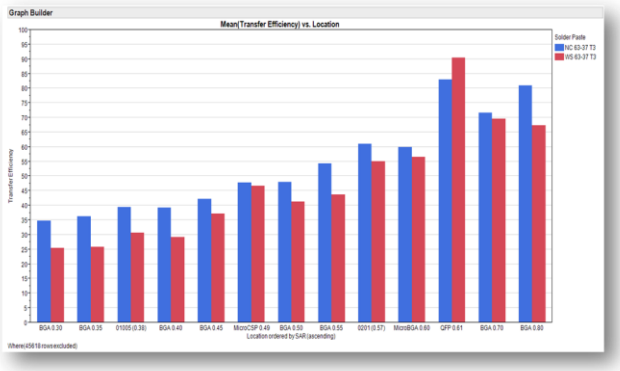

Figure 15: Transfer efficiencies of no clean vs. water soluble, Sn63/Pb37 Type 3 solder pastes and the uncoated stencil

The same general trend is seen with the no clean paste producing higher transfer efficiencies than the water soluble paste. This trend was reversed with the QFP 0.61 SAR apertures.

Leaded vs. Lead-Free Solder Pastes

The data for the varying solder pastes was combined into one graph in order to see the differences of leaded versus lead-free solder pastes (Figure 16). These were all run through the uncoated stencil.

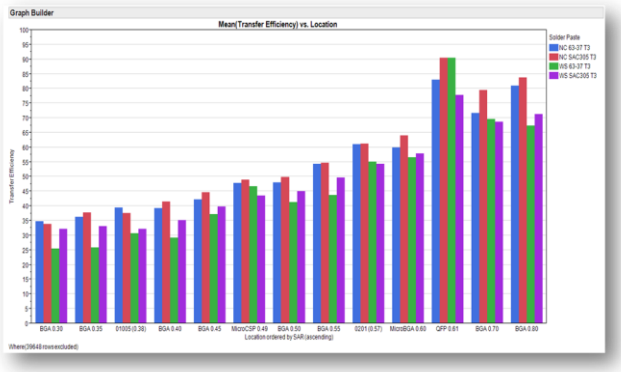

Figure 16: Transfer efficiencies of Type 3 solder pastes printed through the uncoated stencil.

Comparing the no clean leaded paste (blue bars) to the no clean lead-free paste (red bars) shows that the lead-free paste produces higher transfer efficiencies. The difference in transfer efficiencies becomes greater with increasing SAR.

Comparing the water soluble leaded paste (green bars) to the water soluble lead-free paste (purple bars), the same general trend is seen. However, the difference in transfer efficiencies seems to trend in the opposite direction. The difference seems to become greater with decreasing SAR.

This data was condensed into an overall average transfer efficiency for each solder paste run through the uncoated stencil (Figure 17).

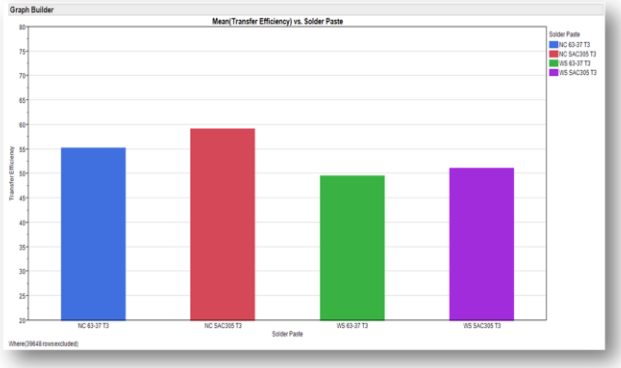

Figure 17: Overall average transfer efficiencies of Type 3 solder pastes printed through the uncoated stencil.

The no clean, lead-free solder paste produced the highest overall transfer efficiency, while the water soluble, leaded solder paste produced the over lowest transfer efficiency. Please be aware that this result is applicable for the solder pastes used in this study, along with the SAR test stencil. Formulations of solder paste from alternate suppliers may show different results. Certain aperture designs, such as the QFP 0.61 SAR, also showed trends different from the rest of the apertures. The main message is that solder paste flux chemistry and alloy both affect transfer efficiency.

STENCIL DESIGN RULES

The current industry standard for stencil design is IPC-7525B [4]. Within this standard are several recommended stencil design guidelines. The intent of these guidelines is to help the stencil user to print the correct amount of solder paste in the correct location, in order to produce a good solder joint. A brief summary of these guidelines is presented here. This is followed by details on how nano-coatings and solder pastes affect these guidelines.

IPC-7525B Section 3.2.1 Aperture Size [4] gives a guideline for aperture size based on the solder powder particle size. The typical guideline is that 4-5 particles of solder powder must fit across the smallest dimension of an aperture. This is summarized in the table below (Table 2).

Table 2: Aperture size based on solder powder size

Type	Mesh	Size (um)	Size (mil)	Min Aperture Size (mil)
2	-200/+325	45 - 75	1.8 - 3.0	15.0
3	-325/+500	25 - 45	1.0 - 1.8	9.0
4	-400/+635	20 - 38	0.8 - 1.5	7.5
5	-500/+800	15 - 25	0.6 - 1.0	5.0

The minimum aperture size listed at the right of Table 2 is calculated based on the maximum particle size times 5 particles. This guideline gives some direction on which solder paste powder type to use. However, this guideline does not take into account stencil thickness, surface area ratio, or the effects of nano-coatings.

IPC-7525B Section 3.2.1.2 Area Ratio/Aspect Ratio [4] gives a guideline to maintain the aspect ratio above 1.5 or the area ratio above 0.66. Aspect ratio is simply the smallest dimension of an aperture divided by the thickness of the stencil. This does not take into account the surface area of the side walls. Area ratio guidelines deal only with the size of the aperture and the thickness of the stencil. Aspect and area ratio do not take into account solder paste or nano-coating effects.

IPC-7525B Table 3-2 General Aperture Design Guideline Examples [4] gives guidelines for surface mount devices.

Table 3: IPC-7525B Table 3-2

Table 3-2 General Aperture Design Guideline Examples for Selective Surface-Mount Devices (Tin Lead Solder Paste)

Part Type	Pitch	Land Footprint Width	Land Footprint Length	Aperture Width	Aperture Length	Stencil Thickness Range	Aspect Ratio Range	Area Ratio Range	Solder Paste Type
PLCC	1.25 mm [49.2 mil]	0.65 mm [25.6 mil]	2.00 mm [78.7 mil]	0.60 mm [23.6 mil]	1.95 mm [76.8 mil]	0.15 - 0.25 mm [5.91 - 9.84 mil]	2.4 - 4.0	0.92 - 1.53	Type 3
QFP	0.65 mm [25.6 mil]	0.35 mm [13.8 mil]	1.50 mm [59.1 mil]	0.30 mm [11.8 mil]	1.45 mm [57.1 mil]	0.15 - 0.175 mm [5.91 - 6.89 mil]	1.7 - 2.0	0.71 - 0.83	Type 3
QFP	0.50 mm [19.7 mil]	0.30 mm [11.8 mil]	1.25 mm [49.2 mil]	0.25 mm [9.84 mil]	[1.20 mm] 47.2 mil	0.125 - 0.15 mm [4.92 - 5.91 mil]	1.7 - 2.0	0.69 - 0.83	Type 3
QFP	0.40 mm [15.7 mil]	0.25 mm [9.84 mil]	1.25 mm [49.2 mil]	0.20 mm [7.87 mil]	[1.20 mm] 47.2 mil	0.10 - 0.125 mm [3.94 - 4.92 mil]	1.6 - 2.0	0.69 - 0.86	Type 3
QFP	0.30 mm [11.8 mil]	0.20 mm [7.87 mil]	1.00 mm [39.4 mil]	0.15 mm [5.91 mil]	0.95 mm [37.4 mil]	0.075 - 0.125 mm [2.95 - 4.92 mil]	1.2 - 2.0	0.52 - 0.86	Type 3
0402	N/A	0.60 mm [19.7 mil]	0.65 mm [25.6 mil]	0.45 mm [17.7 mil]	0.60 mm [23.6 mil]	0.125 - 0.15 mm [4.92 - 5.91 mil]	N/A	0.86-1.03	Type 3
0201	N/A	0.4 mm [9.84 mil]	0.45 mm [15.7 mil]	0.23 mm [9.06 mil]	0.35 mm [13.8 mil]	0.075 - 0.125 mm [2.95 - 4.92 mil]	N/A	0.56 - 0.93	Type 3
01005	N/A	0.200 mm [7.87 mil]	0.300 mm [11.81 mil]	0.175 mm [6.89 mil]	0.250 mm [9.87 mil]	0.063 - 0.089 mm [2.5 - 3.5 mil]	N/A	0.58 - 0.81	Type 4
BGA	1.25 mm [49.2 mil]	CIR 0.55 mm [21.6 mil]		CIR 0.52 mm [20.45 mil]		0.15 - 0.20 mm [5.91 - 7.87 mil]	N/A	0.65 - 0.86	Type 3
Fine-pitch BGA	1.00 mm [39.4 mil]	CIR 0.45 mm [15.7 mil]		SQ 0.42 mm [13.8 mil]		0.115 - 0.135 mm [4.53 - 5.31 mil]	N/A	0.65 - 0.76	Type 3
Fine-pitch BGA	0.50 mm [19.7 mil]	CIR 0.25 mm [9.84 mil]		SQ Overprint 0.28 mm [11.0 mil]		0.075 - 0.125 mm [2.95 - 4.92 mil]	N/A	0.56 - 0.93	Type 3
Fine-pitch BGA	0.40 mm [15.7 mil]	CIR 0.20 mm [7.87 mil]		SQ Overprint 0.23 mm [9 mil]		0.075 - 0.100 mm [2.95 - 4 mil]	N/A	0.56 - 0.75	Type 4

Note 1: It is assumed that the fine-pitch BGA lands are not solder mask defined.
Note 2: N/A implies that only the area ratio should be considered.

Included in table 3 are land dimensions, aperture dimensions, stencil thickness ranges, aspect ratio and area ratios, and recommended solder paste particle size. The authors of the standard combined together specifications for the circuit board, stencil and solder paste. This table could not contain recommendations for every possible combination of these items. Again the effects of solder paste flux, and nano-coatings are not considered.

IPC-7525B Figure 3-2 [4] shows a diagram of area ratio limits for different stencil technologies (Figure 18). This particular figure is for a 5 mil (127 micron) thick stencil. IPC-7525B contains similar figures for other stencil thicknesses.

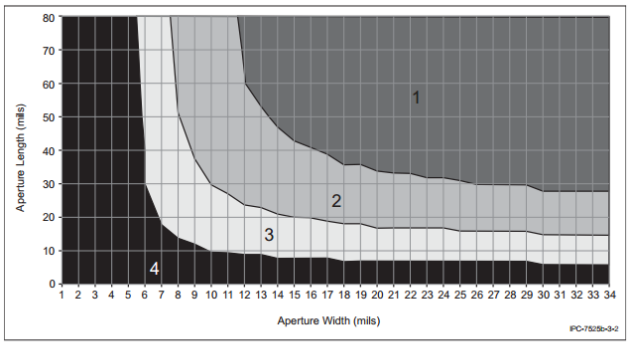

Figure 3-2 5 mil Thick Stencil Tin Lead and Lead Free
1. Electroformed, Laser, High-Precision Etch or Chem-Etch Range (AR >0.9)
2. Electroformed, Laser, High-Precision Etch (0.66< AR <0.9)
3. Electroform Range (0.5< AR <0.66)
4. Recommended Aperture Redesign or Reduce Stencil Thickness (AR <0.5)

Figure 18: IPC-7525B Figure 3-2

This figure gives some guidance on area ratios based on the fact that certain types of stencils can increase transfer efficiency. Solder paste and nano-coating effects are not addressed. One could envision this figure being modified to include nano-coated stencils. Section 4 could be changed to represent those nano-coatings which improve transfer efficiency allowing for printing to area ratios below 0.50. Section 5 would be added below the area ratio limit at which aperture redesign is recommended.

Suggested Minimum SAR Rules

The IPC-7525B stencil design standard does not give a limit for minimum solder paste volume. The assumption is made that when the stencil apertures are designed with a minimum SAR, then the printing process will produce adequate solder paste volume (TE). A generally used limit for acceptable transfer efficiency is 70% [10]. Other studies [7, 11] use a limit of 80% TE. The actual amount of solder paste that is required to create a good solder joint varies based on factors outside of the scope of this study.

A limit of 70% TE was applied to the data in this study, which resulted in the following guidelines for minimum aperture SAR (Table 4).

Table 4: Minimum SAR allowing 70% transfer efficiency

Solder Paste	Uncoated	Coating B	Coating C	Coating D
NC SAC T3	0.61	0.61	0.61	0.55
NC SAC T4	0.61	0.61	0.61	0.49
NC SAC T5	0.57	0.57	0.57	0.45
WS SAC T3	0.70	ND	ND	0.61

ND entries indicate tests that were not run and are therefore not determined. The guidelines in this table take into account both solder paste variation and nano-coating effects. Please be aware that these limits are applicable for the specific solder pastes and nano-coatings used in this experiment. Other solder pastes and coatings [7] may give different results.

When an uncoated stencil is used, the minimum SAR is 0.61 for both type 3 and type 4 SAC305 no clean solder pastes. The minimum SAR drops to 0.57 when type 5 SAC305 no clean paste is used. If water soluble, SAC305 type 3 solder paste is used, then the minimum SAR increases to 0.70.

Nano-coatings B and C gave similar SAR guidelines as the uncoated stencil with the no clean, SAC305 pastes that were used. The slight reduction in transfer efficiency seen with nano-coatings B and C was not enough to impact the SAR guidelines near the pass/fail limit of 70% transfer efficiency.

Nano-coating D gave lower SAR guidelines than the uncoated stencil for all solder pastes tested. All of these guidelines ranging from 0.45 to 0.61 SAR are much lower than the current rule of 0.66 minimum area ratio. This is due to the effect that nano-coating D has on increasing transfer efficiency.

CONCLUSIONS

Nano-coatings and solder pastes both have an impact on transfer efficiency. There are many other factors that affect solder paste release including [11]: stencil design, stencil to PWB registration, PWB design, printer parameters, and environmental conditions. Stencils are not the only consideration when studying transfer efficiency.

Guidelines for stencil design include some recommendations for solder paste powder size. The current guidelines do not address the effects of solder paste flux chemistry or nano-coatings. Solder paste and nano-coatings should be included in future stencil design guidelines.

The continuing trend for miniaturization of electronics ensures that aperture surface area ratios will continue to decrease. There is a need for tools to help print and release solder paste in order to create acceptable solder joints. Solder pastes and nano-coatings are both useful tools which can improve transfer efficiency, and help to meet the needs of future surface mount processes.

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