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Print Performance Studies Comparing Electroform and Laser-Cut Stencils

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ABSTRACT
There has been recent activity and interest in Laser-Cut Electroform blank foils as an alternative to normal Electroform stencils. The present study will investigate and compare the print performance in terms of % paste transfer as well the dispersion in paste transfer volume for a variety of Electroform and Laser-Cut stencils with and without post processing treatments. Side wall quality will also be investigated in detail. A Jabil solder paste qualification test board will be used as the PCB test vehicle. This board has a wide range of pads ranging from 75 micron (3 mil) squares and circles up to 300 micron (12 mil) squares and circles. There are also long rectangular pads with spacing's as low as 75 micron (3 mil). A total of 12 stencils, four stencils of different stencil technologies with three different coating configurations, will be tested as described in 1-4 below:

1- Electroform w/o Nano Coat and with and Nano Coat A and Nano Coat B
2- Laser-Cut Electroform foil w/o Nano-Coat and with Nano Coat A and Nano Coat B
3- Laser-Cut Fine Grain SS w/o Nano Coat and with Nano Coat A and Nano Coat B
4- Laser-Cut Fine Grain SS with Electropolish and Nickel plating, w/o Nano Coat and with Nano Coat A and Nano Coat B

A 100 micron (4 mil) thick stencil is used for all 12 stencils yielding Area Ratios ranging from .31 to .1.21.

Key words: Stencil, Solder Paste Volume, Area Ratio, Solder Paste Inspection (SPI), % Paste Transfer, Stencil Printer

INTRODUCTION

SMT assembly is faced with a common challenge. As components get smaller and smaller, it is difficult to print solder paste to satisfy the requirements of both very small components, such as .4 and .3mm pitch CSP, as well as normal SMT components. On the one hand the large components require more solder paste volume for sufficient solder fillets after reflow. If this same stencil normally used to print solder paste for SMT components is used to print solder paste for the small components the apertures are so small that poor paste release is may encountered. The print process can be divided into two processes: the aperture fill process and the paste transfer process. Both the large and small apertures have good paste fill. The large apertures have good paste transfer but the small apertures do not. The result is good solder paste volume resulting in a good solder joint after reflow for the large apertures but insufficient paste volume for the small apertures due to poor transfer, resulting in dry solder joints. As an alternative a thinner stencil could be used resulting in good paste fill and good paste transfer for both small and large apertures. However this results in insufficient solder paste volume for the large aperture resulting in a poor fillet and lean solder joint. On the other hand there is sufficient solder paste volume for the small components to form good fillets and good solder joints after reflow. The Area Ratio plays a large part in this dilemma. The paste transfer process can be considered as a tug of war. The area under the stencil aperture is trying to pull the solder paste out of the aperture but the aperture walls are trying to hold the paste inside the aperture. The more wall area compared to the area under the aperture the more difficult it is for the paste to be pulled free from the walls. The Area Ratio is defined as the aperture opening area divided by the aperture wall area. The acceptable Area Ratio for >80% paste transfer and < 10% paste volume standard deviation is typically .5 for stencils with smooth aperture walls. Typically for 01005 and .3mm CSP components the stencil thickness would need to be 62u (2.5 mils) to achieve acceptable paste transfer. This is typically too thin a stencil for normal SMT devices. Typically a stencil of at least 100u (4mils) is required for boards having normal SMT components. If 01005 or .3mm CSP components are populated on a SMT board with normal SMT components a 100u (4 mil) thick stencil would need to provide acceptable paste transfer at Area Ratios of .38-.44. There have been several technical publications dealing with optimization of the miniature component solder paste printing process[1-7]. The purpose of this study is to investigate four different stencil technologies in conjunction with three different post process coating technologies to determine if a 100u (4 mil) thick stencil can provide acceptable print performance for Area Ratios in the range of .38.

SCOPE OF THE STUDY

Each or the 12 stencils performance was evaluated in 5 separate categories listed below:
1- <u>Print Performance</u> in terms of % paste transfer and the dispersion in paste transfer volume function of area ratio. The >80% paste transfer and < 10% paste standard deviation will be utilized to define the lowest area ratio for all 12 stencils.

2- Stencil Side Wall Quality. Pictures of a 5 mil (125 micron) square aperture at 700 magnification for all 12 stencils will be compared.
3- Paste Volume change from 1st print to 10th print without wiping the stencil.
4- Paste Smear between solder bricks after 10 prints without wiping the stencil.
5- Paste Smear on bottom of stencil after 10 prints without wiping the stencil.

PRINT SET-UP

The test board selected is Jabil Test board manufactured by Practical Components part number 12855. This test board is used in both stencil and paste evaluations. This board has both mask defined and copper defined pads. Circular and square pads range from 75u (3mil) up to 300u (12 mil). Rectangle pads range from 75u (3mil) up to 300u (12mil) wide by 1.27mm (50mil) long. This study evaluated stencil apertures and pads starting at 125u (5mil) with nominal Area Ratio for Circles and Squares of .31 and .57 for Rectangles. This board also contains 200u (8mil) and 150u (6mil) pads with spacing's equal the pad width. This configuration was useful in evaluating paste spread between solder bricks.
Stencil printer had the following set up:
38.1mm/sec print speed
7kg pressure
Blade width 12"
Separation speed 80mm/sec
Wipe each board for run or 10 boards
Run of 10 boards w/o wipe
Solder paste Type 4.
SPI:
Bare Board Teach was completed to accurately measure the paste deposits from the actual pad surface.
The primary algorithm parameters are
Pad Offset = means that the actual pad height varies from pad to pad across the board.
Paste Measuring threshold = 35um
Dual Threshold (Pad Threshold) setting= 10um
Those two thresholds are used in conjunction with each other to yield more accurate measurements for very small deposits.
Print Sequence:
10 boards were printed and the stencil was wiped after each print.
SPI was collected for all 10 boards. Paste volume data was captured
for the following board locations:
125u (5mil) - 300u (12mil) copper defined circular pads (CD)
125u (5mil) - 300u (12mil) mask defined circular pads (MD)
125u (5mil) - 300u (12mil) copper defined square pads (CD)
125u (5mil) - 300u (12mil) mask defined square pads (MD)
125u (5mil) - 300u (12mil) wide by 50 mil long copper defined rectangle pads (CD)
125u (5mil) - 300u (12mil) wide by 50 mil long mask defined rectangle pads (MD)
The stencil was wiped each time to eliminate paste volume increase due to paste spread under the stencil. However this minimizes paste volume deviations one might see if no wiping was done. Next 10 boards were printed without stencil wiping. Pictures were taken of solder bricks after the first and last print. Pictures were
taken of the underside of the stencil by the printer.

STENCILS

Twelve different stencils were tested. There were four different stencil technologies and three different post coating techniques used for each of the four stencils. The three post coating techniques are: 1- no post processing coating, 2- Nano Coat type A applied, Nano Coat type B applied. The four stencil types are described below:
Stencil 3 is Laser Cut stencil using Fine Grain Stainless steel with normal dross removal but no electropolish.
Stencil 2 is laser cut Electroform foil with normal dross removal but no electropolish.
Stencil 1 is normal Electroformed stencil.
Stencil 4 is Laser cut Fine Grain Stainless steel with Electropolish and Nickel Plating.
These stencil type identifications are used as a short description of the stencils to shorten the names used in graphs and curves and are not a trademark of any company.

Performance Summary in the 5 categories of testing

1- Paste Volume Results

SPI was used to measure solder paste volume and calculate solder paste volume standard deviations. Both of these parameters were plotted versus Area Ratio. Sometimes these parameters are plotted versus nominal aperture size. However the actual aperture size and actual stencil thickness may vary. For this reason we chose to plot paste volume and paste volume standard deviation versus Area Ratio. The Area Ratio was calculated using the actual aperture size and stencil thickness for that particular aperture.

Figure 1-3 show % solder paste volume and % solder paste volume standard deviation for circle apertures for all four stencils with no coating, Nano Coat A, and Nano Coat B respectively. It is interesting to note that the Mask defined pads provide better paste transfer and lower deviation at lower AR in all 12 stencils. Also of interest is Stencil 1 with Nano Coat B provides the best paste transfer and lowest deviation of all twelve stencils.

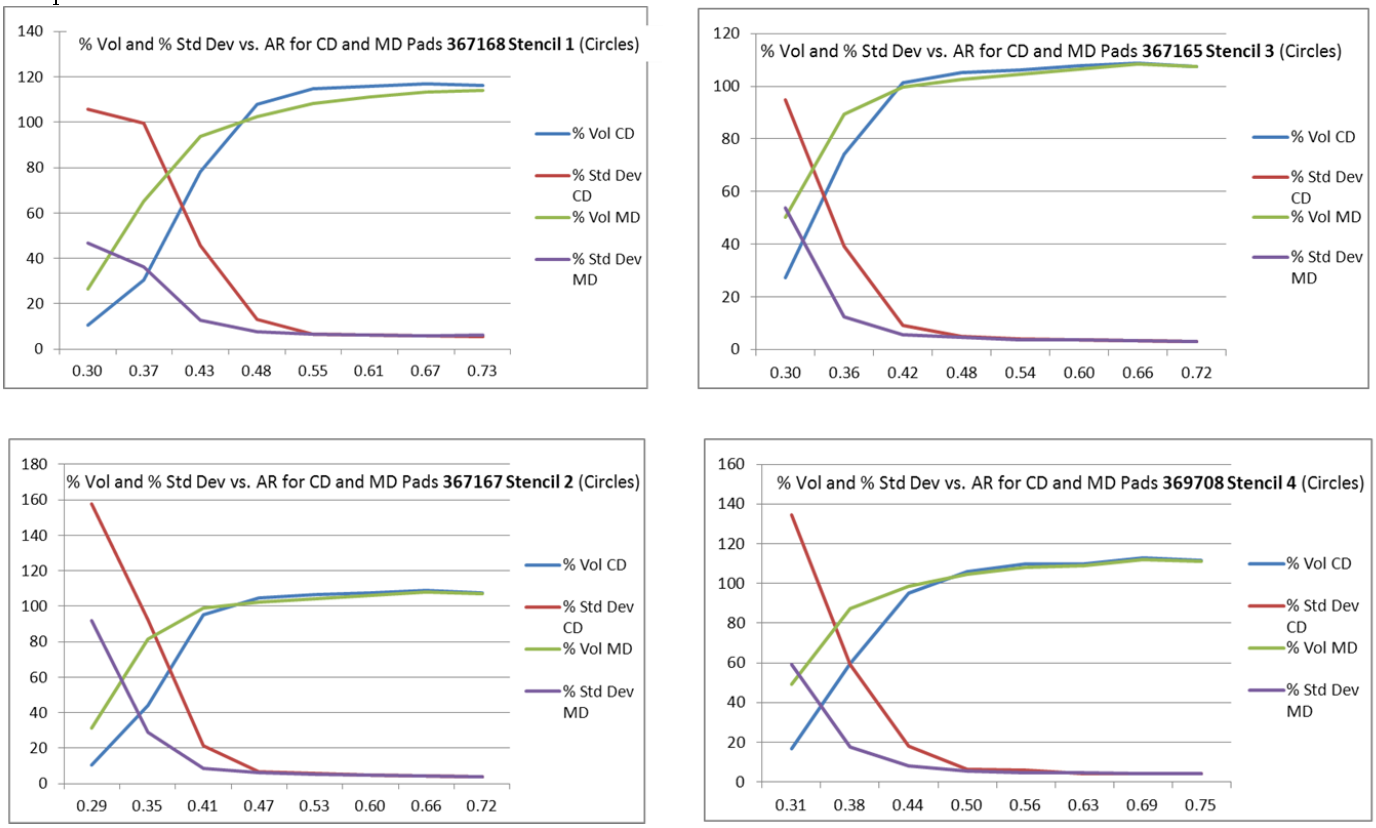


Figure 1 - 4 Stencils w/o Nano Coat (Circles CD and MD)

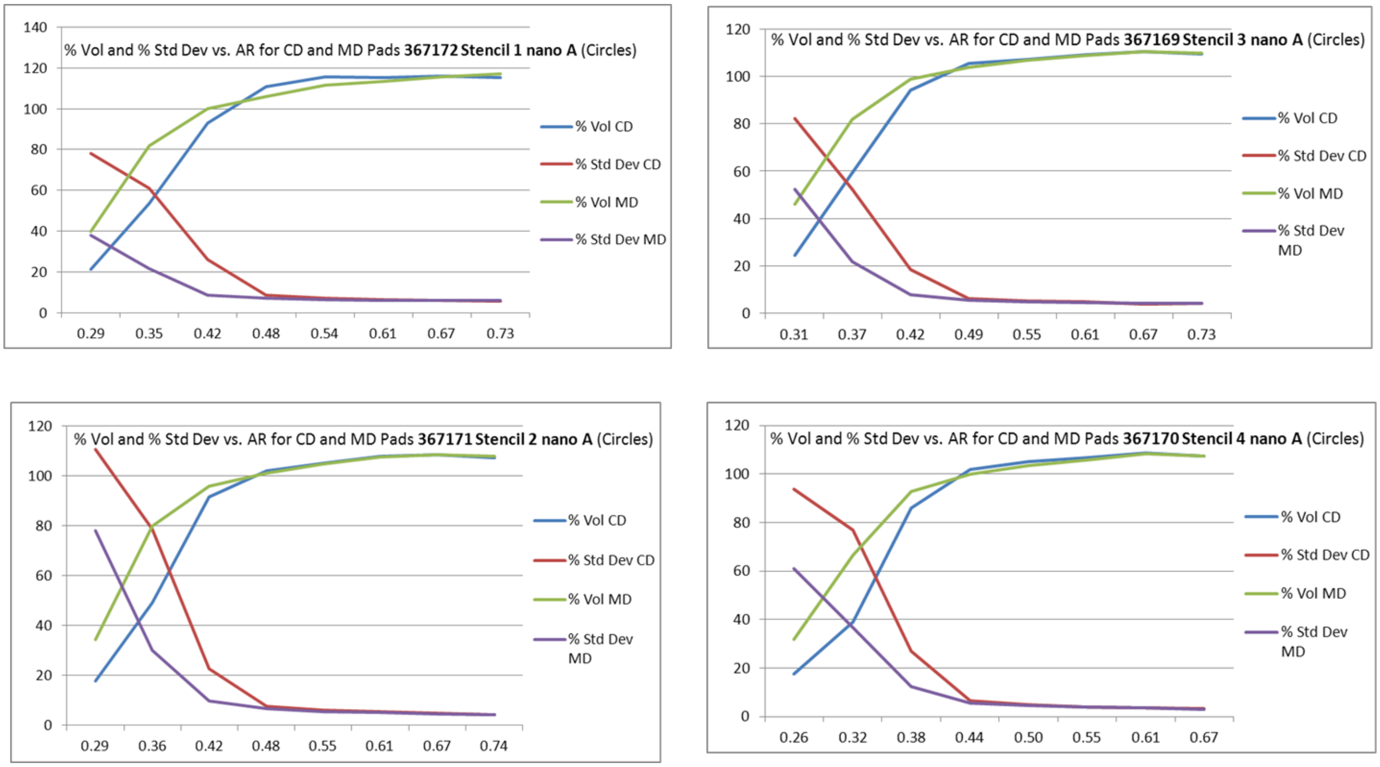


Figure 2 - 4 Stencils with Nano Coat A (Circles CD and MD)

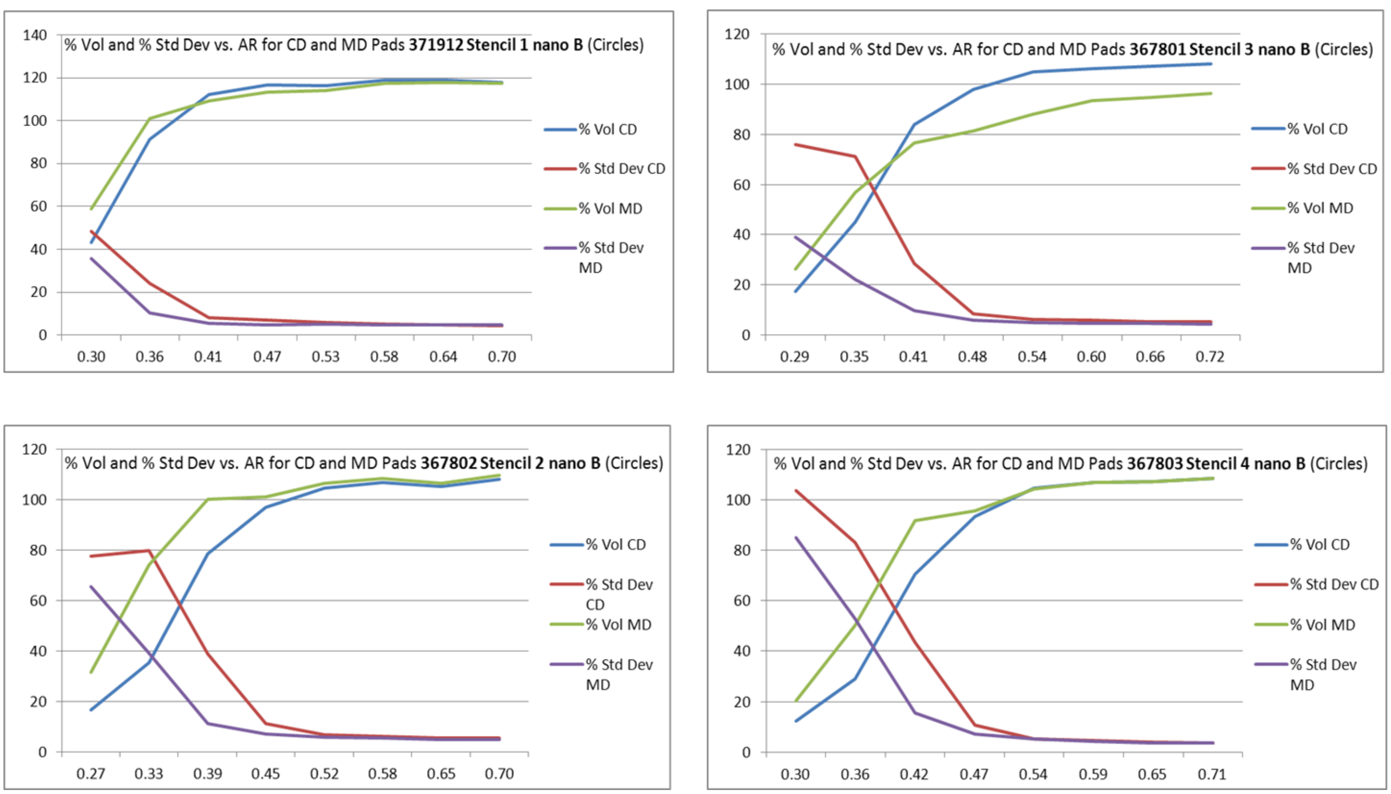


Figure 3 - 4 Stencils with Nano Coat B (Circles CD and MD)

Figures 4-6 show the results for square apertures. The square apertures provide better paste transfer and lower deviation as a general rule across all twelve stencils.

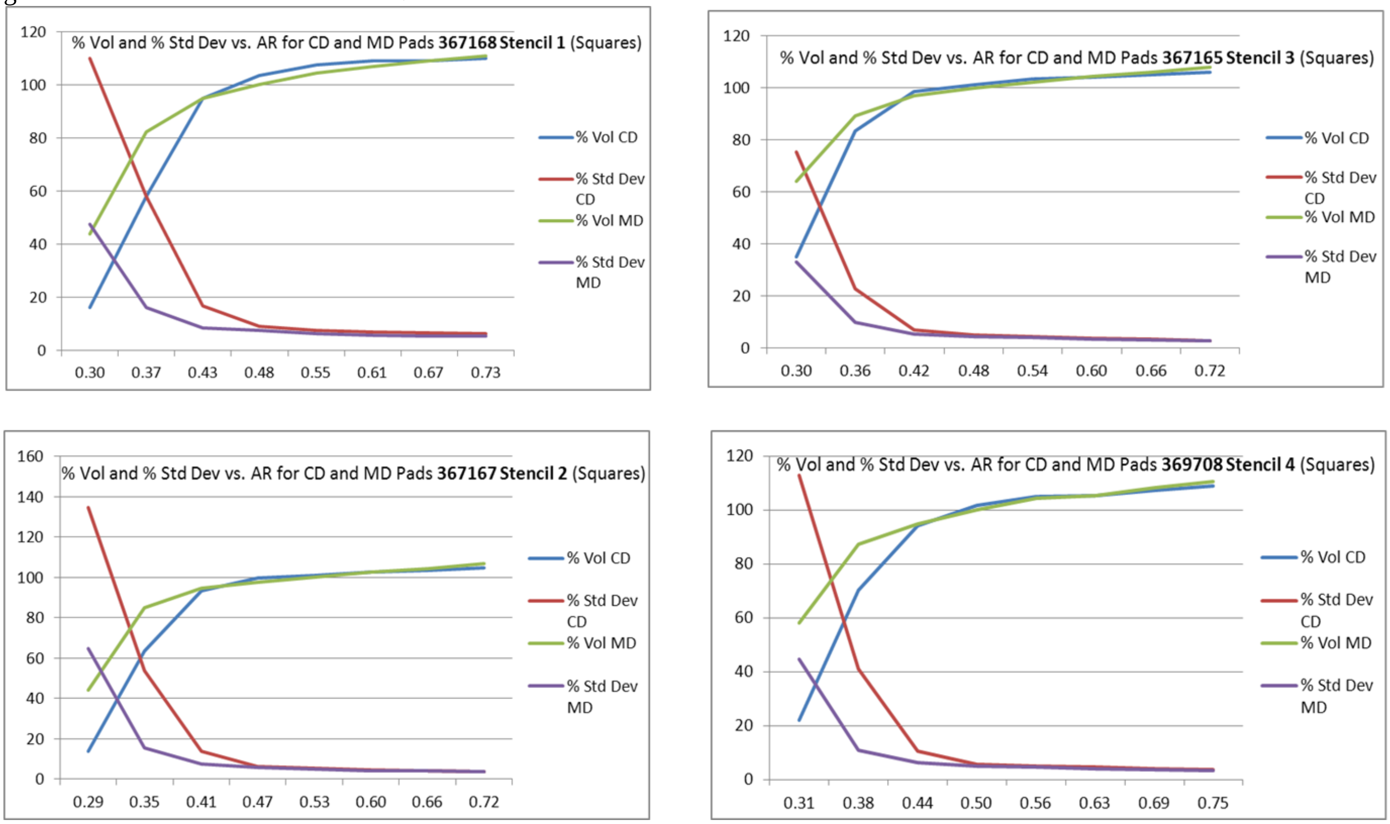


Figure 4 - 4 Stencils w/o Nano Coat (Squares CD and MD)

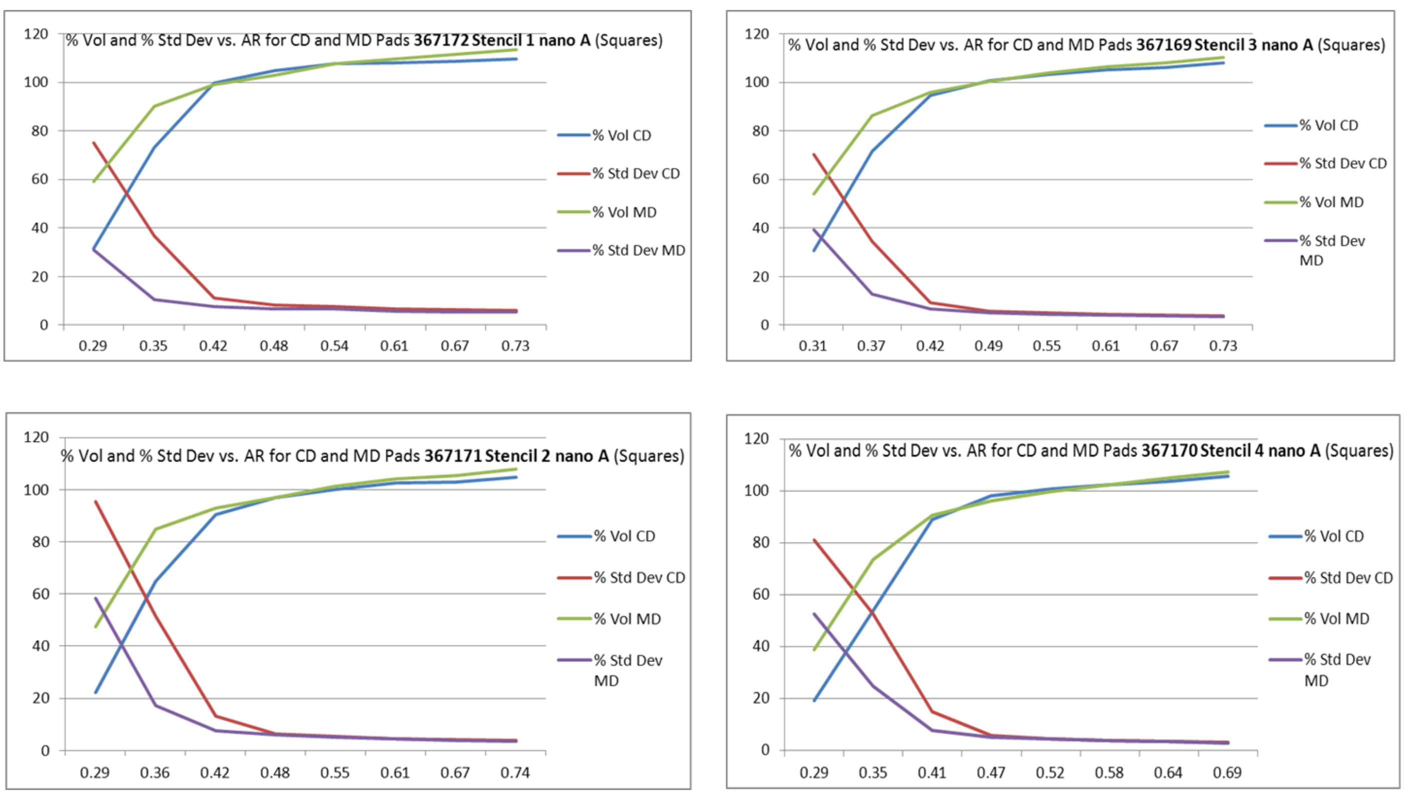


Figure 5 - 4 Stencils with Nano Coat A (Squares CD and MD)

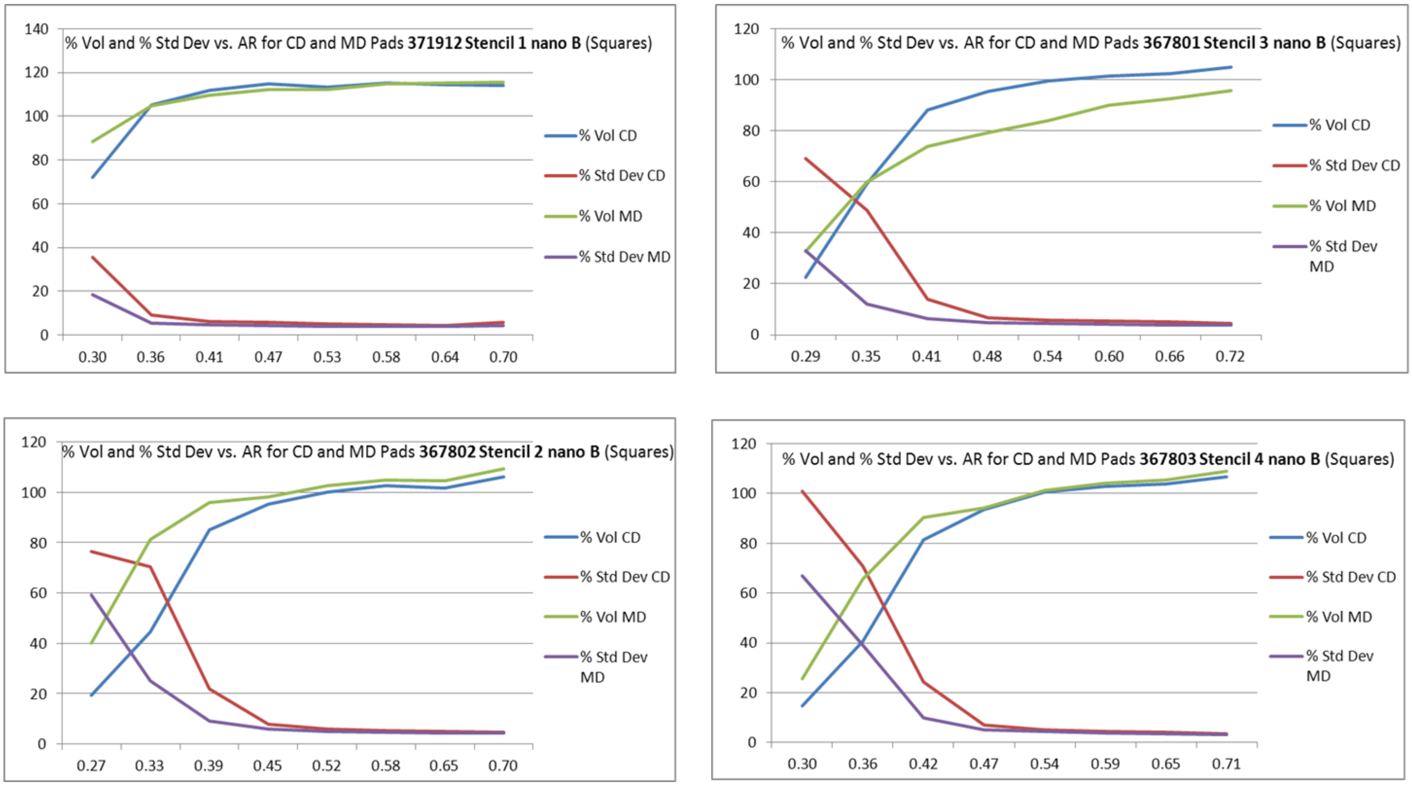


Figure 6 - 4 Stencils with Nano Coat B (Squares CD and MD)

Figure 7 shows results for the rectangle apertures. The lowest area ratio, shown at the left on the X axis represents an aperture width or 125u (5mil). This clearly illustrates when referring to aperture size the difference between a square / circle and rectangle is significant.

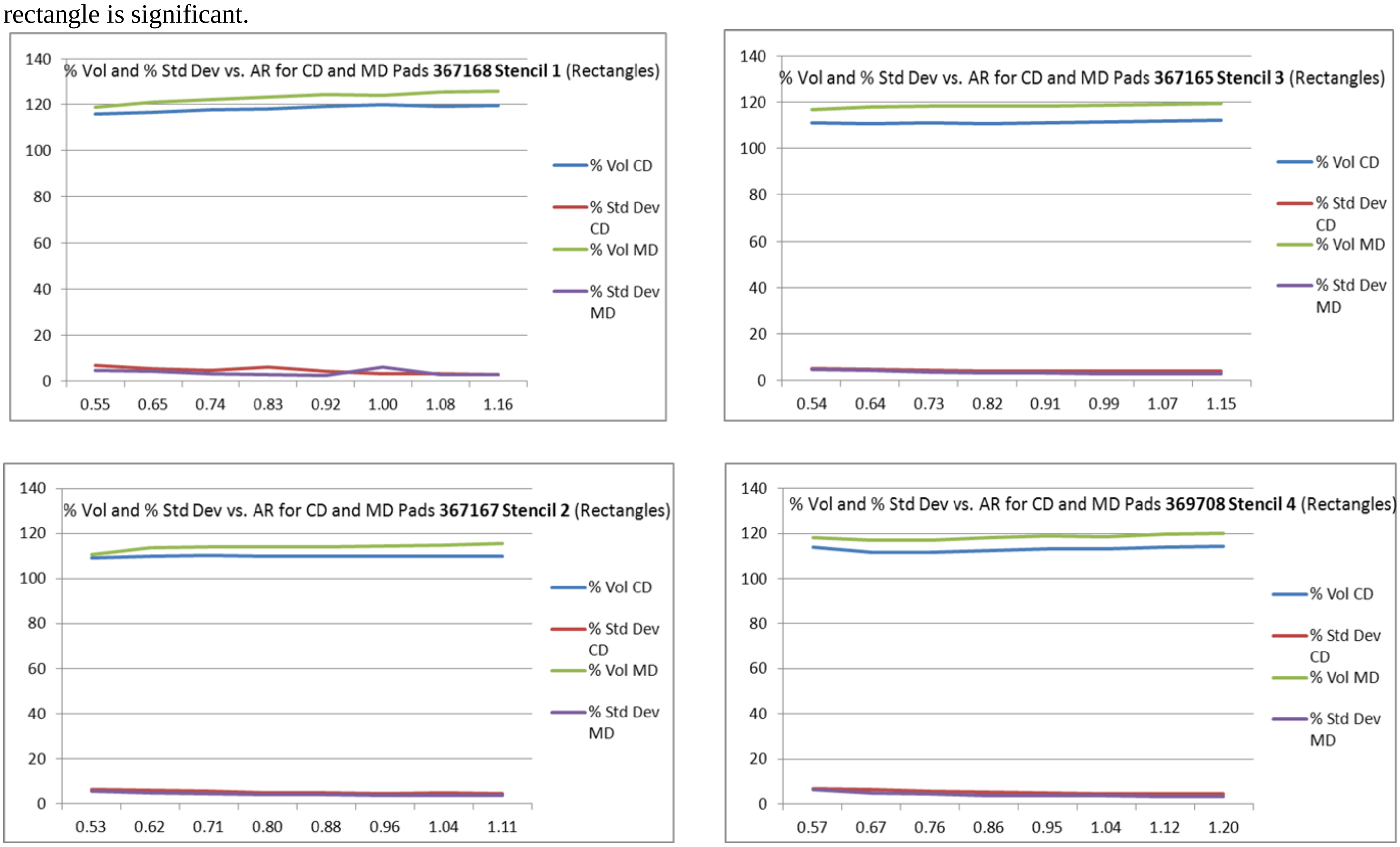


Figure 7 - 4 Stencils w/o Nano Coat (Rectangles CD and MD)

Figure 8 is a bar chart for circle and square apertures for all 12 stencils showing the lowest area ratio attained using the >80% transfer and <10% deviation rule. Figure 9 is a tabulation of these results. Stencil 1 with Nano Coat B provided the lowest area ratio and Mask Defined squares provided the lowest area ratio for each stencil. Figure 10 shows the ranking of all 12 stencils for Lowest Area Ratio achieved in the 4 categories, circles and squares with both copper defined pads and mask defined pads.

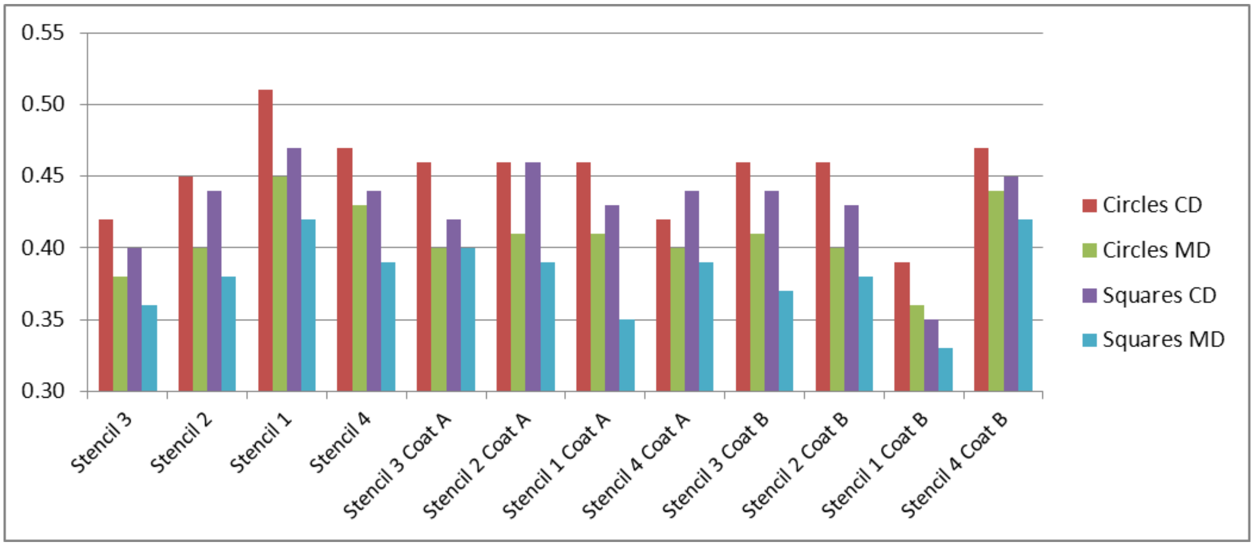


Figure 8 - Lowest AR for all 12 stencils using rule of >80% Paste Transfer and <10% Std. Dev.

Minimum Areas Ratios for all 12 stencils

Stencil #	Type	Coat	Circles CD	Circles MD	Squares CD	Squares MD
165	Stencil 3	No	0.42	0.38	0.40	0.36
167	Stencil 2	No	0.45	0.40	0.44	0.38
168	Stencil 1	No	0.51	0.45	0.47	0.42
708	Stencil 4	No	0.47	0.43	0.44	0.39
169	Stencil 3	Coat A	0.46	0.40	0.42	0.40
171	Stencil 2	Coat A	0.46	0.41	0.46	0.39
172	Stencil 1	Coat A	0.46	0.41	0.43	0.35
170	Stencil 4	Coat A	0.42	0.40	0.44	0.39
801	Stencil 3	Coat B	0.46	0.41	0.44	0.37
802	Stencil 2	Coat B	0.46	0.40	0.43	0.38
912	Stencil 1	Coat B	0.39	0.36	0.35	0.33
803	Stencil 4	Coat B	0.47	0.44	0.45	0.42

CD= Copper Defined Pad
MD= Mask Defined Pad

Figure 9 - Lowest Area Ratio Tabulated using rule of >80% Paste Transfer and <10% Std. D

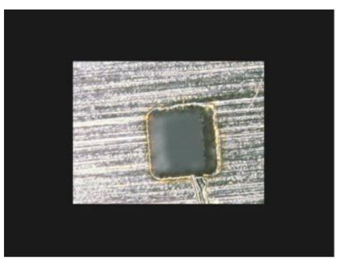
Ratings for Lowest Area Ratio

Stencil #	Type	Coat	Circles CD	Circles MD	Squares CD	Squares MD	Total Points		
								CD= Copper Defined Pad	
								MD= Mask Defined Pad	
165	Stencil 3	No	2	4	2	4	12	Ratings	Points
167	Stencil 2	No	1	2	1	4	8	< .39 E	4
168	Stencil 1	No	0	1	1	2	4	.40-.43 G	2
708	Stencil 4	No	1	2	1	4	8	.44-.50 F	1
169	Stencil 3	Coat A	1	2	2	2	7	> .50 P	0
171	Stencil 2	Coat A	1	2	1	4	8		
172	Stencil 1	Coat A	1	2	2	4	9		
170	Stencil 4	Coat A	2	2	1	4	9		
801	Stencil 3	Coat B	1	2	1	4	8		
802	Stencil 2	Coat B	1	2	2	4	9		
912	Stencil 1	Coat B	4	4	4	4	16		
803	Stencil 4	Coat B	1	1	1	2	5		

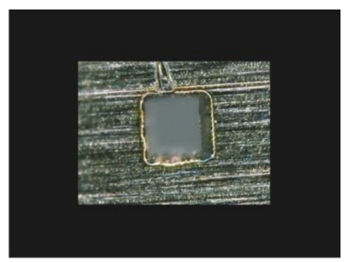
Figure 10 - Ranking of 12 Stencils for Lowest Area Ratio

2- <u>Aperture wall Quality</u>

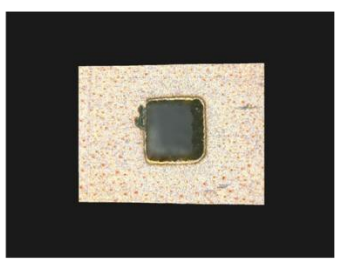
Figures 11 through 14 show the aperture walls for 125 micron (5 mil) aperture of all 4 stencils with the 3 different coatings at 700 magnification looking at the aperture wall opening at a 9 degree angle using a microscope. The same back and front lighting were used in all pictures. Pictures were taken with the contact side facing the scope. There is a slight glare on the Stencil 1 aperture edge. This is due to the aperture edge build up (gasketing effect) at the aperture edge. The Stencil 1 produced the smoothest walls. Stencil 2 was the next smoothest wall.



Stencil 3 No Nano Coat

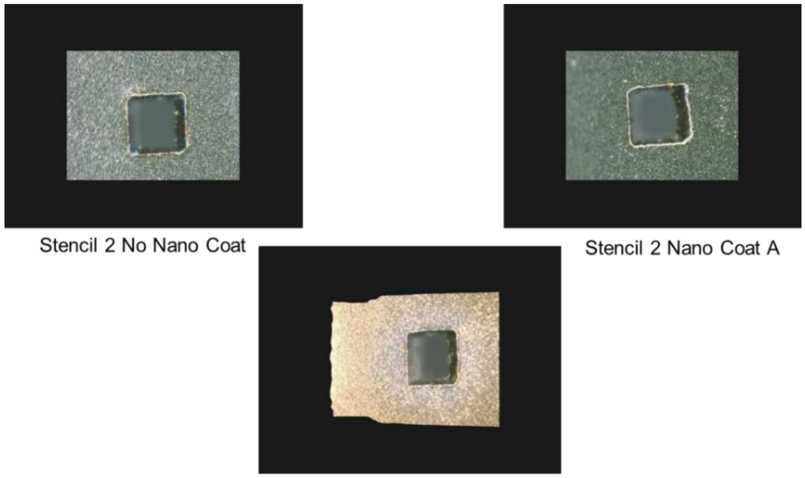


Stencil 3 Nano Coat A



Stencil 3 Nano Coat B

Figure 11 – Stencil 3 125 u Square Apertures 700x (Ranking Fair – Points 1)

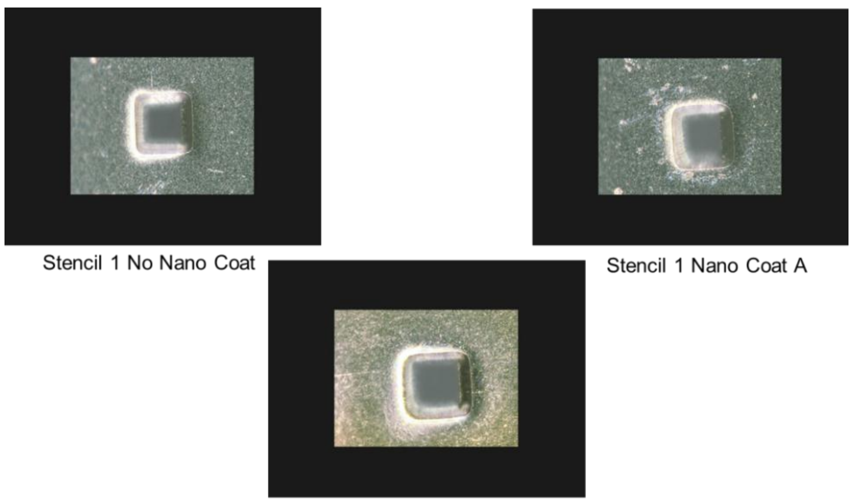


Stencil 2 No Nano Coat

Stencil 2 Nano Coat A

Stencil 2 Nano Coat B

Figure 12 – Stencil 2 125 u Square Apertures 700x (Ranking Good – Points 2)

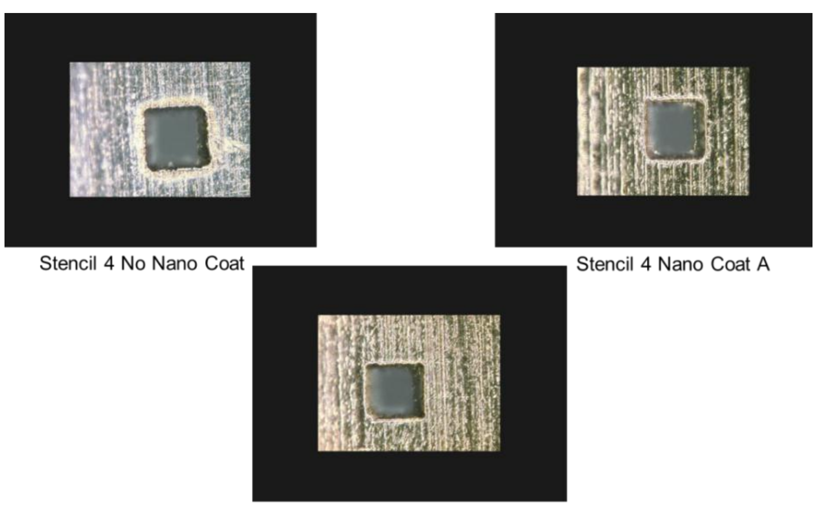


Stencil 1 No Nano Coat

Stencil 1 Nano Coat A

Stencil 1 Nano Coat B

Figure 13 – Stencil 1 125 u Square Apertures 700x (Ranking Excellent – Points 4)



Stencil 4 No Nano Coat

Stencil 4 Nano Coat A

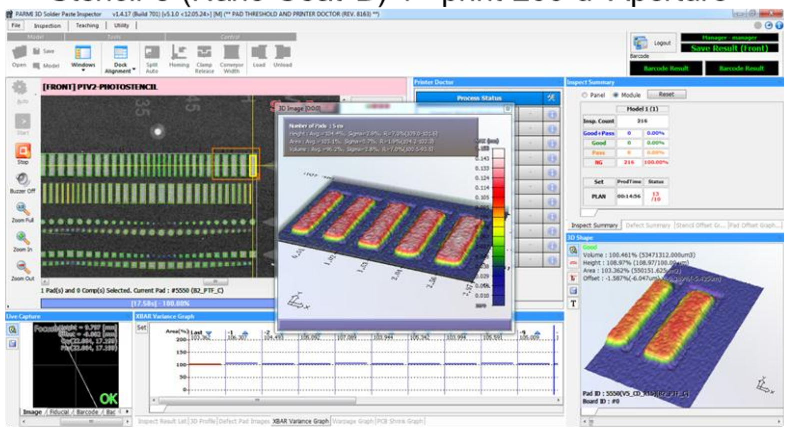
Stencil 4 Nano Coat B

Figure 14 – Stencil 4 125 u Square Apertures 700x (Ranking Fair – Points 1)

3- <u>Paste Volume / Spreading changes 1st to 10th Print w/o wiping</u>

Ten consecutive prints without any under stencil cleaning were performed using the printer. Measurements were made after each print capturing pictures of the 200u (8 mil) rectangle solder bricks. The solder volume of these bricks was also recorded after the 1st and 10th print. Figure 15 shows the solder brick pictures for Stencil 3 with Nano Coat B, the worst performing stencil of the group of 12. Figure 16 shows data for Stencil 2 with Nano Coat B, the best performing stencil of the group of 12. The upper left corner shows solder bricks for circles squares and rectangles, the smallest being 75 microns (3 mils). A red X indicates excess solder paste and a blue shaded area indicates insufficient solder paste. The 5 solder bricks boxed off are shown enlarged on the right. It can be visually seen that the enlarged solder bricks are the same for the 1st and last print in Figure 16 but change remarkably in Figure 15. In this evaluation section stencils are ranked as to how stable the paste volume is after 10 prints with no stencil wiping. Figure 17 is a summary of the % volume change for 10 of the 12 stencils. Unfortunately 2 stencils were left out with no data collected for this section, namely Stencil 3 and Stencil 2 with no coatings.

Stencil 3 (Nano-Coat B) 1st print 200 u Aperture



Stencil 3 (Nano-Coat B) 10th print 200 u Aperture

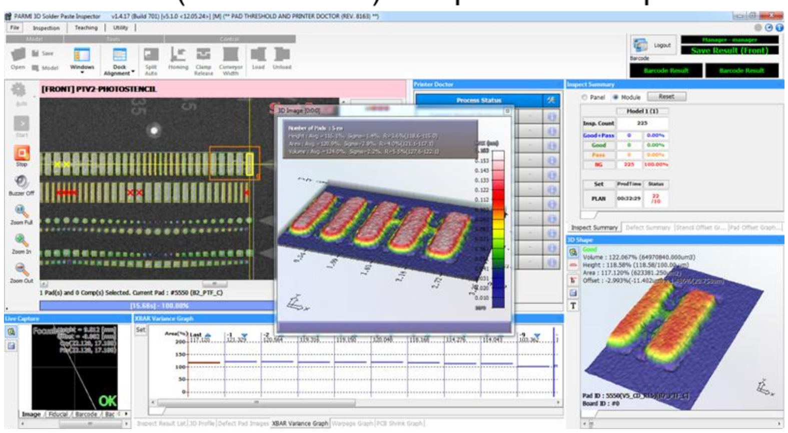
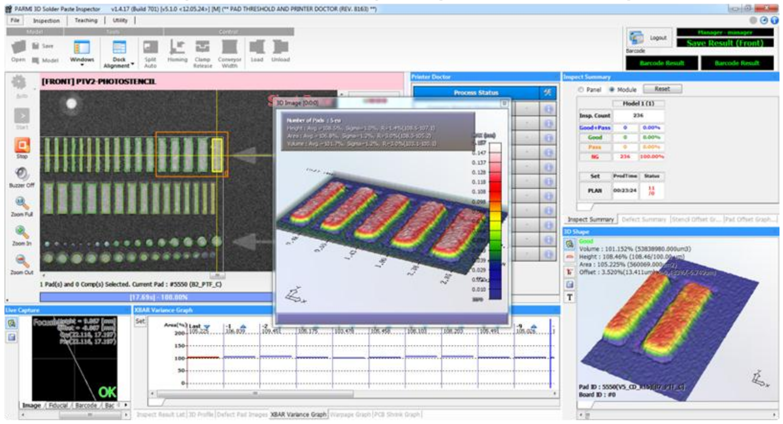


Figure 15 - Worst Performing Stencil

Stencil 2 (Nano-Coat B) 1st print 200 u Aperture



Stencil 2 (Nano-Coat B) 10th print 200 u Aperture

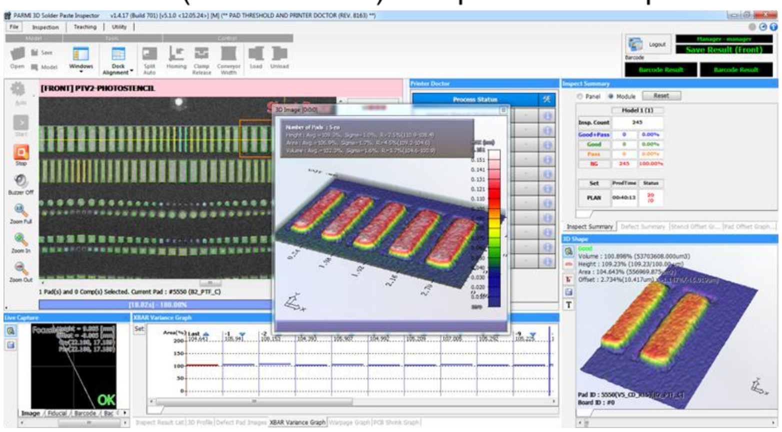


Figure 16 - Best Performing Stencil

4- Paste Smear between solder bricks after 10 prints without wiping the stencil.

In this category the spread of solder paste for 150u (6 mil) apertures with 150u (6 mil) space between apertures was evaluated. Ten prints were performed without wiping the underside of the stencil. Pictures of the solder bricks are shown in Figures 18 through 20. Each stencil was rated from (E) Excellent to (P) Poor which are shown on each picture. Unfortunately the Stencil 2 without coating picture was not captured. It was assigned a natural rating of 2 for this category. In general the Stencil 1 had similar performance with all 3 coating conditions. Stencil 2 showed significant improvement from Nano Coat A to Nano Coat B. Surprisingly Stencil 3 had poor results with no coating and Nano Coat B but good results with Nano Coat A. Figure 21 shows stencil rankings for the paste smear category.

Stencil #	Type	Coat	% Vol Change	Points
165	Stencil 3	No	N/A	2
167	Stencil 2	No	N/A	2
168	Stencil 1	No	9.8	2
708	Stencil 4	No	19.7	1
169	Stencil 3	Coat A	18.3	1
171	Stencil 2	Coat A	16.2	1
172	Stencil 1	Coat A	16.7	1
170	Stencil 4	Coat A	9.7	2
801	Stencil 3	Coat B	21.4	0
802	Stencil 2	Coat B	0.3	4
912	Stencil 1	Coat B	9.1	2
803	Stencil 4	Coat B	5.3	2
	Rating	Points		
	0-5% E	4		
	5%-10% G	2		
	10%-20% F	1		
	>20% P	0		

Figure 17 - Stencil Ranking for % Volume Change

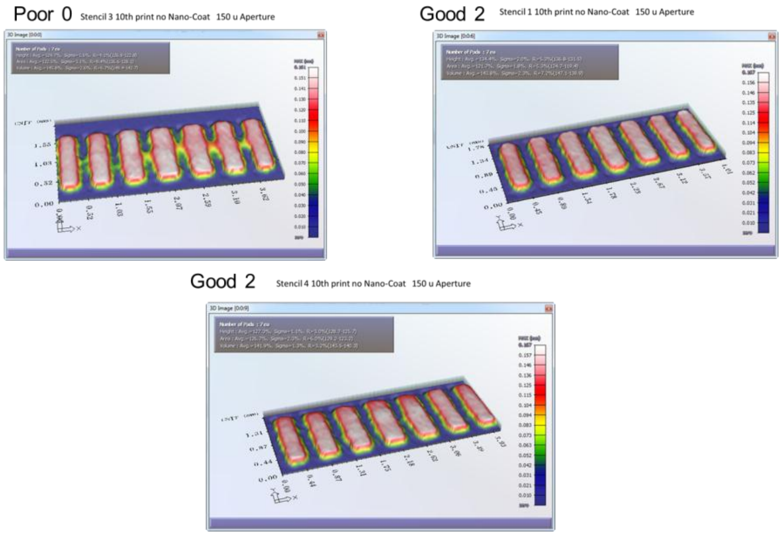


Figure 18 - Paste Bricks for 150 u Aperture (10th Print) Stencils with no coating

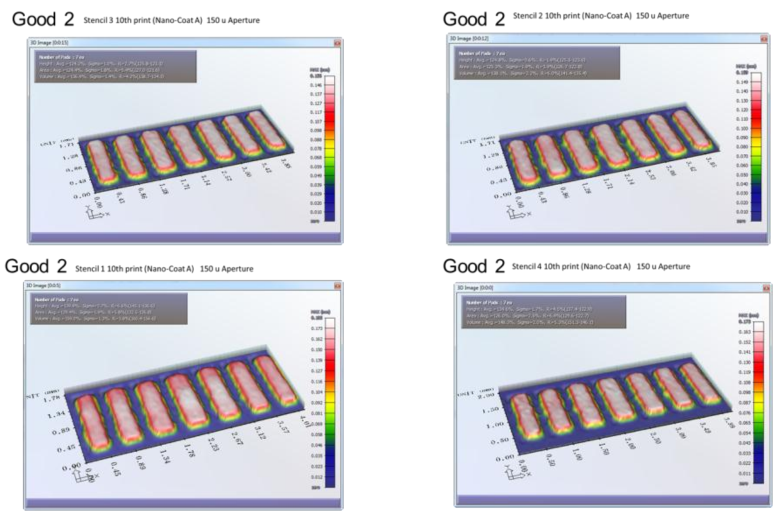


Figure 19 - Paste Bricks for 150 u Aperture (10th Print) Stencils with Nano Coat A

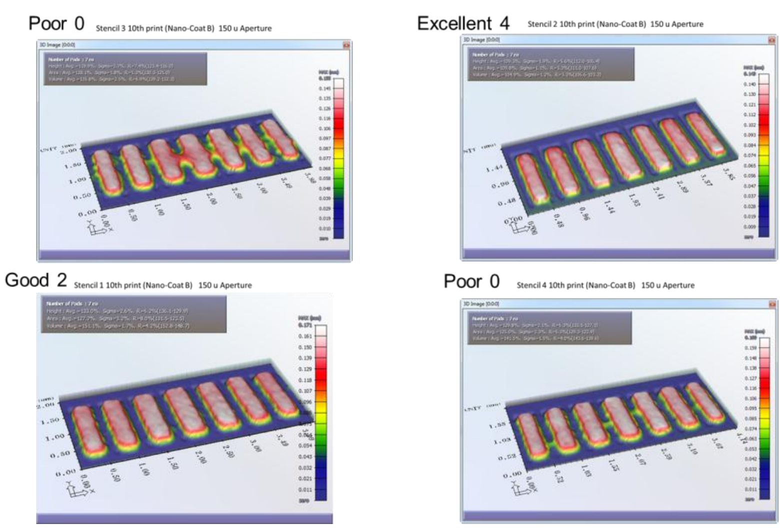


Figure 20 - Paste Bricks for 150 u Aperture (10th Print) Stencils with Nano Coat B

Stencil #	Type	Coat	Rating	Points
165	Stencil 3	No	Poor	0
167	Stencil 2	No	Good	2
168	Stencil 1	No	Good	2
708	Stencil 4	No	Good	2
169	Stencil 3	Coat A	Good	2
171	Stencil 2	Coat A	Good	2
172	Stencil 1	Coat A	Good	2
170	Stencil 4	Coat A	Good	2
801	Stencil 3	Coat B	Poor	0
802	Stencil 2	Coat B	Excellent	4
912	Stencil 1	Coat B	Good	2
803	Stencil 4	Coat B	Poor	0
	Rating	Points		
	Excellent	4		
	Good	2		
	Fair	1		
	Poor	0		

Figure 21 - Paste Smear Rankings 150 u Aperture after 10 prints w/o wipe

5- <u>Paste Smear</u> on bottom of stencil after 10 prints without wiping the stencil.

Another visual measure of stencil print performance is the residual solder paste left on the bottom of the stencil after several prints without wiping the bottom side of the stencil. The printer has the ability to capture a picture of the bottom side of the stencil. Pictures of paste smear were recorded after the 1st print and after the 10th print with no under stencil wiping for all 12 stencils. Figure 22 shows the worst performing stencil for bottom side paste smear after 10 prints without bottom side stencil wiping. Figure 23 shows the best performing stencil in this category. Figure 24 is a summary of the performance of all 12 stencils for bottom side paste smear.

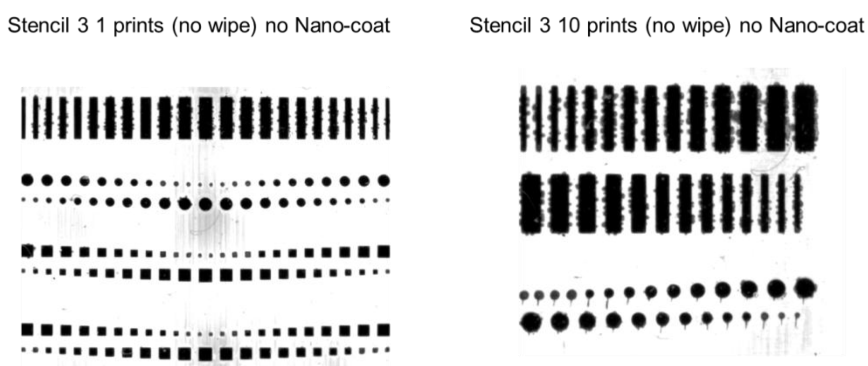


Figure 22 - Worst Stencil for Bottom Side Paste Smear

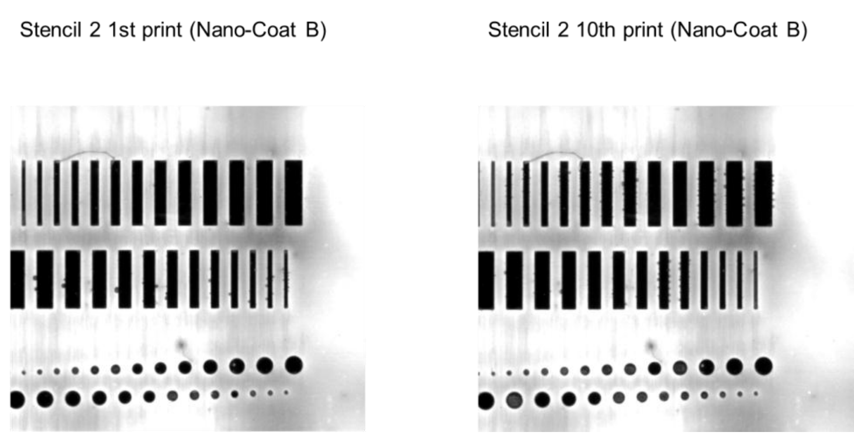


Figure 23 - Best Stencil for Bottom Side Paste Smear

Stencil #	Type	Coat	Rating	Points
165	Stencil 3	No	Poor	0
167	Stencil 2	No	Fair	1
168	Stencil 1	No	Fair	1
708	Stencil 4	No	Good	2
169	Stencil 3	Coat A	Good	2
171	Stencil 2	Coat A	Fair	1
172	Stencil 1	Coat A	Fair	1
170	Stencil 4	Coat A	Good	2
801	Stencil 3	Coat B	Fair	1
802	Stencil 2	Coat B	Excellent	4
912	Stencil 1	Coat B	Excellent	4
803	Stencil 4	Coat B	Poor	1
	Rating	Points		
	Excellent	4		
	Good	2		
	Fair	1		
	Poor	0		

Figure 24 - Ratings for Bottom side Paste Smear with 10 prints w/o wipe

CONCLUSIONS AND OBSERVATIONS

Figure 25 shows the rankings of the 12 stencils in all five categories. The Stencil 1, Electroform, stencil with Nano Coat B had the best overall ranking. Stencil 2, Laser-cut Electroform foil, scored second in the rankings. The Stencil 2 with Nano Coat B provided the cleanest print after 10 prints without stencil wiping. Stencil 1 with Nano Coat B demonstrated the lowest Area Ratios (.33-.39). Mask defined pads generally provided lower area ratios for all 12 stencils compared to copper defined pads. Square apertures provided lower area ratios compared to circular apertures. Rectangles having the same aperture widths as squares and circles provided better paste transfer and lower standard deviations mainly due to their higher area ratios.

	Assigner points for Ranking						Excellent = 4, Good = 2, Fair = 1, Poor = 0						
	Category			1			2	3	4	5			
			Lowest Area Ratio					Volume	Paste	Paste	Total	Position	
			CR	CR	SQ	SQ	Aper	Change	Smear	Smear	Points		
			CD	MD	CD	MD	Qual	1-10	Bricks	Stencil			
Stencil #	Type	Coat											
165	Stencil 3	No	2	4	2	4	1	2	0	0	15	5	
167	Stencil 2	No	1	2	1	4	2	2	2	1	15	5	
168	Stencil 1	No	0	1	1	2	4	2	2	1	13	7	
708	Stencil 4	No	1	2	1	4	1	1	1	2	13	7	
169	Stencil 3	Coat A	1	2	2	2	1	1	2	2	13	7	
171	Stencil 2	Coat A	1	2	1	4	2	1	2	1	14	6	
172	Stencil 1	Coat A	1	2	2	4	4	1	2	1	17	3	
170	Stencil 4	Coat A	2	2	1	4	1	2	2	2	16	4	
801	Stencil 3	Coat B	1	2	1	4	1	0	0	1	10	8	
802	Stencil 2	Coat B	1	2	2	4	2	4	4	4	23	2	
912	Stencil 1	Coat B	4	4	4	4	4	2	2	4	28	1	

Figure 25 - Ranking of the 12 Stencils

FUTURE WORK

It was observed that smearing and paste volume varied widely among the 12 stencils from the 1st to the 12th print. The minimum Area Ratio calculated from the (80% paste transfer and <10% standard deviation) rule exhibited a relatively small range (.33-.51) for the 12 stencils tested when the underside of the stencils was wiped after every print. We expect the range of Area Ratios to be much broader when printing without wiping between each print, going 10 prints without wiping. We expect the standard deviation to be much higher for some of the 12 stencils tested. This data will be studied and presented in a future publication.

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